Nokia Service Router Linux
7215 Interconnect System
7220 Interconnect Router
7250 Interconnect Router
7730 Service Interconnect Router

Release 26.3

Advanced Configuration Guide

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Nokia is committed to diversity and inclusion. We are continuously reviewing our customer documentation and consulting with standards bodies to ensure that terminology is inclusive and aligned with the industry. Our future customer documentation will be updated accordingly.

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1 About this guide

This document describes how to configure advanced solutions for the Nokia Service Router Linux (SR Linux). Advanced configurations are defined as more complex network-level configurations where additional guidance and more detailed procedures may be required.

This document is intended for network technicians, administrators, operators, service providers, and others who need to understand how to use and configure advanced solutions.

This manual covers the current release and may also contain some content that will be released in later maintenance loads. See the *SR Linux Release Notes* for information about features supported in each load.

Configuration and command outputs shown in this guide are examples only; actual displays may differ depending on supported functionality and user configuration.

1.1 Precautionary and information messages

The following are information symbols used in the documentation.

DANGER: Danger warns that the described activity or situation may result in serious personal injury or death. An electric shock hazard could exist. Before you begin work on this equipment, be aware of hazards involving electrical circuitry, be familiar with networking environments, and implement accident prevention procedures.

WARNING: Warning indicates that the described activity or situation may, or will, cause equipment damage, serious performance problems, or loss of data.

Caution: Caution indicates that the described activity or situation may reduce your component or system performance.

Note: Note provides additional operational information.

Tip: Tip provides suggestions for use or best practices.

1.2 Conventions

The Nokia SR Linux documentation uses the following command conventions:

- **Bold** type indicates a command that the user must enter.
- Input and output examples are displayed in `Courier` text.
- A vertical bar (|) indicates a mutually exclusive argument.
- Square brackets ([ ]) indicate optional elements.

- Braces ({ }) indicate a required choice. When braces are contained within square brackets, they indicate a required choice within an optional element.
- *Italic* type indicates a variable.

The following table outlines platform grouping conventions used in the SR Linux documentation suite.

Note: Some platforms in the 7250 IXR support mixed systems. For more information about mixed system support, see "Chassis types" in the *Configuration Basics Guide*.

Table 1: Platform grouping legend

Platform group	Description
7215 IXS	7215 IXS-A1
7220 IXR	All 7220 IXR platforms
7220 IXR-D*x*	7220 IXR-D1, 7220 IXR-D2, 7220 IXR-D2L, 7220 IXR-D3, 7220 IXR-D3L, 7220 IXR-D4, 7220 IXR-D5
7220 IXR-H*x*	7220 IXR-H2, 7220 IXR-H3, 7220 IXR-H4, 7220 IXR-H4-32D, 7220 IXR-H5-32D, 7220 IXR-H5-64D, 7220 IXR-H5-64O
7250 IXR[1]	7250 IXR platforms
7250 IXR Gen 2	7250 IXR-6, 7250 IXR-10
7250 IXR Gen 2c+	7250 IXR-6e with IMM2, 7250 IXR-10e with IMM2, 7250 IXR-X1b, 7250 IXR-X3b
7250 IXR Gen 3	7250 IXR-6e with IMM3, 7250 IXR-10e with IMM3, 7250 IXR-18e, 7250 IXR-X4
7250 IXR-6e/10e (mixed system)	7250 IXR-6e (mixed system)[2], 7250 IXR-10e (mixed system)[2]
7730 SXR	7730 SXR-1-32D, 7730 SXR-1d-32D, 7730 SXR-1x-44S

1 References to the 7250 IXR platform group may be appended with (including mixed systems) or (excluding mixed systems) to indicate mixed system support.

2 References to this platform as part of 7250 IXR (mixed system) indicate mixed system support of 7250 IXR Gen 2c+ (IMM2) and 7250 IXR Gen 3 (IMM3). That is, the 7250 IXR-6e and 7250 IXR-10e can hold and support both IMM2 and IMM3 at the same time.

2 What's new

This section lists the changes that were made in this release.

Table 2: What's new in 26.3.1

Topic	Location
BGP Segment Routing Using the Prefix SID Attribute	BGP Segment Routing Using the Prefix SID Attribute
LDP Point-to-Point LSPs	LDP Point-to-Point LSPs
MPLS LDP LFA using ISIS as IGP	MPLS LDP LFA using ISIS as IGP
Segment Routing – Traffic Engineered Tunnels	Segment Routing – Traffic Engineered Tunnels
Segment Routing with IS-IS Control Plane	Segment Routing with IS-IS Control Plane
Shared Risk Link Groups for Uncolored SR-MPLS Policy-based LSPs	Shared Risk Link Groups for Uncolored SR-MPLS Policy-based LSPs
Static MPLS LSPs	Static MPLS LSPs
Uncolored SR-MPLS TE policies with local CSPF path computation	Uncolored SR-MPLS TE policies with local CSPF path computation

3 BGP Segment Routing Using the Prefix SID Attribute

This chapter describes BGP Segment Routing using the prefix SID attribute.

Topics in this chapter include:

3.1 Applicability

The information and configuration in this chapter are based on SR Linux Release 25.10.R1. BGP Segment Routing (SR) is supported in SR Linux Release 24.10.R6, and later.

3.2 Overview

Segment Routing (SR) has become a foundational technology for Software-Defined Networking (SDN) in Wide Area Networks (WANs). Also, SR is being extended beyond WAN borders into Data Centers (DCs).

SR allows an ingress node to route a packet from the source, by prepending an SR header containing an ordered list of segment identifiers (SIDs). A SID represents a topological or service-based instruction. A SID can have a local meaning for one specific node, or a global meaning within the SR domain, such as the instruction to forward a packet on the Equal-Cost Multipath (ECMP) aware shortest path to reach some prefix.

In WAN networks, infrastructure IP reachability is nearly always conveyed by an IGP protocol, such as IS-IS and OSPF, but in large-scale DCs, BGP has become the protocol of choice. In a typical DC design, BGP is used for endpoint reachability, as follows:

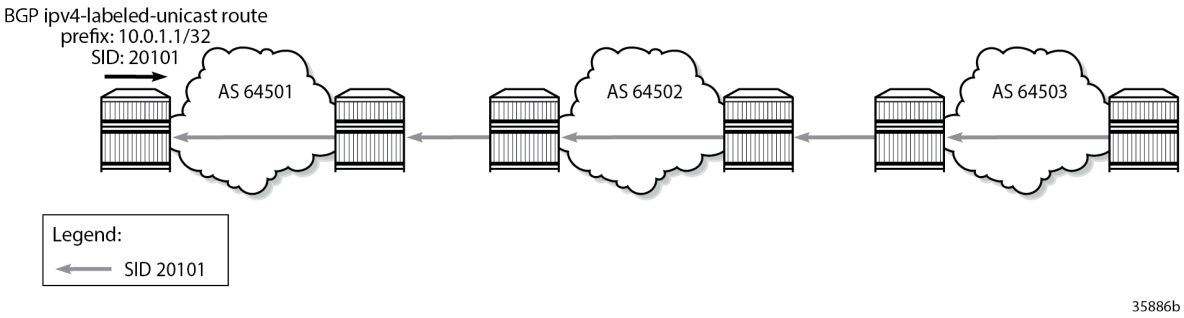
- Each node (Top of Rack (TOR), leaf, spine, and so on) has its own Autonomous System (AS).
- Each node has an eBGP session to each of its directly connected peers.
- Each node originates the IPv4 (or IPv6) address of its loopback interface into BGP and announces it to its neighbors.

To extend SR-MPLS into DCs that use this type of BGP design, the SR Linux nodes must advertise their loopback IP prefix in a BGP ipv4-labeled-unicast (BGP-LU) IPv4 route with a prefix SID attribute. The prefix SID attribute is ignored when attached to other types of BGP routes, including BGP-LU IPv6 routes, but it is still propagated.

A BGP prefix SID is always a global SID within the SR domain and identifies an instruction to forward the packet along the ECMP-aware BGP-computed best paths to reach the prefix. The BGP prefix SID attribute can also help to create SR paths that transit across multiple administrative domains that do not share IGP SR topology information.

Figure 1: BGP-LU IPv4 route with prefix SID BGP path attribute shows a node in AS 64501 advertising a BGP-LU IPv4 route for prefix 10.0.1.1/32 with SID 20101. The SR-capable nodes forward packets with SID 20101 via the best BGP path to 10.0.1.1, using any of the available multipaths computed by BGP.

Figure 1: BGP-LU IPv4 route with prefix SID BGP path attribute

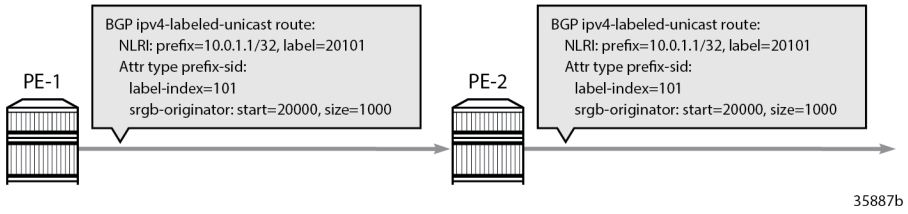


The BGP prefix SID attribute is an optional and transitive BGP path attribute, meaning that the attribute is expected to be propagated by routers that do not recognize the type value. When SR is deployed using an MPLS dataplane (SR-MPLS), the BGP prefix SID encodes:

- A 32-bit label-index Type-Length-Value (TLV) (mandatory TLV)
- An originator Segment Routing Global Block (SRGB) TLV containing one or more SRGB fields (optional TLV). If the SRGB field occurs multiple times in the SRGB TLV, the SRGB space of the ingress node consists of multiple ranges that are concatenated.

Figure 2: BGP signaling overview shows that node PE-1 exports a BGP-LU IPv4 route with prefix 10.0.1.1/32 and label 20101. The BGP prefix SID attribute contains an SR label index of 101 and the originator SRGB with start label 20000 and size 1000 (from 20000 to 20999). Node PE-2 imports the BGP-LU IPv4 route and exports it to the next node.

Figure 2: BGP signaling overview



To add, replace, or process a BGP prefix SID, SR must be administratively enabled in the **bgp** context. The BGP prefix SID range is equal to the SRGB that is also used by SR-ISIS or SR-OSPF and that is defined in the **system mpls label-ranges** context. All BGP prefix SID label values must reside within the global SRGB.

To originate BGP SR prefixes, two policies are required with **action bgp label-allocation prefix-sid**, which may or may not be identical:

- **export policy [<policy-name>]** to advertise a prefix to a neighbor with an SR label index
- **route-table-import <policy-name>** used to populate a local BGP-SR table with an SR label index

In the example topology used in this chapter, the export policy and the route-table-import policy are identical and have an **action** entry with **policy-result accept** and **bgp label-allocation prefix-sid**, so

on PE-1, the prefix SID for the prefix 10.0.1.1/32 equals 20101, which is the sum of the start label for the prefix SID range 20000 and the SR label index 101.

A unique SR label index value must be assigned to each different IPv4 prefix that is advertised with a BGP prefix SID. However, in case of a conflict with another SR-programmed Label Forwarding Instance Base (LFIB) entry, the conflict situation is addressed as follows:

- If the conflict is with another BGP-LU IPv4 route for a different prefix with a prefix SID attribute, all the conflicting BGP-LU IPv4 routes for both prefixes are advertised with normal BGP-LU labels from the dynamic label range, not from the dedicated SR label range.
- If the conflict is with an IGP route and the route-table-import policy action contains **reuse-igp false** in the **bgp label-allocation prefix-sid** command, the BGP-LU IPv4 route loses to the IGP route and is advertised with a normal BGP-LU label from the dynamic SR label range.
- If the conflict is with an IGP route and the route-table-import policy action contains **reuse-igp true** in the **bgp label-allocation prefix-sid** command, this is not considered a conflict and BGP uses the IGP-signaled SR label index to derive its advertised label. This stitches the BGP SR tunnel to the IGP SR tunnel.

Stitching of SR-ISIS or SR-OSPF to SR-BGP is one of the main advantages of implementing SR-BGP.

Any /32 BGP-LU IPv4 route containing a prefix SID attribute is resolvable and usable in the same way as /32 BGP-LU IPv4 routes without prefix SID attribute. The routes can be installed in the route table and tunnel table, have ECMP next hops or FRR backup next hops, and can be used as transport tunnels.

Receiving a /32 BGP-LU IPv4 route with prefix SID attribute does not create a tunnel in the SR database; it only creates a label swap entry when the route is re-advertised with a new next hop. This means that the first SID in any SID list of an SR policy should not be based on a BGP prefix SID because the data path would not be programmed correctly. However, the BGP prefix SID can be used as a non-first SID in any SR policy.

Each node capable of receiving and propagating the BGP prefix SID attribute can be configured with the **optional-attributes block-prefix-sid** command at the BGP group or neighbor configuration levels to:

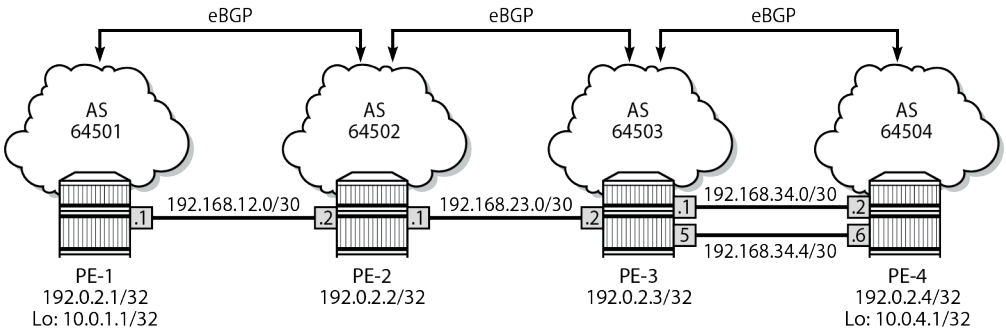
- block the propagation of the attribute outside its local SR domain
- block inbound propagation of the attribute from another SR domain

When **optional-attributes block-prefix-sid** applies to a BGP session, the prefix SID attribute is stripped from all sent and received routes on that session, even if the prefix SID attribute was added to the outbound routes by the local router. By default, this feature is not configured, so the prefix SID is propagated freely to and from all BGP peers.

3.3 Configuration

Figure 3: Example topology shows the example topology with four nodes in different ASs. The loopback addresses 10.0.1.1/32 on PE-1 and 10.0.4.1/32 on PE-4 are exported in BGP-LU IPv4 routes with prefix SID attribute.

Figure 3: Example topology



The initial configuration includes:

- cards, MDAs, ports
- interfaces
- PE-3 and PE-4 have **ecmp** and **multipath ebgp max-paths** set to 2 for BGP address family **ipv4-labeled-unicast**

No IGP is configured, so SR-ISIS or SR-OSPF cannot be used.

3.3.1 Configure eBGP

Configure eBGP on all PEs for the **ipv4-labeled-unicast** address family, as follows. PE-3 and PE-4 have **multipath ebgp max-paths** set to 2 for BGP address family **ipv4-labeled-unicast**.

```
# on all PEs:
enter candidate
    network-instance default {
        protocols {
            bgp {
                admin-state enable
                autonomous-system 64501    # 64504 on PE-4
                router-id 192.0.2.1        # 192.0.4.1 on PE-4
                ebgp-default-policy {
                    import-reject-all false
                    export-reject-all false
                }
                afi-safi ipv4-labeled-unicast {
                    admin-state enable
                    multipath {            # only between PE-3 and PE-4
                        ebgp {
                            maximum-paths 2
                        }
                    }
                }
                group grp-EBGP {
                    admin-state enable
                }
```

```
                neighbor 192.168.12.2 {    # 192.168.34.1 and 192.168.34.5 on PE-4
                    admin-state enable
                    peer-as 64502            # 64503 on PE-4
                    peer-group grp-EBGP
                }
            }
        }
    }
```

The configuration is similar on PE-2 and PE-3. PE-3 and PE-4 have two interfaces toward each other.

3.3.2 Configure BGP segment routing using prefix SID

Configure the SRGB and enable BGP SR on all PEs, as follows:

```
# on all PEs:
enter candidate
    system {
        mpls {
            label-ranges {
                static srgb-static {
                    shared true
                    start-label 20000
                    end-label 20999
                }
            }
        }
    }
    network-instance default {
        segment-routing {
            mpls {
                global-block {
                    label-range srgb-static
                }
            }
        }
        protocols {
            bgp {
                segment-routing-mpls {
                    admin-state enable
                }
            }
        }
    }
```

Configure a loopback interface for network instance default, with IP address 10.0.1.1/32 on PE-1 and with IP address10.0.4.1/32 on PE-4, as follows:

```
# on PE-1, PE-4:
enter candidate
    interface lo0 {
        admin-state enable
        subinterface 0 {
            admin-state enable
            ipv4 {
                admin-state enable
                address 10.0.1.1/32 { }     # 10.0.4.1/32 on PE-4
            }
        }
    }
```

```
    network-instance default {
        interface lo0.0 {
            interface-ref {
                interface lo0
                subinterface 0
            }
        }
    }
```

Assign a local prefix SID label index **ipv4-label-index** to each loopback interface, as follows:

```
# on PE-1, PE-4:
enter candidate
    network-instance default {
        segment-routing {
            mpls {
                local-prefix-sid 1 {
                    interface lo0.0
                    ipv4-label-index 101    # 104 on PE-4
                }
            }
        }
    }
```

Define policies with **action bgp label-allocation prefix-sid** for exporting and importing the prefixes. It is possible to define different policies for exporting and importing the prefixes. In this example, PE-1 and PE-4 have no explicit import policy. PE-1 an PE-4 each use a single policy as an export policy and as a route-table-import policy. Define the following policy on PE-1 for exporting prefix 10.0.1.1/32 and importing it in the local route table:

```
# on PE-1, PE-4:
enter candidate
    routing-policy {
        prefix-set ps-10 {
            prefix 10.0.1.1/32 mask-length-range exact { }    # 10.0.4.1/32 on PE-4
        }
        policy pol-10 {
            statement 10 {
                match {
                    prefix {
                        prefix-set ps-10
                    }
                }
                action {
                    policy-result accept
                    bgp {
                        label-allocation {
                            prefix-sid {
                                reuse-igp false
                            }
                        }
                    }
                }
            }
        }
    }
```

Configure the export policy in the BGP group, as follows:

```
# on PE-1, PE-4:
enter candidate
```

```
    network-instance default {
        protocols {
            bgp {
                group grp-EBGP {
                    export-policy [ pol-10 ]
                }
            }
        }
    }
```

Populate a local BGP-SR table for the **ipv4-labeled-unicast** address family with the **route-table-import <policy-name>** command in the **bgp rib-management** context, as follows:

```
# on PE-1, PE-4:
enter candidate
    network-instance default {
        protocols {
            bgp {
                rib-management {
                    table ipv4-labeled-unicast {
                        route-table-import pol-10
                    }
                }
            }
        }
    }
```

As a result, PE-1 exports prefix 10.0.1.1/32 with SR label index 101, corresponding with a BGP prefix SID 20101 (start label 20000 + index 101 = 20101).

Likewise, PE-4 exports prefix 10.0.4.1/32 with SR label index 104, corresponding with a BGP prefix SID 20104 (start label 20000 + index 104 = 20104).

The following **info from state** commands display the BGP-SR table on the different PEs. Two labels are allocated from the SR label range on each PE.

PE-1 advertises SR label 20101 for its local prefix 10.0.1.1/32 to its neighbor on PE-2. PE-1 receives SR label 20104 for remote prefix 10.0.4.1/32 from its neighbor on PE-2.

```
A:admin@PE-1# info from state with-context / network-instance default bgp-rib afi-safi ipv4-
labeled-unicast
 ipv4-labeled-unicast rib-in-out rib-out-post route * neighbor * path-id 0 | as table |filter
 fields attr-id advertised-mpls-label
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+
|   Network-instance   |       Afi-safi       |        Prefix        |       Neighbor       |
 Path-id   |       Attr-id        |   Advertised-mpls-   |
|                      |                      |                      |                      |
          |                      |        label         |
+======================+======================+======================+======================+==
==========+======================+======================+
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.12.2         |
        0 |                   65 | 20101                |
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+

A:admin@PE-1# info from state with-context / network-instance default bgp-rib afi-safi ipv4-
labeled-unicast
 ipv4-labeled-unicast rib-in-out rib-in-pre route * neighbor * path-id 0 | as table |filter
 fields attr-id received-mpls-label
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+
```

```
|   Network-instance   |       Afi-safi       |        Prefix        |       Neighbor       |
 Path-id   |       Attr-id        | Received-mpls-label  |
+======================+======================+======================+======================+==
==========+======================+======================+
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.12.2         |
        0 |                   66 | 20104                |
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+

A:admin@PE-1# info from state with-context / system mpls label-ranges static * | as table |
 filter fields *
+-------------------------------------------------------------------+--------+-------------+-----
------+-----------------+-------------+----------------+
|                            Name                                   | Shared | Start-label | End-
label | Allocated-labels | Free-labels |     Status     |
+===================================================================+========+=============+=====
======+=================+=============+================+
| srgb-static                                                       | true   |       20000 |
 20999 |               2 |         998 | ready          |
+-------------------------------------------------------------------+--------+-------------+-----
------+-----------------+-------------+----------------+
```

PE-2 receives SR label 20101 for remote prefix 10.0.1.1/32 from its neighbor on PE-1. PE-2 advertises that SR label 20101 to its neighbor on PE-3.

PE-2 receives SR label 20104 for remote prefix 10.0.4.1/32 from its neighbor on PE-3. PE-2 advertises that SR label 20104 to its neighbor on PE-1.

```
A:admin@PE-2# info from state with-context / network-instance default bgp-rib afi-safi ipv4-
labeled-unicast
 ipv4-labeled-unicast rib-in-out rib-out-post route * neighbor * path-id 0 | as table |filter
 fields attr-id advertised-mpls-label
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+
|   Network-instance   |       Afi-safi       |        Prefix        |       Neighbor       |
 Path-id   |       Attr-id        |   Advertised-mpls-   |
|                      |                      |                      |                      |
          |                      |        label         |
+======================+======================+======================+======================+==
==========+======================+======================+
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.23.2         |
        0 |                   51 | 20101                |
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.12.1         |
        0 |                   53 | 20104                |
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+

A:admin@PE-2# info from state with-context / network-instance default bgp-rib afi-safi ipv4-
labeled-unicast
 ipv4-labeled-unicast rib-in-out rib-in-pre route * neighbor * path-id 0 | as table |filter
 fields attr-id received-mpls-label
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+
|   Network-instance   |       Afi-safi       |        Prefix        |       Neighbor       |
 Path-id   |       Attr-id        | Received-mpls-label  |
+======================+======================+======================+======================+==
==========+======================+======================+
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.12.1         |
        0 |                   50 | 20101                |
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.23.2         |
        0 |                   52 | 20104                |
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+
```

```
A:admin@PE-2# info from state with-context / system mpls label-ranges static * | as table |
 filter fields *
+-------------------------------------------------------------------+--------+-------------+-----
------+-----------------+-------------+----------------+
|                            Name                                   | Shared | Start-label | End-
label | Allocated-labels | Free-labels |     Status     |
+===================================================================+========+=============+=====
======+=================+=============+================+
| srgb-static                                                       | true   |       20000 |
 20999 |                2 |         998 | ready          |
+-------------------------------------------------------------------+--------+-------------+-----
------+-----------------+-------------+----------------+
```

Because PE-3 and PE-4 have BGP multipath configured, traffic flows can be sprayed over two links.

PE-3 receives SR label 20101 for remote prefix 10.0.1.1/32 from its neighbor on PE-2. PE-3 advertises that SR label 20101 to two neighbors on PE-4. PE-3 also receives SR label 20101 for remote prefix 10.0.1.1/32 from one neighbor on PE-4 but does not use it.

PE-3 receives SR label 20104 for remote prefix 10.0.4.1/32 from two neighbors on PE-4 but uses SR label 20104 from only one neighbor on PE-4. PE-3 advertises that SR label 20104 to its neighbor on PE-2 and to the other neighbor on PE-4.

```
A:admin@PE-3# info from state with-context / network-instance default bgp-rib afi-safi ipv4-
labeled-unicast
 ipv4-labeled-unicast rib-in-out rib-out-post route * neighbor * path-id 0 | as table |filter
 fields attr-id advertised-mpls-label
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+
|   Network-instance   |       Afi-safi       |        Prefix        |       Neighbor       |
 Path-id   |       Attr-id        |   Advertised-mpls-   |
|                      |                      |                      |                      |
          |                      |        label         |
+======================+======================+======================+======================+==
==========+======================+======================+
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.34.2         |
        0 |                   67 | 20101                |
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.34.6         |
        0 |                   67 | 20101                |
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.23.1         |
        0 |                   71 | 20104                |
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.34.6         |
        0 |                   71 | 20104                |
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+

A:admin@PE-3# info from state with-context / network-instance default bgp-rib afi-safi ipv4-
labeled-unicast
 ipv4-labeled-unicast rib-in-out rib-in-pre route * neighbor * path-id 0 | as table |filter
 fields attr-id received-mpls-label
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+
|   Network-instance   |       Afi-safi       |        Prefix        |       Neighbor       |
 Path-id   |       Attr-id        | Received-mpls-label  |
+======================+======================+======================+======================+==
==========+======================+======================+
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.23.1         |
        0 |                   66 | 20101                |
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.34.6         |
        0 |                   68 | 20101                |
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.34.2         |
        0 |                   70 | 20104                |
```

```
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.34.6         |
        0 |                   69 | 20104               |
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+

A:admin@PE-3# info from state with-context / system mpls label-ranges static * | as table |
 filter fields *
+-------------------------------------------------------------------+--------+-------------+-----
------+-----------------+-------------+----------------+
|                            Name                                   | Shared | Start-label | End-
label | Allocated-labels | Free-labels |     Status     |
+===================================================================+========+=============+=====
======+=================+=============+================+
| srgb-static                                                        | true   |       20000 |
 20999 |                2 |         998 | ready          |
+-------------------------------------------------------------------+--------+-------------+-----
------+-----------------+-------------+----------------+
```

Because PE-3 and PE-4 have BGP multipath configured, traffic flows can be sprayed over two links.

PE-4 advertises SR label 20104 for its local prefix 10.0.4.1/32 to two neighbors on PE-3. PE-4 also receives SR label 20104 for its local prefix 10.0.4.1/32 from one neighbor on PE-3 but does not use it.

PE-4 receives SR label 20101 for remote prefix 10.0.1.1/32 from two neighbors on PE-3 but uses SR label 20101 from only one neighbor on PE-3. PE-4 advertises that SR label 20101 to the other neighbor on PE-3.

```
A:admin@PE-4# info from state with-context / network-instance default bgp-rib afi-safi ipv4-
labeled-unicast
 ipv4-labeled-unicast rib-in-out rib-out-post route * neighbor * path-id 0 | as table |filter
 fields attr-id advertised-mpls-label
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+
|   Network-instance   |       Afi-safi       |        Prefix        |       Neighbor       |
 Path-id   |       Attr-id        |   Advertised-mpls-   |
|                      |                      |                      |                      |
          |                      |        label         |
+======================+======================+======================+======================+==
==========+======================+======================+
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.34.5         |
        0 |                   82 | 20101               |
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.34.1         |
        0 |                   84 | 20104               |
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.34.5         |
        0 |                   84 | 20104               |
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+

A:admin@PE-4# info from state with-context / network-instance default bgp-rib afi-safi ipv4-
labeled-unicast
 ipv4-labeled-unicast rib-in-out rib-in-pre route * neighbor * path-id 0 | as table |filter
 fields attr-id received-mpls-label
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+
|   Network-instance   |       Afi-safi       |        Prefix        |       Neighbor       |
 Path-id   |       Attr-id        | Received-mpls-label  |
+======================+======================+======================+======================+==
==========+======================+======================+
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.34.1         |
        0 |                   83 | 20101               |
| default              | ipv4-labeled-unicast | 10.0.1.1/32          | 192.168.34.5         |
        0 |                   81 | 20101               |
```

```
| default              | ipv4-labeled-unicast | 10.0.4.1/32          | 192.168.34.5         |
        0 |                   85 | 20104               |
+----------------------+----------------------+----------------------+----------------------+--
----------+----------------------+----------------------+

A:admin@PE-4# info from state with-context / system mpls label-ranges static * | as table |
 filter fields *
+-------------------------------------------------------------------+--------+-------------+-----
------+-----------------+-------------+----------------+
|                            Name                                   | Shared | Start-label | End-
label | Allocated-labels | Free-labels |     Status     |
+===================================================================+========+=============+=====
======+=================+=============+================+
| srgb-static                                                        | true   |       20000 |
 20999 |               2 |         998 | ready          |
+-------------------------------------------------------------------+--------+-------------+-----
------+-----------------+-------------+----------------+
```

The tunnel table on PE-1 shows that a BGP tunnel with ID 262145 is available toward destination 10.0.4.1/32:

```
A:admin@PE-1# show / network-instance default tunnel-table ipv4
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
| IPv4 Prefix  | Tunnel Type  |  Tunnel ID   |     FIB      |    Metric    |  Preference  |
 Last Update  |    Backup    |   Next-hop   |   Next-hop   |
|              |              |              |              |              |              |
          |   Nexthops   |    (Type)    |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 10.0.4.1/32  | bgp          | 262145       | Y            | 1000         | 12           |
 2026-01-     |              | 192.168.12.2 | ethernet-    |
|              |              |              |              |              |              |
 21T22:09:31. |              | (mpls)       | 1/2.1        |
|              |              |              |              |              |              |
 623Z         |              |              |              |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
1 BGP tunnels, 1 active, 0 inactive
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
```

The detail provides more information on the label (20104) and the next hop (192.168.12.2):

```
A:admin@PE-1# show / network-instance default tunnel-table ipv4 detail
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Show report for network instance "default" tunnel table
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
=================================================================================================
=======================================================
Destination        : 10.0.4.1/32
Tunnel Type        : bgp
Tunnel ID          : 262145
```

```
Metric             : 1000
Preference         : 12
Last Update        : 2026-01-21T22:09:31.623Z
FIB Status         : active
Next-hops
  192.168.12.2 (mpls) via [ethernet-1/2.1]
      pushed MPLS labels : [20104]
============================================================================================================
============================================================
```

On PE-2, two BGP tunnels are available: one toward destination 10.0.1.1/32 with SR label 20101 and another toward destination 10.0.4.1/32 with SR label 20104:

```
A:admin@PE-2# show / network-instance default tunnel-table ipv4
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------
IPv4 tunnel table of network-instance "default"
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
| IPv4 Prefix  | Tunnel Type  |  Tunnel ID   |     FIB      |    Metric    |  Preference  |
 Last Update  |    Backup    |   Next-hop   |   Next-hop   |
|              |              |              |              |              |              |
          |   Nexthops   |    (Type)    |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 10.0.1.1/32  | bgp          | 262145       | Y            | 1000         | 12           |
 2026-01-     |              | 192.168.12.1 | ethernet-    |
|              |              |              |              |              |              |
 21T22:09:09. |              | (mpls)       | 1/1.1        |
|              |              |              |              |              |              |
 618Z         |              |              |              |
| 10.0.4.1/32  | bgp          | 262146       | Y            | 1000         | 12           |
 2026-01-     |              | 192.168.23.2 | ethernet-    |
|              |              |              |              |              |              |
 21T22:09:30. |              | (mpls)       | 1/3.1        |
|              |              |              |              |              |              |
 161Z         |              |              |              |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------
2 BGP tunnels, 2 active, 0 inactive
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------

A:admin@PE-2# show / network-instance default tunnel-table ipv4 detail
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------
Show report for network instance "default" tunnel table
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------
============================================================================================================
============================================================
Destination        : 10.0.1.1/32
Tunnel Type        : bgp
Tunnel ID          : 262145
Metric             : 1000
Preference         : 12
Last Update        : 2026-01-21T22:09:09.618Z
FIB Status         : active
Next-hops
```

```
  192.168.12.1 (mpls) via [ethernet-1/1.1]
      pushed MPLS labels : [20101]
============================================================================================================
============================================================
Destination        : 10.0.4.1/32
Tunnel Type        : bgp
Tunnel ID          : 262146
Metric             : 1000
Preference         : 12
Last Update        : 2026-01-21T22:09:30.161Z
FIB Status         : active
Next-hops
  192.168.23.2 (mpls) via [ethernet-1/3.1]
      pushed MPLS labels : [20104]
============================================================================================================
============================================================
```

On PE-3, two BGP tunnels are available: one toward destination 10.0.1.1/32 with SR label 20101 and one toward destination 10.0.4.1/32 with SR label 20104. The BGP tunnel toward destination 10.0.4.1/32 has two next hops.

```
A:admin@PE-3# show / network-instance default tunnel-table ipv4
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------
IPv4 tunnel table of network-instance "default"
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
| IPv4 Prefix  | Tunnel Type  |  Tunnel ID   |     FIB      |    Metric    |  Preference  |
 Last Update  |    Backup    |   Next-hop   |   Next-hop   |
|              |              |              |              |              |              |
          |   Nexthops   |    (Type)    |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 10.0.1.1/32  | bgp          | 262145       | Y            | 1000         | 12           |
 2026-01-     |              | 192.168.23.1 | ethernet-    |
|              |              |              |              |              |              |
 21T22:09:25. |              | (mpls)       | 1/2.1        |
|              |              |              |              |              |              |
 951Z         |              |              |              |
| 10.0.4.1/32  | bgp          | 262146       | Y            | 1000         | 12           |
 2026-01-     |              | 192.168.34.2 | ethernet-    |
|              |              |              |              |              |              |
 21T22:09:27. |              | (mpls)       | 1/4.1        |
|              |              |              |              |              |              |
 953Z         |              |              |              |
|              |              |              |              |              |              |
          |              | 192.168.34.6 | ethernet-    |
|              |              |              |              |              |              |
          |              | (mpls)       | 1/6.1        |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------
2 BGP tunnels, 2 active, 0 inactive
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------

A:admin@PE-3# show / network-instance default tunnel-table ipv4 detail
------------------------------------------------------------------------------------------------------------
------------------------------------------------------------
Show report for network instance "default" tunnel table
```

```
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
=================================================================================================
=====================================================
Destination        : 10.0.1.1/32
Tunnel Type        : bgp
Tunnel ID          : 262145
Metric             : 1000
Preference         : 12
Last Update        : 2026-01-21T22:09:25.951Z
FIB Status         : active
Next-hops
  192.168.23.1 (mpls) via [ethernet-1/2.1]
      pushed MPLS labels : [20101]
=================================================================================================
=====================================================
Destination        : 10.0.4.1/32
Tunnel Type        : bgp
Tunnel ID          : 262146
Metric             : 1000
Preference         : 12
Last Update        : 2026-01-21T22:09:27.953Z
FIB Status         : active
Next-hops
  192.168.34.2 (mpls) via [ethernet-1/4.1]
      pushed MPLS labels : [20104]
  192.168.34.6 (mpls) via [ethernet-1/6.1]
      pushed MPLS labels : [20104]
=================================================================================================
=====================================================
```

On PE-4, one BGP tunnel is available toward destination 10.0.1.1/32 with SR label 20101. The BGP tunnel toward destination 10.0.1.1/32 has two next hops.

```
A:admin@PE-4# show / network-instance default tunnel-table ipv4
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
| IPv4 Prefix  | Tunnel Type  |  Tunnel ID   |     FIB      |    Metric    |  Preference  |
 Last Update  |    Backup    |   Next-hop   |   Next-hop   |
|              |              |              |              |              |              |
          |   Nexthops   |    (Type)    |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 10.0.1.1/32  | bgp          | 262145       | Y            | 1000         | 12           |
 2026-01-     |              | 192.168.34.1 | ethernet-    |
|              |              |              |              |              |              |
 21T22:09:17. |              | (mpls)       | 1/3.1        |
|              |              |              |              |              |              |
 151Z         |              |              |              |
|              |              |              |              |              |              |
          |              | 192.168.34.5 | ethernet-    |
|              |              |              |              |              |              |
          |              | (mpls)       | 1/5.1        |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
1 BGP tunnels, 1 active, 0 inactive
-------------------------------------------------------------------------------------------------
-----------------------------------------------------

A:admin@PE-4# show / network-instance default tunnel-table ipv4 detail
```

```
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Show report for network instance "default" tunnel table
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
=================================================================================================
=======================================================
Destination        : 10.0.1.1/32
Tunnel Type        : bgp
Tunnel ID          : 262145
Metric             : 1000
Preference         : 12
Last Update        : 2026-01-21T22:09:17.151Z
FIB Status         : active
Next-hops
  192.168.34.1 (mpls) via [ethernet-1/3.1]
      pushed MPLS labels : [20101]
  192.168.34.5 (mpls) via [ethernet-1/5.1]
      pushed MPLS labels : [20101]
=================================================================================================
=======================================================
```

PE-1 advertises a BGP-LU IPv4 route for prefix 10.0.1.1/32 with label 20101 to PE-2. The following command on PE-2 shows the received route:

```
A:admin@PE-2# show / network-instance default protocols bgp routes ipv4-labeled-unicast prefix
 10.0.1.1/32
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Show report for the BGP routes to network "10.0.1.1/32" network-instance  "default"
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Network: 10.0.1.1/32
Received Paths: 1
  Path 1: <Best,Valid,Used,>
    Route source    : neighbor 192.168.12.1
    Route Preference: MED is -, No LocalPref
    BGP next-hop    : 192.168.12.1
    Path            :  i [64501]
    Communities     : None
Path 1 was advertised to:
[ 192.168.23.2 ]
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
```

The detail shows the label, as follows:

```
A:admin@PE-2# show / network-instance default protocols bgp routes ipv4-labeled-unicast prefix
 10.0.1.1/32 detail
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Show report for the BGP routes to network "10.0.1.1/32" network-instance  "default"
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Network: 10.0.1.1/32
Received Paths: 1
  Path 1: <Best,Valid,Used,>
    Route source      : neighbor 192.168.12.1
    Route Preference  : MED is -, No LocalPref
    BGP next-hop      : 192.168.12.1
    Path              :  i [64501]
    Received Label    : [20101]
```

```
    Communities       : None
    RR Attributes     : No Originator-ID, Cluster-List is [ - ]
    Aggregation       : Not an aggregate route
    Unknown Attr      : None
    Invalid Reason    : None
    Tie Break Reason  : none
    Route Flap Damping: None

Path 1 was advertised to:
[ 192.168.23.2 ]
Route Preference: MED is -, No LocalPref
Path            :  i [64502, 64501]
Communities     : None
RR Attributes   : No Originator-ID, Cluster-List is [ - ]
Aggregation     : Not an aggregate route
Unknown Attr    : None
-------------------------------------------------------------------------------------------
-------------------------------------------------------
```

PE-2 advertises this route to PE-3 and PE-3 advertises it further to PE-4. The following command on PE-4 shows two BGP-LU IPv4 routes for prefix 10.0.1.1/32 with label 20101: one with next hop 192.168.34.1 and another one with next hop 192.168.34.5.

```
A:admin@PE-4# show / network-instance default protocols bgp routes ipv4-labeled-unicast prefix
 10.0.1.1/32
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Show report for the BGP routes to network "10.0.1.1/32" network-instance  "default"
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Network: 10.0.1.1/32
Received Paths: 2
  Path 1: <Best,Valid,Used,>
    Route source    : neighbor 192.168.34.1
    Route Preference: MED is -, No LocalPref
    BGP next-hop    : 192.168.34.1
    Path            :  i [64503, 64502, 64501]
    Communities     : None
  Path 2: <Best,Valid,Used,>
    Route source    : neighbor 192.168.34.5
    Route Preference: MED is -, No LocalPref
    BGP next-hop    : 192.168.34.5
    Path            :  i [64503, 64502, 64501]
    Communities     : None
Path 2 was advertised to:
[ 192.168.34.5 ]
-------------------------------------------------------------------------------------------
-------------------------------------------------------
```

The detailed output for the BGP-LU IPv4 routes on PE-4 shows the label, as follows:

```
A:admin@PE-4# show / network-instance default protocols bgp routes ipv4-labeled-unicast prefix
 10.0.1.1/32 detail
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Show report for the BGP routes to network "10.0.1.1/32" network-instance  "default"
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Network: 10.0.1.1/32
Received Paths: 2
  Path 1: <Best,Valid,Used,>
    Route source      : neighbor 192.168.34.1
```

```
    Route Preference  : MED is -, No LocalPref
    BGP next-hop      : 192.168.34.1
    Path              :  i [64503, 64502, 64501]
    Received Label    : [20101]
    Communities       : None
    RR Attributes     : No Originator-ID, Cluster-List is [ - ]
    Aggregation       : Not an aggregate route
    Unknown Attr      : None
    Invalid Reason    : None
    Tie Break Reason  : none
    Route Flap Damping: None
  Path 2: <Best,Valid,Used,>
    Route source      : neighbor 192.168.34.5
    Route Preference  : MED is -, No LocalPref
    BGP next-hop      : 192.168.34.5
    Path              :  i [64503, 64502, 64501]
    Received Label    : [20101]
    Communities       : None
    RR Attributes     : No Originator-ID, Cluster-List is [ - ]
    Aggregation       : Not an aggregate route
    Unknown Attr      : None
    Invalid Reason    : None
    Tie Break Reason  : peer-ip
    Route Flap Damping: None

Path 2 was advertised to:
[ 192.168.34.5 ]
Route Preference: MED is -, No LocalPref
Path            :  i [64504, 64503, 64502, 64501]
Communities     : None
RR Attributes   : No Originator-ID, Cluster-List is [ - ]
Aggregation     : Not an aggregate route
Unknown Attr    : None
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
```

The route table for network instance default on PE-4 is as follows. It shows that prefix 10.0.1.1/32 has two active ECMP routes (two next hops).

```
A:admin@PE-4# show / network-instance default route-table ipv4-unicast summary
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
+----------------+------+-----------+--------------------+---------+---------+--------+--------
---+-----------+-----------+-----------+-----------+
|     Prefix     |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
   | Next-hop  | Next-hop  |  Backup   |  Backup   |
|                |      |   Type    |                    |         | Network |        |
   |  (Type)   | Interface | Next-hop  | Next-hop  |
|                |      |           |                    |         | Instanc |        |
   |           |           |  (Type)   | Interface |
|                |      |           |                    |         |    e    |        |
   |           |           |           |           |
+================+======+===========+====================+=========+=========+========+========
===+===========+===========+===========+===========+
| 10.0.1.1/32    | 0    | bgp-label | bgp_label_mgr      | True    | default | 0      | 170
   | 192.168.3 | ethernet- |           |           |
|                |      |           |                    |         |         |        |
   | 4.1       | 1/3.1     |           |           |
|                |      |           |                    |         |         |        |
   | (mpls)    | ethernet- |           |           |
```

```
|                 |      |           |                     |         |         |        |
   | 192.168.3 | 1/5.1     |           |           |
|                 |      |           |                     |         |         |        |
   | 4.5       |           |           |           |
|                 |      |           |                     |         |         |        |
   | (mpls)    |           |           |           |
| 10.0.4.1/32     | 14   | host      | net_inst_mgr        | True    | default | 0      | 0
   | None      | None      |           |           |
| 192.0.2.4/32    | 13   | host      | net_inst_mgr        | True    | default | 0      | 0
   | None      | None      |           |           |
| 192.168.34.0/3 | 11   | local     | net_inst_mgr        | True    | default | 0      | 0
   | 192.168.3 | ethernet- |           |           |
| 0               |      |           |                     |         |         |        |
   | 4.2       | 1/3.1     |           |           |
|                 |      |           |                     |         |         |        |
   | (direct)  |           |           |           |
| 192.168.34.2/3 | 11   | host      | net_inst_mgr        | True    | default | 0      | 0
   | None      | None      |           |           |
| 2               |      |           |                     |         |         |        |
   |           |           |           |           |
| 192.168.34.3/3 | 11   | host      | net_inst_mgr        | True    | default | 0      | 0
   | None      | None      |           |           |
| 2               |      |           |                     |         |         |        |
   |           |           |           |           |
| 192.168.34.4/3 | 12   | local     | net_inst_mgr        | True    | default | 0      | 0
   | 192.168.3 | ethernet- |           |           |
| 0               |      |           |                     |         |         |        |
   | 4.6       | 1/5.1     |           |           |
|                 |      |           |                     |         |         |        |
   | (direct)  |           |           |           |
| 192.168.34.6/3 | 12   | host      | net_inst_mgr        | True    | default | 0      | 0
   | None      | None      |           |           |
| 2               |      |           |                     |         |         |        |
   |           |           |           |           |
| 192.168.34.7/3 | 12   | host      | net_inst_mgr        | True    | default | 0      | 0
   | None      | None      |           |           |
| 2               |      |           |                     |         |         |        |
   |           |           |           |           |
+----------------+------+-----------+---------------------+---------+---------+--------+--------
---+-----------+-----------+-----------+-----------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv4 routes total                    : 9
IPv4 prefixes with active routes     : 9
IPv4 prefixes with active ECMP routes: 1
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

The following **info from state** commands show how the prefix SID attribute is advertised in BGP:

```
A:admin@PE-1# info from state with-context / network-instance default bgp-rib afi-safi ipv4-
labeled-unicast
    network-instance default {
        bgp-rib {
            afi-safi ipv4-labeled-unicast {
                ipv4-labeled-unicast {
                    ---snip---
                    rib-in-out {
                        ---snip---
                        rib-out-post {
                            route 10.0.1.1/32 neighbor 192.168.12.2 path-id 0 {
                                attr-id 65
                                advertised-mpls-label [
```

```
                                    20101
                                ]
                            }
                        }
                    }
                }
            }
        }
    }

A:admin@PE-1# info from state with-context / network-instance default bgp-rib attr-sets attr-
set *
    network-instance default {
        bgp-rib {
            attr-sets {
                ---snip---
                attr-set 65 {
                    ---snip---
                    prefix-sid {
                        tlv label-index {
                            label-index {
                                label-index 101
                            }
                        }
                        tlv srgb-originator {
                            srgb-originator {
                                srgb [
                                    20000:1000
                                ]
                            }
                        }
                    }
                }
            }
        }
        }
```

The following **show** command gives information about the BGP session establishment. Only the **ipv4-labeled-unicast** address family (via inheritance from the BGP level) is configured for BGP group **grp-EBGP**.

```
A:admin@PE-4# show / network-instance default protocols bgp neighbor *
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
BGP neighbor summary for network-instance "default"
Flags: S static, D dynamic, L discovered by LLDP, B BFD enabled, - disabled, * slow
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
+----------------+-----------------------+-----------------+------+---------+--------------+-
------------+------------+-----------------------+
|    Net-Inst    |          Peer         |      Group      | Flag | Peer-AS |    State     |
   Uptime    |  AFI/SAFI  |     [Rx/Active/Tx]    |
|               |            |                       |                 |  s   |         |              |
             |            |         |                       |
+================+=======================+=================+======+=========+==============+=
=============+============+=======================+
| default        | 192.168.34.1          | grp-EBGP        | S    | 64503   | established  |
 0d:0h:10m:39 | ipv4-      | [1/1/1]               |
|                |                       |                 |      |         |              |
 s           | labeled-   |                       |
```

```
|                 |                          |                 |      |         |              |
             | unicast    |                          |
| default         | 192.168.34.5             | grp-EBGP        | S    | 64503   | established  |
 0d:0h:10m:39 | ipv4-      | [2/1/2]                  |
|                 |                          |                 |      |         |              |
 s            | labeled-   |                          |
|                 |                          |                 |      |         |              |
             | unicast    |                          |
+-----------------+--------------------------+-----------------+------+---------+--------------+-
------------+------------+------------------------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
Summary:
2 configured neighbors, 2 configured sessions are established, 0 disabled peers
0 dynamic peers
```

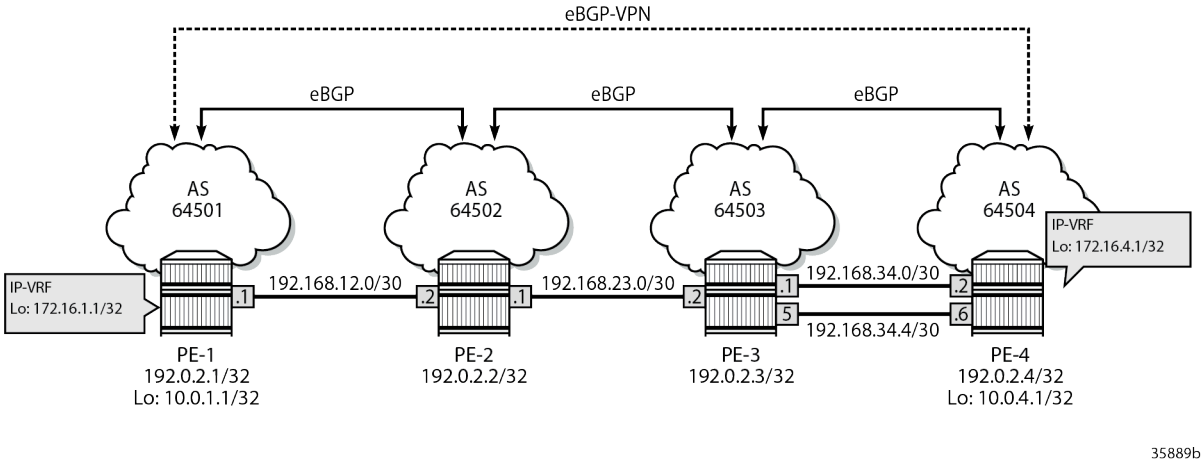
The following **show** command gives more detailed information per BGP group neighbor:

```
A:admin@PE-4# show / network-instance default protocols bgp neighbor * detail
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
Peer : 192.168.34.1, remote AS: 64503, local AS: 64504, peer-type : ebgp
Type : static
Description : None
Group : grp-EBGP
Export policies : ['pol-10']
Import policies: []
---snip---
Admin-state is enable, session-state is established, up for 0d:0h:10m:39s
TCP connection is 192.168.34.2 [179] -> 192.168.34.1 [44365]
---snip---
Ipv4-labeled-unicast AFI/SAFI
    End of RIB                    : sent, received
    Received routes               : 1
    Rejected routes               : None
    Active routes                 : 1
    Advertised routes             : 1
    Prefix-limit-received         : None
    Prefix-limit-accepted         : None
    Default originate             : disabled
    Advertise with IPv6 next-hops  : False
    Peer requested GR helper      : None
    Peer preserved forwarding state: None
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
Peer : 192.168.34.5, remote AS: 64503, local AS: 64504, peer-type : ebgp
Type : static
Description : None
Group : grp-EBGP
Export policies : ['pol-10']
Import policies: []
---snip---
Admin-state is enable, session-state is established, up for 0d:0h:10m:39s
TCP connection is 192.168.34.6 [179] -> 192.168.34.5 [41361]
---snip---
Ipv4-labeled-unicast AFI/SAFI
    ---snip---
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

3.3.3 Configure an IP VRF

Figure 4: Example topology with network instance IP-VRF shows the example topology with a basic IP VRF to demonstrate the end-to-end control plane signaling and data plane verification.

Figure 4: Example topology with network instance IP-VRF



Configure an eBGP multi-hop session for address family **l3vpn-ipv4-unicast** between the GRT loopback addresses 10.0.1.1/32 on PE-1 and 10.0.4.1/32 on PE-4. The additional BGP configuration is as follows:

```
# on PE-1, PE-4:
enter candidate
    network-instance default {
        protocols {
            bgp {
                group grp-EBGP-VPN {
                    admin-state enable
                    afi-safi l3vpn-ipv4-unicast {
                        admin-state enable
                    }
                }
                neighbor 10.0.4.1 {              # 10.0.1.1 on PE-4
                    admin-state enable
                    peer-as 64504                # 64501 on PE-4
                    peer-group grp-EBGP-VPN
                    multihop {
                        admin-state enable
                        maximum-hops 64
                    }
                    transport {
                        local-address 10.0.1.1    # 10.0.4.1 on PE-4
                    }
                }
            }
        }
    }
```

Configure a dynamic label range for non-default network instances on all PEs, as follows:

```
# on all PEs:
enter candidate
```

```
    system {
        mpls {
            label-ranges {
                dynamic dynamic-vrfs {
                    start-label 40000
                    end-label 40099
                }
            }
            services {
                network-instance {
                    dynamic-label-block dynamic-vrfs
                }
            }
        }
```

In addition, configure a loopback interface for network instance IP-VRF, with IP address 172.16.1.1/32 on PE-1 and with IP address 172.16.4.1/32 on PE-4, as follows:

```
# on PE-1, PE-4:
enter candidate
    interface lo0 {
        admin-state enable
        subinterface 1 {
            admin-state enable
            description "loopback interface in IP-VRF"
            ipv4 {
                admin-state enable
                address 172.16.1.1/32 {             # 172.16.4.1/32 on PE-4
                    primary
                }
            }
        }
    }
    network-instance IP-VRF {
        type ip-vrf
        admin-state enable
        router-id 10.0.1.1                          # 10.0.4.1 on PE-4
        interface lo0.1 {
            interface-ref {
                interface lo0
                subinterface 1
            }
        }
```

Configure BGP VPN and BGP IP VPN with **ecmp 2** and **allowed-tunnel-types [bgp]** for network instance IP-VRF, as follows:

```
# on PE-1, PE-4:
enter candidate
    network-instance IP-VRF {
        protocols {
            bgp-ipvpn {
                bgp-instance 1 {
                    admin-state enable
                    ecmp 2
                    mpls {
                        next-hop-resolution {
                            allowed-tunnel-types [ bgp ]
                        }
                    }
                }
            }
```

```
            bgp-vpn {
                bgp-instance 1 {
                    route-distinguisher {
                        rd 10.0.1.1:0               # 10.0.4.1:0 on PE-4
                    }
                    route-target {
                        export-rt target:64501:0    # target:64504:0 on PE-4
                        import-rt target:64504:0    # target:64501:0 on PE-4
                    }
                }
            }
        }
    }
```

PE-1 receives the following **l3vpn-ipv4-unicast** route:

```
A:admin@PE-1# show / network-instance default protocols bgp neighbor 10.0.4.1 received-routes
 l3vpn-ipv4-unicast
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Peer        : 10.0.4.1, remote AS: 64504, local AS: 64501
Type        : static
Description : None
Group       : grp-EBGP-VPN
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Status codes: u=used, *=valid, >=best, x=stale, b=backup, w=unused-weight-only
Origin codes: i=IGP, e=EGP, ?=incomplete
+-----------------------------------------------------------------------------------------------
-----------------------------------------------+
|    Status          Route-          Network         Path-id        Next Hop           MED
      LocPref         AsPath          Origin     |
|                distinguisher
                                                |
+===============================================================================================
===============================================+
|      u*>        10.0.4.1:0      172.16.4.1/32   0              10.0.4.1             -
                   [64504]              i       |
+-----------------------------------------------------------------------------------------------
-----------------------------------------------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
1 received BGP routes : 1 used 1 valid
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
```

The route table for IP-VRF on PE-1 is as follows:

```
A:admin@PE-1# network-instance IP-VRF route-table ipv4-unicast summary
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 unicast route table of network instance IP-VRF
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
+---------------+------+-----------+-------------------+---------+---------+--------+--------
---+-----------+-----------+-----------+-----------+
|     Prefix     |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
   | Next-hop  | Next-hop  |  Backup   |  Backup   |
|                |      |   Type    |                    |         | Network |        |
   |  (Type)   | Interface | Next-hop  | Next-hop  |
|                |      |           |                    |         | Instanc |        |
   |           |           |  (Type)   | Interface |
```

```
|                |      |           |                    |         |    e    |        |
   |           |          |           |           |
+================+======+===========+====================+=========+=========+========+========
===+===========+===========+===========+============+
| 172.16.1.1/32  | 12   | host      | net_inst_mgr       | True    | IP-VRF  | 0      | 0
   | None      | None      |           |           |
| 172.16.4.1/32  | 0    | bgp-ipvpn | bgp_ipvpn_mgr      | True    | IP-VRF  | 1000   | 170
   | 10.0.4.1/ |           |           |           |
|                |      |           |                    |         |         |        |
   | 32 (indir |           |           |           |
|                |      |           |                    |         |         |        |
   | ect/bgp)  |           |           |           |
+----------------+------+-----------+--------------------+---------+---------+--------+--------
---+-----------+-----------+-----------+-----------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
IPv4 routes total                    : 2
IPv4 prefixes with active routes     : 2
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
```

The following **show** command gives information about the BGP session establishment. Both the **ipv4-labeled-unicast** (via inheritance from the BGP level) and **l3vpn-ipv4-unicast** address families are configured for BGP group **grp-EBGP-VPN**.

```
A:admin@PE-4# show / network-instance default protocols bgp neighbor *
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
BGP neighbor summary for network-instance "default"
Flags: S static, D dynamic, L discovered by LLDP, B BFD enabled, - disabled, * slow
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
+-----------------+-----------------------+-----------------+------+---------+--------------+-
-------------+------------+-----------------------+
|    Net-Inst     |          Peer         |      Group      | Flag | Peer-AS |    State     |
   Uptime    |  AFI/SAFI  |     [Rx/Active/Tx]    |
|                 |                       |                 |  s   |         |              |
             |            |                       |
+=================+=======================+=================+======+=========+==============+=
=============+============+=======================+
| default         | 10.0.1.1              | grp-EBGP-VPN    | S    | 64501   | established  |
 0d:0h:8m:19s | ipv4-      | [1/0/1]               |
|                 |                       |                 |      |         |              |
             | labeled-   | [1/1/1]               |
|                 |                       |                 |      |         |              |
             | unicast    |                       |
|                 |                       |                 |      |         |              |
             | l3vpn-ipv4 |                       |
|                 |                       |                 |      |         |              |
             | -unicast   |                       |
| default         | 192.168.34.1          | grp-EBGP        | S    | 64503   | established  |
 0d:0h:24m:38 | ipv4-      | [1/1/1]               |
|                 |                       |                 |      |         |              |
 s           | labeled-   |                       |
|                 |                       |                 |      |         |              |
             | unicast    |                       |
| default         | 192.168.34.5          | grp-EBGP        | S    | 64503   | established  |
 0d:0h:24m:38 | ipv4-      | [2/1/2]               |
|                 |                       |                 |      |         |              |
 s           | labeled-   |                       |
```

```
|                |                       |                |      |        |              |
             | unicast    |                       |
+----------------+-----------------------+----------------+------+--------+--------------+-
-------------+------------+-----------------------+
-------------------------------------------------------------------------------------------
-----------------------------------------------------
Summary:
3 configured neighbors, 3 configured sessions are established, 0 disabled peers
0 dynamic peers
```

The following **show** command gives more detailed information per BGP neighbor:

```
A:admin@PE-4# show / network-instance default protocols bgp neighbor * detail
-------------------------------------------------------------------------------------------
-----------------------------------------------------
Peer : 10.0.1.1, remote AS: 64501, local AS: 64504, peer-type : ebgp
Type : static
Description : None
Group : grp-EBGP-VPN
Export policies : []
Import policies: []
---snip---
Admin-state is enable, session-state is established, up for 0d:0h:8m:19s
TCP connection is 10.0.4.1 [179] -> 10.0.1.1 [38165]
---snip---
L3vpn-ipv4-unicast AFI/SAFI
    End of RIB                    : sent, received
    Received routes               : 1
    Rejected routes               : None
    Active routes                 : 1
    Advertised routes             : 1
    Prefix-limit-received         : 4294967295 routes, warning at 90, prevent-teardown False
    Prefix-limit-accepted         : None
    Default originate             : disabled
    Advertise with IPv6 next-hops  : False
    Peer requested GR helper      : None
    Peer preserved forwarding state: None
-------------------------------------------------------------------------------------------
-----------------------------------------------------
Ipv4-labeled-unicast AFI/SAFI
    End of RIB                    : sent, received
    Received routes               : 1
    Rejected routes               : None
    Active routes                 : None
    Advertised routes             : 1
    Prefix-limit-received         : None
    Prefix-limit-accepted         : None
    Default originate             : disabled
    Advertise with IPv6 next-hops  : False
    Peer requested GR helper      : None
    Peer preserved forwarding state: None
-------------------------------------------------------------------------------------------
-----------------------------------------------------
-------------------------------------------------------------------------------------------
-----------------------------------------------------
Peer : 192.168.34.1, remote AS: 64503, local AS: 64504, peer-type : ebgp
Type : static
Description : None
Group : grp-EBGP
Export policies : ['pol-10']
Import policies: []
---snip---
Admin-state is enable, session-state is established, up for 0d:0h:24m:38s
```

```
TCP connection is 192.168.34.2 [179] -> 192.168.34.1 [44365]
---snip---
Ipv4-labeled-unicast AFI/SAFI
    ---snip---
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
Peer : 192.168.34.5, remote AS: 64503, local AS: 64504, peer-type : ebgp
Type : static
Description : None
Group : grp-EBGP
Export policies : ['pol-10']
Import policies: []
---snip---
Admin-state is enable, session-state is established, up for 0d:0h:24m:38s
TCP connection is 192.168.34.6 [179] -> 192.168.34.5 [41361]
---snip---
Ipv4-labeled-unicast AFI/SAFI
    ---snip---
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

3.4 Conclusion

With BGP SR, it is possible to use SR without the use of an IGP protocol (for example, to cross AS boundaries). It is also possible to stitch SR-IGP and SR-BGP tunnels together. BGP SR uses the prefix SID attribute.

4 BGP for underlay routing

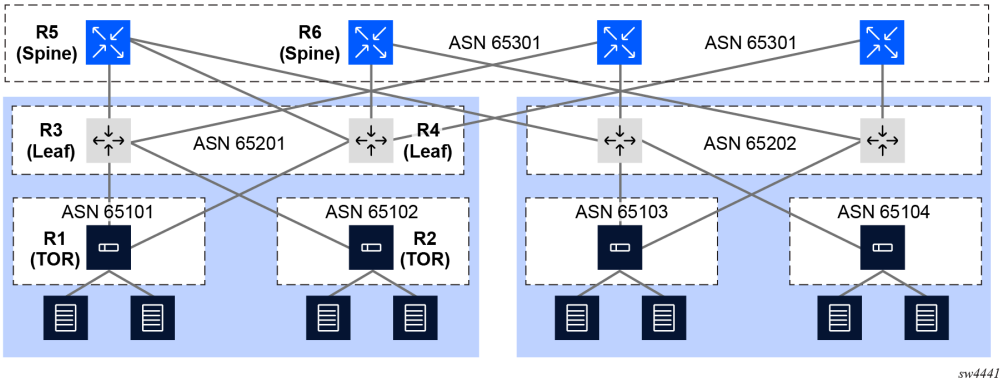
A routing protocol is needed to dynamically discover the shortest loop-free path through the underlay of a DC fabric to reach every destination IP subnet. The Border Gateway Protocol (BGP) is one of the leading technologies for this purpose as a result of its simplicity, scalability, and ease of multi-vendor interoperability.

BGP also provides policy mechanisms to perform hop-by-hop traffic engineering, leveraging functionality originally designed for this same purpose in the public Internet.

4.1 BGP underlay routing example

The following figure shows a 3-stage Clos fabric design using only BGP for underlay routing.

Figure 5: BGP underlay routing example



This design example shows the following:

- Each Top-of-Rack (TOR) switch is a BGP router assigned with its own unique Autonomous System Number (ASN).
- Each TOR switch is dual-homed to the two leaf switches in its same POD or container and adding more leaf switches later can achieve scale capacity.
- Each TOR forms one single-hop External Border Gateway Protocol (EBGP) session to each of its upstream leaf switches. From a TOR perspective, these sessions are single-hop because each leaf switch is a BGP neighbor in the same IP subnet as its interface address toward the leaf switch.
- Each leaf switch is a BGP router. All of the leaf switches in one POD or container belong to the same ASN, but this ASN is unique in the data center.
- Each leaf switch has two uplinks into the spine layer. More uplinks could be added later to achieve scale capacity. Each leaf switch forms one single-hop EBGP session with each of its upstream spine switches.
- Each spine switch is a BGP router. All of the spine switches in one data center belong to the same ASN but this ASN is unique in the network.

4.1.1 Advantages of BGP for underlay routing

Using BGP as shown in Figure 5: BGP underlay routing example has the following advantages:

- Standard operation of the BGP best-path selection algorithm chooses the route to each destination with the AS_PATH length. This equates to the lowest hop count when each device prepends one ASN to the AS_PATH.
- Standard operation of the BGP multipath algorithm sprays traffic across all paths with the same shortest AS_PATH length.
- When a link goes down in the topology, the BGP session is taken down immediately if fast-failover is enabled. This may cause a new BGP best path to be advertised by the routers at each end of the failed session. Other routers may also advertise their own new best paths, but typically the failure does not propagate beyond routers that do not change their best path.
- Traffic can be rerouted around any node in the topology by having it prepend extra AS numbers to the AS_PATH.
- The best path or set of multipaths available to reach a destination TOR are visible in any device by looking at the AS_PATH attribute. This can be helpful with troubleshooting.

4.2 BGP configuration for underlay routing

The following examples define how to bring up a static, preconfigured EBGP session between Router 3 and Router 5 (as shown in Figure 5: BGP underlay routing example). Use the following two examples to define the minimum configuration required for each router:

- Example: Configure Router 3 for static EBGP session
- Example: Configure Router 5 for static EBGP session

4.2.1 Example: Configure Router 3 for static EBGP session

About this task

Use the following example to configure Router 3 for the static EBGP session.

Procedure

Step 1. In candidate mode, create a network-instance that owns the IP subinterface toward Router 5.

Example

```
--{ candidate shared default}--[ network-instance default ]--
# info detail
    type default
    admin-state enable
    ip-load-balancing {
    }
    interface ethernet-1/1.0 {
    }
    protocols {
    }
```

Ensure the following:

- The network-instance is operationally enabled.
- The subinterface is operationally enabled.
- The subinterface has at least one IPv4 or IPv6 address assigned.

Step 2. Add the BGP protocol to the network-instance.

By default, it is administratively enabled when the configuration is committed.

Example

```
--{ candidate shared default}--[ network-instance default ]--
# protocols bgp
```

Step 3. Assign a global ASN to the BGP instance.

This is the ASN reported to peers when this network-instance opens a BGP session toward another router (unless it is overridden by a local-as configuration).

Router 3 has a global ASN of 65201.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# autonomous-system 65201
```

Step 4. Assign a router-ID to the BGP instance.

This is the BGP identifier reported to peers when this network-instance opens a BGP session toward another router. This overrides the router-id configuration at the network-instance level.

Router 3 has a router-id of 192.0.3.1.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# router-id 192.0.3.1
```

Step 5. Enable all address families that should be enabled globally as a default for all peers of the BGP instance.

When you later configure individual neighbors or groups, you can override the enabled families at those levels.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# afi-safi ipv4-unicast admin-state enable
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# afi-safi ipv6-unicast admin-state enable
```

Step 6. Create a peer group to contain the neighbor session with Router 5.

A peer-group should include sessions that have a similar or almost identical configuration.

In this example, the peer group is named "spine" because it is used to contain all spine layer peers. New groups are administratively enabled by default.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
```

```
# group spine
```

Step 7. All of the configuration that is common to all peers in the group must be configured at the group level.

In this example, this includes:

- peer-as (of the spine peers)
- export-policy

The export policy (named "pass-all" in the example) in the configuration output below was previously created in this work flow (if it does not exist, the commit fails). The export policy is required to advertise any routes to R5. This is because R5 is an EBGP peer, and by default, no routes are advertised to EBGP peers without an export policy. Note: this can be controlled by a setting in the network-instance protocols "bgp ebgp-default-policy" container.

The "pass-all" export policy matches and accepts all BGP routes, while rejecting all non-BGP routes.

Example

```
--{ candidate shared default }--[ network-instance default protocols bgp group spine ]
# info
    peer-as 65301
    export-policy pass-all
```

```
--{ candidate shared default }--[  ]
# info from running routing-policy
    routing-policy {
        policy pass-all {
            default-action {
                reject {
                }
            }
            statement 10 {
                match {
                    protocol bgp
                }
                action {
                    accept
                }
            }
        }
    }
```

Step 8. Configure the BGP session with router R5.

In this example, router R5 is reachable to R3 through the ethernet-1/1.0 subinterface. On this subnet, router R5 has the global-unicast IPv6 address 2001:db8::c11.

In this minimal configuration example, the only required configuration for the neighbor is its association with the group "spine" that was previously created. New neighbors are administratively enabled by default.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# neighbor 2001:db8::c11 peer-group spine
```

Step 9. Review all changes and, if everything appears correct, commit the changes:

Example

```
# commit stay
```

4.2.2 Example: Configure Router 5 for static EBGP session

About this task

Use the following example to configure Router 5 for the static EBGP session.

Procedure

Step 1. In candidate mode, create a network-instance that owns the IP subinterface toward Router 3. Ensure that:

- The network-instance is operationally enabled.
- The subinterface is operationally enabled.
- The subinterface has at least one IPv4 or IPv6 address assigned.

Example

```
--{ candidate shared default}--[ network-instance default ]--
# info detail
    type default
    admin-state enable
    ip-forwarding {
        receive-ipv4-check true
        receive-ipv6-check true
    }
    ip-load-balancing {
    }
    interface ethernet-3/1.1 {
    }
    protocols {
    }
    mtu {
        path-mtu-discovery true
    }
```

Step 2. Add the BGP protocol to the network-instance. By default, it is administratively enabled when the configuration is committed.

Example

```
--{ candidate shared default}--[ network-instance default ]--
# protocols bgp
```

Step 3. Assign a global autonomous system number to the BGP instance.

Router 5 has a global autonomous system number of 65301.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# autonomous-system 65301
```

Step 4. Assign a router-ID to the BGP instance.

This is the BGP identifier reported to peers when this network-instance opens a BGP session toward another router. This overrides the router-ID configuration at the network-instance level.

Router 5 has a router-ID of 192.0.5.1.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# router-id 192.0.5.1
```

Step 5. Enable all address families that should be enabled globally as a default for all peers of the BGP instance.

When you later configure individual neighbors or groups, you can override the enabled families at those levels.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# afi-safi ipv4-unicast admin-state enable
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# afi-safi ipv6-unicast admin-state enable
```

Step 6. Create a peer-group to contain the neighbor session with Router 3. A peer-group should include sessions that have a similar or almost identical configuration.

In this example, the peer-group is named "leaf-pod1" because it is used to contain all leaf peers in POD1. New groups are administratively enabled by default.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# group leaf-pod1
```

Step 7. All of the configuration that is common to all peers in the group must be configured at the group level.

In this example, this includes:

- peer-as (of the leaf peers in POD1)
- export-policy

The export policy (named "pass-all" in the example) is shown in the following running configuration output, and is required to advertise any routes to R3. This is because R3 is an EBGP peer and, by default, no routes are advertised to EBGP peers without an export policy.

Note: This can be controlled by a setting in the network-instance protocols "bgp ebgp-default-policy" container.

The "pass-all" export policy is a simple policy that matches all BGP routes and accepts them, while rejecting all non-BGP routes.

Example

```
--{ candidate Shared default}--[ network-instance default protocols bgp group leaf-
pod1 ]--
# info
    peer-as 65201
    export-policy pass-all
--{ candidate }--[ network-instance default protocols bgp group leaf-pod1 ]--
# exit all
```

```
--{ candidate shared default}--[  ]
# info from running routing-policy
    routing-policy {
        policy pass-all {
            default-action {
                reject {
                }
            }
            statement 10 {
                match {
                    protocol bgp
                }
                action {
                    accept
                }
            }
```

Step 8. Configure the BGP session with router R3.

In this example, router R3 is reachable to R5 through the ethernet-3/1.1 subinterface. On this subnet, router R5 has the global-unicast IPv6 address 2001:db8::c12.

In this minimal configuration example, the only required configuration for the neighbor is its association with the group "leaf-pod1" that was previously created. New neighbors are administratively enabled by default.

Example

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# neighbor 2001:db8::c12 peer-group leaf-pod1
```

Step 9. Review all changes and if everything looks correct, commit the changes.

Step 10. From Router 3, verify that the session is up (State is established) using the **show neighbor** command under the network-instance protocols BGP hierarchy.

Example

```
--{running}--{ network-instance default protocols bgp }--
srlinux# show neighbor
-----------------------------------------------------------------------------------------------
BGP neighbor summary for network-instance "default"
Flags: S static, D dynamic, L discovered by LLDP, B BFD enabled, - disabled, * slow
-----------------------------------------------------------------------------------------------
+----------+--------------+-------+-------+-------+-------------+----------+--------------+---------+
| Net-Inst |  Peer        | Group | Flags | Peer- | State       | Uptime   | AFI/SAFI     |  RX/    |
|          |              |       |       |  AS   |             |          |              | Active  |
|          |              |       |       |       |             |          |              |  /TX    |
+==========+==============+=======+=======+=======+=============+==========+==============+=========+
| default  | 2001:db8::cli | spine | S     | 65301 | established | 0d:0h:   | ipv4-unicast | [4/3/1] |
|          |              |       |       |       |             | 34min 7s | ipv6-unicast | [1/1/1] |
+----------+--------------+-------+-------+-------+-------------+----------+--------------+---------+
-----------------------------------------------------------------------------------------------
Summary:
1 configured neighbors, 1 configured sessions are established, 0 disabled peers
None dynamic sessions are established
```

4.3 Advanced configuration: BGP timers

When two BGP routers form a session, they each propose a value for the session hold-time in their OPEN messages. The lowest of the two proposed values becomes the operational hold-time for the lifetime of the session. If the operational hold-time is greater than zero, both routers are agreeing to send keepalive messages to each other. This ensures that any loss of connectivity between them can be detected.

Each router restarts its hold-timer every time it receives a message from the other peer. If the operational hold-timer reaches zero without receiving any keepalive or related message from the peer, the session is torn down (returned to the Idle state). Each router sends a keepalive message to its peer no more than one message every keepalive interval. The default value for the keepalive interval is one third of the operational hold-time, but it possible to configure a different interval.

In a data center environment, an EBGP session failure is usually caused by an interface going down. Interface events are propagated to BGP if fast-failover is enabled. The hold-timer expiry is not the usual mechanism for detecting connectivity problems. However, there may be some circumstances where some adjustment of the hold-time and the keepalive interval can be used.

4.3.1 Modifying timer-related defaults

About this task

With SR Linux, the default hold-time is 90 seconds and the default keepalive interval is 30 seconds.

Procedure

To change the hold-time on a session to 24 seconds with a keepalive interval of 8 seconds (1/3 of 24), you only need to change the hold-time value to 24, as shown in the following example:

Example: Change hold-time

```
--{ candidate shared default}--[ network-instance default protocols bgp neighbor
 2001:db8::c11 ]--
# timers hold-time 24
```

After this change is committed, the affected session flaps and the new operational timer values are shown in the output of the **show network-instance protocols bgp neighbor detail** command. For example:

```
srlinux# show network-instance default protocols bgp neighbor 2001:db8::c11 detail
-------------------------------------------------------------------------------
Peer : 2001:db8::c11, remote AS: 65301, local AS: 65201
Type : static
Description : None
Group : spine
Export policies : pass-all
Import policies: pass-all
-------------------------------------------------------------------------------
Admin-state is enable, session-state is established, up for 0d:0h:6m:37s
TCP connection is 2001:db8::c12 [45492] -> 2001:db8::c11 [179]
0 messages in input queue, 0 messages in output queue
-------------------------------------------------------------------------------
Last-state was active, last-event was recvOpen, 24 peer-flaps
Last received Notification was Error:Message Header Error SubError: Bad Message Type
Failure detection: BFD is False, fast-failover is False
```

```
-------------------------------------------------------------------------------
Graceful Restart
   Restarts by the peer : 0
   Last restart : N/A
   Peer requested restart-time : 300
   Stale routes time : 360
+-----------------------------------+---------------------------------+------------+
|               Timer               |     Configured/Operational      |     Next   |
+===================================+=================================+============+
| connect-retry                     | 120                             | -          |
| keepalive-interval                | 30/8                            | -          |
| hold-time                         | 24/24                           | -          |
| minimum-advertisement-interval    | 5                               | -          |
+-----------------------------------+---------------------------------+------------+
-------------------------------------------------------------------------------
Cap Sent:  MP_BGP ROUTE_REFRESH EXT_NH_ENCODING 4-OCTET_ASN
Cap Recv:  MP_BGP ROUTE_REFRESH EXT_NH_ENCODING 4-OCTET_ASN
-------------------------------------------------------------------------------
+-----------------------------------+---------------------------------+--------------+
|              Messages             |              Sent               |  Received    |
+===================================+=================================+==============+
| Non Updates                       | 55                              | 52           |
| Updates                           | 424                             | 2            |
| Malformed updates                 | 0                               | 0            |
+-----------------------------------+---------------------------------+--------------+
-------------------------------------------------------------------------------
Ipv4-unicast AFI/SAFI
    End of RIB                    : sent, not received
    Received routes               : 4
    Rejected routes               : None
    Active routes                 : 3
    Advertised routes             : 1
    Prefix-Limit                  : None
    Default originate             : disabled
    Advertise with IPv6 next-hops  : False
    Peer requested GR helper      : None
    Peer preserved forwarding state: None
-------------------------------------------------------------------------------
Ipv6-unicast AFI/SAFI
    End of RIB                    : sent, not received
    Received routes               : 1
    Rejected routes               : None
    Active routes                 : 1
    Advertised routes             : 1
    Prefix-Limit                  : None
    Default originate             : disabled
    Advertise with IPv6 next-hops  : N/A
    Peer requested GR helper      : None
    Peer preserved forwarding state: None
-------------------------------------------------------------------------------
--{ candidate shared }--[  ]--
```

4.4 Advanced configuration: BGP convergence optimization

By default, the SR Linux BGP process (running the BGP control plane) does not advertise a route for an IPv4 or IPv6 prefix until it has positive confirmation from the FIB manager process that the route is in the FIB of all installed line cards. This ensures that the router does not attract traffic destined for an IP prefix until all line cards have the ability to forward the traffic.

Note:
The BGP process does not delay route withdrawals until it knows that all line cards have removed the FIB state as this is not needed.

4.4.1 Configuring wait-for-fib-install

About this task

Nokia recommends that the **wait-for-fib-install** functionality remain enabled on routers that are in the datapath (that is, routers that set BGP next-hop-self). However, this does cause the rate of RIB-OUT route advertisements to slow to the rate of FIB programming.

Procedure

If the objective of a BGP performance test is to reach the highest possible route advertisement rate, set the **wait-for-fib-install** configuration leaf to **false**. For example:

Example: Set wait-for-fib-install leaf to false

```
--{ candidate shared default}--[network-instance default protocols bgp route-
advertisement]--
# wait-for-fib-install false
```

4.4.2 Convergence process optimization after restarts

The BGP protocol and its state machine must attempt to reconverge whenever the following occurs:

- the router starts up
- the BGP manager (control plane) application restarts
- all peers of a network-instance are hard-reset by a **tools reset-peer** command

When any of these conditions are met, the router resynchronizes its BGP RIB with the BGP RIB of other routers in the network. When resynchronization completes, BGP has "converged". During convergence, the following occurs to the restarting router:

- It must reestablish its sessions with configured (and discovered) BGP neighbors.
- It must relearn all BGP routes advertised by its direct BGP neighbors (their best paths, plus potentially some additional paths).
- It must advertise to its direct neighbors, its own locally originated BGP routes plus the received routes that it considers its own set of best paths.

The default behavior of SR Linux BGP is to execute all of the preceding steps in parallel. As soon as the first BGP session has reestablished, the restarting router begins to advertise its own best paths to that BGP neighbor (even though it is still in the early stages of rebuilding its RIB-IN database).

As more sessions come up and more routes are learned, it is likely that routes previously considered best are no longer best, leading to multiple route advertisements for the same prefix with each incrementally better than the previous one. The best route is not determined until the last advertisement. The intermediate route advertisements can substantially increase the processing workload on the restarting router as well as its BGP neighbors. This can lengthen the overall convergence time and cause short term inefficiencies in traffic forwarding.

4.4.2.1 Configuring min-wait-to-advertise to delay BGP route advertisement

About this task

Instead of reconverging as previously described, SR Linux BGP can also be configured to delay the advertisement of BGP routes in a particular address family until convergence has occurred for that address family or until a configured time limit has expired.

Procedure

To activate this behavior, configure a non-zero value for the **min-wait-to-advertise** configuration leaf. For example:

Example: Set min-wait-to-advertise

```
--{ candidate shared default}--[ network-
instance default protocols bgp convergence ]--
# min-wait-to-advertise 600
```

4.4.2.2 Configuring max-wait-to-advertise

Procedure

You can configure the **max-wait-to-advertise** leaf value for the IPv4-unicast and IPv6-unicast address families, or you can accept their default values (3x the **min-wait-to-advertise** value). To configure a **max-wait-to-advertise** leaf with a non-default value, the value must be greater than the configured **min-wait-to-advertise** timer. In the following example, the **max-wait-to-advertise** timer is set to 900 seconds for IPv4-unicast and set to 800 seconds for IPv6-unicast.

Example: Set max-wait-to-advertise

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
# afi-safi ipv4-unicast ipv4-unicast convergence max-wait-to-advertise max-wait-to-
advertise 900
# afi-safi ipv6-unicast ipv6-unicast convergence max-wait-to-advertise 800
```

4.4.2.3 BGP min-/max-wait-to-advertise timers behavior

The min-wait-to-advertise timer begins after one of the following triggers occurs and the first BGP session becomes established.

- BGP instance admin state set to enable or disable
- Running **tools clear network-instance protocols bgp reset-peer**
- BGP application restart
- Node reboot

When the first session that supports the exchange of IPv4-unicast routes is established, the max-wait-to-advertise timer of the IPv4 address family starts. Likewise, when the first session that supports the exchange of IPv6-unicast routes is established, the max-wait-to-advertise timer of the IPv6 address family starts.

While the **min-wait-to-advertise** timer is running, BGP sessions come up, and routes are learned and sorted according to preference by the BGP decision process. However, no routes are advertised to any of the peers.

When the min-wait-to-advertise expires, BGP makes a list of IPv4 and IPv6 peers (that is, peers that support the exchange of IPv4-unicast routes and IPv6-unicast routes). It expects to receive the IPv4-unicast End of RIB (EOR) marker from each neighbor in the list of IPv4 peers, and it expects to receive the IPv6-unicast EOR from each neighbor in the list of IPv6 peers.

When BGP in the restarting router receives the last expected IPv4-unicast EOR, it declares that address family as converged and starts to advertise its best IPv4-unicast routes. Likewise, when BGP receives the last expected IPv6-unicast EOR, it declares that address family as converged and starts to advertise its best IPv6-unicast routes.

If the max-wait-to-advertise timer expires before the last expected EOR, is received for an address family, the convergence state for the address family moves to "timeout" and a RIB-OUT advertisement is triggered. This occurs even though convergence is not complete. The max-wait-to-advertise timers are fail-safe. They handle the scenario when one or more peers come up within the min-wait-to-advertise window, but their EORs are not sent.

4.4.2.4 Displaying convergence snapshot

Procedure

Use the **show network-instance protocols bgp summary** command to display a snapshot of the BGP convergence process. In the example that follows, the BGP convergence process is triggered by a hard reset of all peers of the BGP instance:

Example: Trigger BGP convergence using reset-peer

```
--{ * candidate shared default}--[  ]--
# tools network-instance default protocols bgp reset-peer
/network-instance[name=default]/protocols/bgp:
    Successfully executed the tools clear command.
```

If the **show network-instance protocols bgp summary** command is issued a few minutes after the session restarts, a snapshot of the convergence process can be viewed. For example, in the following output example, ten IPv4-unicast sessions are established when the min-wait-to-advertise timer expires and IPv4-unicast convergence takes 517 seconds.

Example: Display convergence snapshot

```
# show network-instance default protocols bgp summary
-------------------------------------------------------------------------------
BGP is enabled and up in network-instance "default"
Global AS number  : 65201
BGP identifier    : 192.0.3.1
-------------------------------------------------------------------------------
  Total paths               : 27
  Received routes           : 200000
  Received and active routes: 200000
  Total UP peers            : 20
  Configured peers          : 20, 0 are disabled
  Dynamic peers             : None
-------------------------------------------------------------------------------
Default preferences
  BGP Local Preference attribute: 100
```

```
  EBGP route-table preference   : 170
  IBGP route-table preference   : 170
-------------------------------------------------------------------------------
Wait for FIB install to advertise: True
Send rapid withdrawals           : False
-------------------------------------------------------------------------------
Ipv4-unicast AFI/SAFI
    Received routes               : 100000
    Received and active routes    : 100000
    Max number of multipaths      : 8, 1
    Multipath can transit multi AS: True
-------------------------------------------------------------------------------
    Min adv delay after restart(slow peer thresh): 600s
    Currently established sessions               : 10
    Sessions established at slow peer thresh     : 10
    First session establishment after restart    : 5s
    Last session established after restart       : 252s
-------------------------------------------------------------------------------
    Max advertisement delay after first peer UP: 900s
    Max adv delay exceeded after last restart  : None
    Current convergence state                  : converged
    Converged peers                            : 10
    Convergence time after last restart        : 517s
-------------------------------------------------------------------------------
Ipv6-unicast AFI/SAFI
    Received routes               : 100000
    Received and active routes    : 100000
    Max number of multipaths      : 1,1
    Multipath can transit multi AS: True
-------------------------------------------------------------------------------
    Min adv delay after restart(slow peer thresh): 600s
    Currently established sessions               : 10
    Sessions established at slow peer thresh     : 10
    First session establishment after restart    : 8s
    Last session established after restart       : 312s
-------------------------------------------------------------------------------
    Max advertisement delay after first peer UP: 800s
    Max adv delay exceeded after last restart  : None
    Current convergence state                  : converged
    Converged peers                            : 10
    Convergence time after last restart        : 705s
-------------------------------------------------------------------------------
```

4.5 Advanced configuration: IPv4 route advertisement with IPv6 next-hops

Some data centers are migrating away from an IPv4/IPv6 dual-stack infrastructure and moving toward an IPv6-only infrastructure. In an IPv6-only design, each interface in the fabric (such as the leaf-spine, leaf-TOR) is assigned one or more IPv6 addresses, but no IPv4 addresses.

To route and forward IPv4 packets over an IPv6-only fabric, the leaf and spine switches must support the following:

- The ability to advertise a BGP route for IPv4 Network Level Reachability Information (NLRI) with an IPv6 BGP next-hop address.
- The ability to receive a BGP route for IPv4 NLRI with an IPv6 BGP next-hop address.
- The ability to accept IPv4 packets on an IPv6-only interface.

4.5.1 Advertising a BGP route for IPv4 NLRI with an IPv6 BGP next-hop address

About this task

On SR Linux, the ability to advertise a BGP route for IPv4 NLRI with an IPv6 BGP next-hop address is not enabled by default.

Procedure

To enable this functionality, use the **advertise-ipv6-next-hops** command, which is available on a per-session basis. The following is a sample configuration:

Example: Advertise BGP route for IPv4 NLRI with IPv6 BGP next-hop

```
--{ candidate shared default}--[ network-instance default protocols bgp ]--
#  afi-safi ipv4-unicast ipv4-unicast advertise-ipv6-next-hops true
```

4.5.2 Receiving a BGP route for IPv4 NLRI with an IPv6 BGP next-hop address

About this task

On SR Linux, the ability to receive a BGP route for IPv4 NLRI with an IPv6 BGP next-hop address is not enabled by default. To enable this functionality, use the **receive-ipv6-next-hops** command, which is available on a per-session basis.

This command allows SR Linux to advertise the extended-next-hop-encoding BGP capability, defined in RFC 5549, to the peers included in the scope of the command. This BGP capability encodes NLRI AFI 1, NLRI SAFI 1, and next-hop AFI 2. It informs peers that they can advertise MP-BGP encoded IPv4 routes with IPv6 next-hops. When the routes are received, the router then attempts to resolve them using IPv6 routes.

If the router receives an IPv4 route with an IPv6 next-hop that is resolved by a static or direct IPv6 route (and an IPv6 neighbor entry for the next-hop host address), the IPv4 route is programmed in the FIB so that matching IPv4 packets are sent without additional encapsulation. Packets are sent through the indicated interface with a MAC destination address provided by the IPv6 neighbor entry.

Procedure

To enable receipt of BGP routes for IPv4 NLRI with an IPv6 BGP next-hop address, use the **receive-ipv6-next-hops** command.

Example: Receive BGP route for IPv4 NLRI with IPv6 BGP next-hop

```
--{ candidate shared }--[ network-instance default protocols bgp ]--
# afi-safi ipv4-unicast ipv4-unicast receive-ipv6-next-hops true
```

4.5.3 Accepting IPv4 packets on an IPv6-only interface

About this task

The datapath of the SR Linux checks for and discards all IPv4 packets that are received on an IPv6-only subinterface (that is, a subinterface with no configured IPv4 addresses). This is done for security reasons.

However, if the router has advertised IPv4 routes with IPv6 next-hops to a peer, the check should be disabled on all subinterfaces that could be used by the peer when it installs the IPv4 route.

Procedure

To disable this check on all subinterfaces bound to a specific network-instance, set the **ipv4-receive-check leaf** to **false**.

Example: Accept IPv4 packets on an IPv6-only interface

```
--{ candidate shared default}--[ network-instance default ]--
# ip-forwarding receive-ipv4-check false
```

5 Configuring IP-VPN services

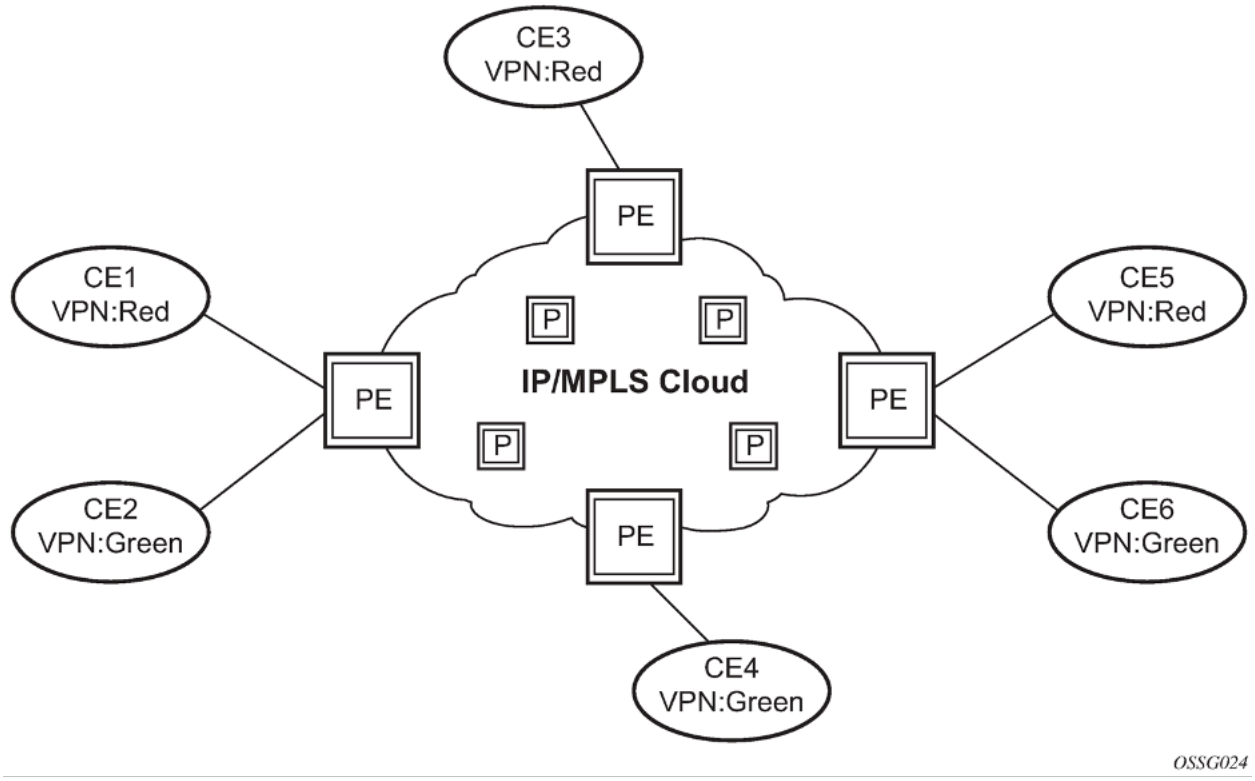
IP-VPN services use a combination of MP-BGP and MPLS to distribute IPv4/v6 routing information and provide Layer 3 VPN services.

Each IP-VPN consists of a set of customer end points connected to one or more PE routers. Each associated PE router maintains a separate IP forwarding table for each IP-VPN instance. Additionally, the PE routers exchange the routing information configured or learned from all customer sites via MP-BGP peering. Each route exchanged via the MP-BGP protocol includes a Route Distinguisher (RD), which identifies the IP-VPN association and handles any potential IP address overlap.

Multi-Protocol BGP (MP-BGP) is used to exchange the routes of a particular VPN among the PE routers that are attached to that VPN. This route exchange is done in a way that ensures that routes from different VPNs remain distinct and separate, even if two VPNs have an overlapping address space. When BGP distributes a VPN route it also distributes an MPLS label for that route to identify the advertising IP-VPN instance.

Before a customer data packet travels across the service provider's backbone, it is encapsulated with the MPLS label that corresponds, in the customer's IP-VPN, to the route that best matches the packet's destination address. The MPLS packet is further encapsulated with one or more MPLS labels corresponding to the resolving MPLS path to deliver the packet to the intended egress PE router. The following figure displays an IP-VPN network diagram example.

Figure 6: IP Virtual Private Network



Example: IP-VPN configuration

The following is an example of an IP-VPN configuration.

```
--{ * candidate shared default }--[  ]--
A:srl1# info interface ethernet-1/2
    interface ethernet-1/2 {
        admin-state enable
        subinterface 1 {
            type routed
            admin-state enable
            ipv4 {
                address 10.30.30.1/24 {
                }
            }
        }
    }
A:srl1# info network-instance Base
    network-instance Base {
        type default
        protocols {
            bgp {
                admin-state enable
                autonomous-system 65550
                router-id 10.10.10.1
                afi-safi l3vpn-ipv4-unicast {
                    admin-state enable
                }
                group base-group {
```

```
                }
                neighbor 10.10.10.2 {
                    peer-group base-group
                }
            }
        }
    }

--{ * candidate shared default }--[  ]--
A:srl1# info network-instance ip-vrf-red
    network-instance ip-vrf-red {
        type ip-vrf
        interface ethernet-1/2 {
            interface-ref {
                interface ethernet-1/2
                subinterface 1
            }
        }
        protocols {
            bgp-ipvpn {
                bgp-instance 1 {
                    admin-state enable
                    ecmp 8
                    mpls {
                        next-hop-resolution {
                            allowed-tunnel-types [
                                ldp
                                sr-isis
                            ]
                        }
                    }
                }
            }
            bgp {
                admin-state enable
                autonomous-system 65551
                router-id 10.10.10.1
                afi-safi ipv4-unicast {
                    admin-state enable
                }
                group ip-vrf-red-peers {
                    admin-state enable
                    afi-safi ipv4-unicast {
                    }
                }
                neighbor 10.10.10.3 {
                    peer-group ip-vrf-red-peers
                    }
                }
            }
            bgp-vpn {
                bgp-instance 1 {
                    route-distinguisher {}
                    route-target {}
                }
            }
        }
```

6 EVPN-VXLAN for layer-2 and multi-homing

Ethernet Virtual Private Network (EVPN) is a standard technology in multi-tenant Data Centers (DCs). EVPN provides a control frame framework for many functions. This chapter details the configuration and operation of an EVPN and VXLAN (EVPN-VXLAN) solution for the following components:

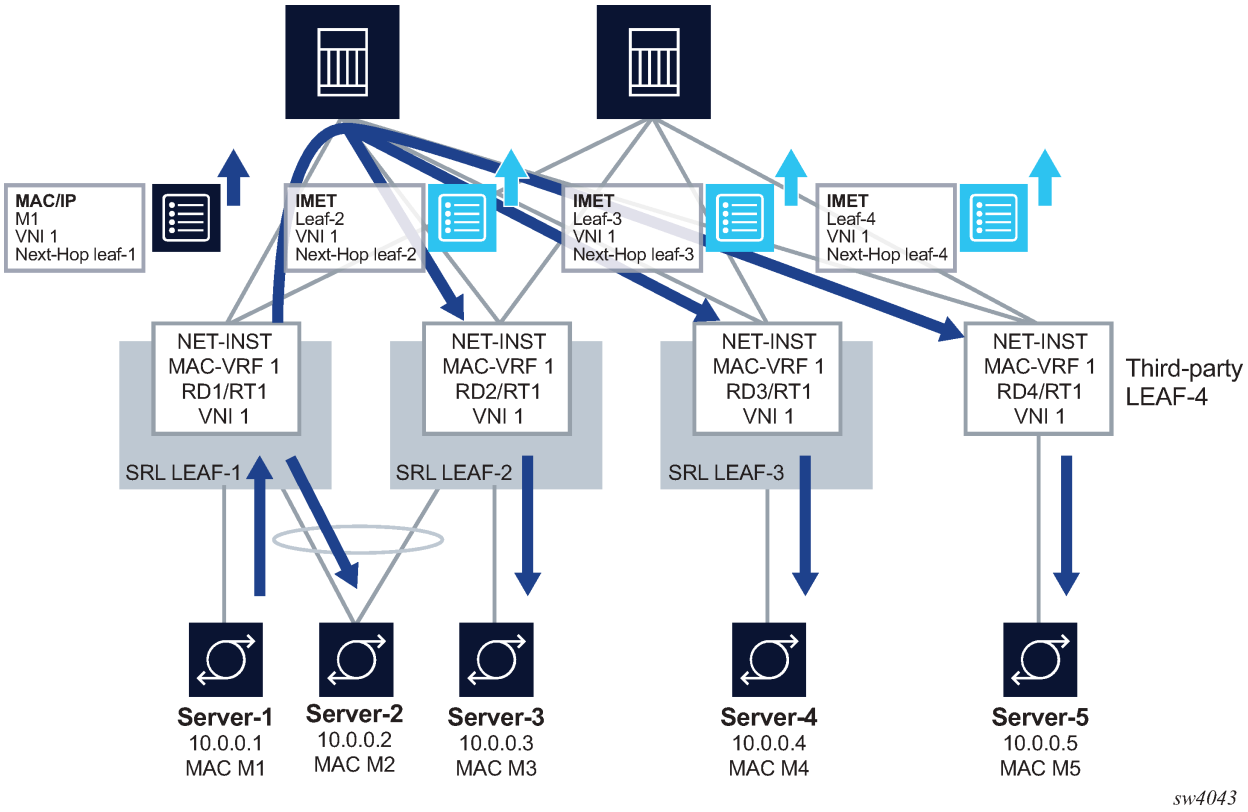
- Bridged sub-Interfaces associated with a specific vlan-id or default sub-interfaces, that capture untagged and non-explicitly configured vlan-tagged frames in tagged sub-interfaces.
- MAC-VRF type network-instances that are EVPN-enabled so that they can use Virtual Extended LAN (VXLAN) tunnels to connect to other MAC-VRFs of the same Broadcast Domains (BD).
- EVPN-VXLAN control and data plane extensions as in [RFC8365], including EVPN route type 2 (MAC/IP) and route type 2 (Inclusive Multicast Ethernet Tag [IMET]).
- Distributed security and protection for static-macs.
- The MAC duplication mechanism, extended to support EVPN, to provide loop protection.
- EVPN L2 multi-homing, including Ethernet Segment (ES) model configuration for all-active multi-homing.

6.1 Overview

EVPN-VXLAN provides Layer-2 connectivity in multi-tenant DCs. EVPN-VXLAN Broadcast Domains (BD) can span several leaf routers connected to the same IP fabric, allowing hosts attached to the same BD to communicate as though they were connected to the same layer-2 switch. VXLAN tunnels bridge the layer-2 frames between leaf routers with EVPN providing the control plane to automatically setup tunnels and use them efficiently.

The following diagram shows this concept. In this example, four leaf routers are attached to the same BD that is instantiated by a MAC-VRF on each leaf. SR Linux leaf routers support standard-based EVPN-VXLAN [RFC8365]; therefore third-party leaf routers (LEAF-4 in this example) can be attached to the same BD as the SR Linux leaf routers as long as they follow standard [RFC8365].

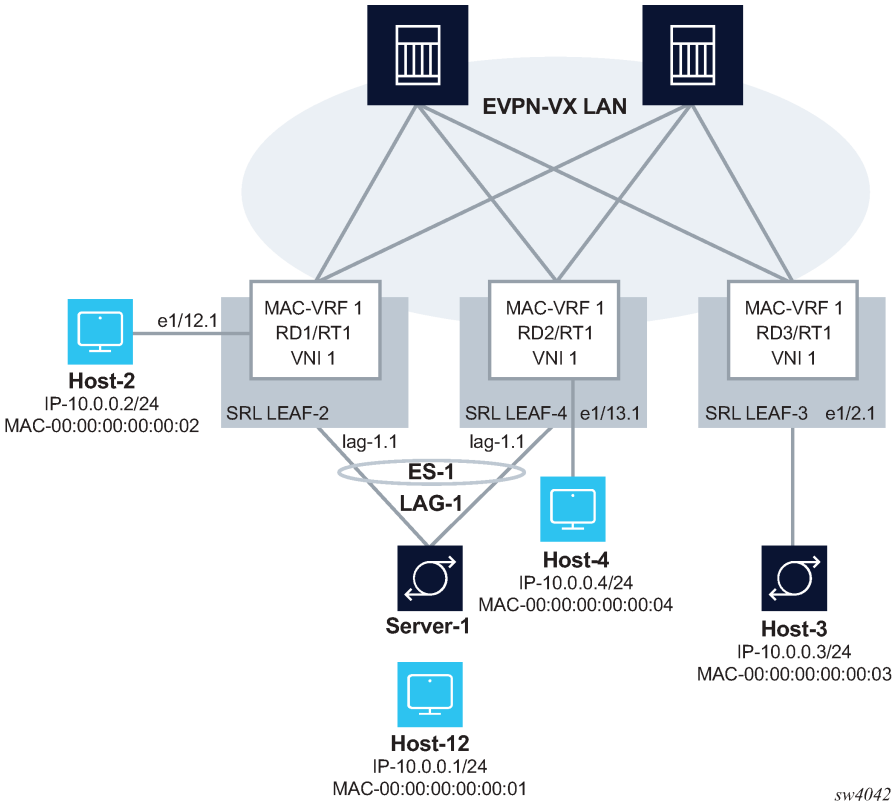
Figure 7: EVPN broadcast domain in a multi-tenant DCs



6.2 Configuration of EVPN-VXLAN broadcast domains

The following figure shows a configuration example of an EVPN-VXLAN BD that is distributed in multiple leaf nodes in the same DC. The BD is instantiated by MAC-VRF-1 in each of the three leaf nodes. The sections that follow describe how to configure and operate MAC-VRF-1 in each node.

Figure 8: Example of EVPN-VXLAN broadcast domain



6.2.1 Configuring the underlay network

About this task

Before configuring the overlay BD, the underlay connectivity must be configured. In Figure 8: Example of EVPN-VXLAN broadcast domain, the leaf routers are connected to the spines using routed links. A routing protocol is enabled in the default network-instance of each leaf and spine node, so that reachability of all the leaf VXLAN Termination End Point (VTEP) addresses is distributed throughout the IP fabric. In SR Linux, you can use the following for the underlay routing protocol:

- ISIS
- OSPF
- eBGP

The EVPN family must also be enabled for the distribution of EVPN routes among leaf routers of the same tenant. EVPN is enabled using iBGP and typically a Route Reflector (RR), or eBGP.

Procedure

To configure the underlay network in this example, configure an eBGP-underlay BGP group to enable the IPv4 and IPv6 unicast families, and configure an iBGP-evpn group for the distribution of the EVPN routes, as shown in the following configuration on LEAF-3. In this case, a full mesh of iBGP EVPN sessions is established among the three leaf routers, but a pair of RRs is typical.

Example: Underlay Configuration

```
--{ [FACTORY] + candidate shared default }--[ network-instance default ]--
A:dut3# info
    type default
    admin-state enable
    description "Default network instance"
    router-id 3.3.3.3
    interface ethernet-1/1.1 {
    }
    interface ethernet-1/3.1 {
    }
    interface system0.0 {
    }
    protocols {
        bgp {
            admin-state enable
            afi-safi ipv4-unicast {
                admin-state enable
            }
            autonomous-system 3333
            router-id 3.3.3.3
            group eBGP-underlay {
                admin-state enable
                export-policy export-all
                import-policy import-all
                timers {
                    connect-retry 5
                    hold-time 5
                    keepalive-interval 2
                    minimum-advertisement-interval 2
                }
            }
            group iBGP-evpn {
                admin-state enable
                export-policy export-all
                import-policy import-all
                afi-safi evpn {
                    admin-state enable
                }
                local-as as-number 1234 {
                }
                timers {
                    minimum-advertisement-interval 1
                }
            }
            afi-safi ipv4-unicast {
                admin-state enable
            }
            afi-safi ipv6-unicast {
                admin-state enable
            }
            neighbor 1.1.1.1 {
                admin-state enable
                peer-as 1234
                peer-group iBGP-evpn
                transport {
                    local-address 3.3.3.3
                }
            }
            neighbor 2.2.2.2 {
                admin-state enable
                peer-as 1234
                peer-group iBGP-evpn
```

```
                transport {
                    local-address 3.3.3.3
                }
            }
            neighbor 4.4.4.4 {
                admin-state enable
                peer-as 1234
                peer-group iBGP-evpn
                transport {
                    local-address 3.3.3.3
                }
            }
            neighbor 10.2.3.2 {
                admin-state enable
                peer-as 2222
                peer-group eBGP-underlay
            }
            neighbor 10.3.4.4 {
                admin-state enable
                peer-as 4444
                peer-group eBGP-underlay
            }
            trace-options {
                flag packets {
                    modifier detail
                }
                flag update {
                    modifier detail
                }
                flag route {
                    modifier detail
                }
                flag socket {
                    modifier detail
                }
                flag notification {
                    modifier detail
                }
            }
        }
        linux {
            export-routes true
            export-neighbors true
        }
    }
```

In the example above, eBGP is used for underlay reachability, and iBGP for overlay EVPN route distribution. The command **local-as** overrides the configuration of the bgp>autonomous-system so that the overlay BGP sessions are established using the same autonomous system in the three leaf routers.

The system0.0 interface hosts the loopback address used to originate and typically terminate VXLAN packets. This address is also used by default as the next-hop of all EVPN routes.

Example: system0.0 interface configuration

The following example shows the configuration of the system0.0 interface in LEAF-3.

```
--{ [FACTORY] + candidate shared default }--[ interface system0 ]--
A:dut3# info
    admin-state enable
    subinterface 0 {
        admin-state enable
```

```
        ipv4 {
            admin-state enable
            address 3.3.3.3/32 {
            }
        }
    }
```

6.2.2 Configuring LEAF-3 with an EVPN-VXLAN enabled MAC-VRF

About this task

After LEAF-3 is configured as defined in Configuring the underlay network, use the following steps to enable EVPN-VXLAN on LEAF-3.

In this example, Ethernet-1/2 connects HOST-3 to LEAF-3. Although this interface could be defined untagged, this example configures the interface as tagged and using vlan-id (vlan-tagging true).

A subinterface with index 1 is created under the interface. The subinterface must be configured as type bridged. Bridged subinterfaces can be associated with MAC-VRF instances so that MAC learning and layer-2 forwarding can be enabled on each.

Procedure

Step 1. In candidate mode, create the interfaces and bridged subinterfaces to connect LEAF-3 to HOST-3.

Example

creation of interfaces/bridged subinterfaces

```
--{ [FACTORY] + candidate shared default }--[ interface ethernet-1/2 ]--
A:dut3# info
    description dut3_host3
    admin-state enable
    vlan-tagging true
    subinterface 1 {
        type bridged
        admin-state enable
        vlan {
            encap {
                single-tagged {
                    vlan-id 1
                }
            }
        }
    }
```

In the above example, the subinterface uses vlan-id 1 since this is the VLAN ID used by HOST-3 to send and receive frames. If you wanted HOST-3 to sent and received untagged traffic, the vlan encap command can be configured with either of these options:

- **vlan encap single-tagged vlan-id optional** - where 'optional' captures all traffic when no specific vlan-id has been defined.
- **vlan encap untagged** - where 'untagged' captures traffic with no tags or vlan-tag 0.

Step 2. After creating the access subinterfaces, create the vxlan-interfaces.

This allows MC-VRFs of the same BD to be connected throughout the IP fabric.

The SR Linux models VXLAN as tunnels and vxlan-interfaces exist within them. The network-instance and main property is the VNI or VXLAN network identifier. SR Linux VXLAN model characteristics include:

- The tunnel-interface for vxlan is configured as vxlan<*N*> where the value of *N* is 0-255.
- Multiple tunnel-interfaces can be configured. The tunnel-interface can host multiple vxlan-interfaces.
- vxlan-interfaces are configured under tunnel-interfaces with an associated number in the range 0-4294967295. Minimally, the vxlan-interface must have an index, type, and ingress VNI.
- A vxlan-interface can only be associated with one network-instance, and in the R21.3, a network-instance can have only one vxlan-interface.
- The vxlan-interface type can be routed or bridged. When used for EVPN-VXLAN Layer-2 in MAC-VRFs, the type must be "bridged".
- The ingress VNI must be configured. The VNI is used to find the MAC-VRF where the inner MAC lookup is performed. The egress VNI is *not* configured and is determined by the imported EVPN routes. SR Linux requires that the egress VNI (discovered) matches the configured ingress VNI so that two leaf routers attached to the same BD can exchange packets.

Example

vxlan1 vxlan-interface configuration

```
--{ [FACTORY] + candidate shared default }--[ tunnel-interface * ]--
A:dut3# info
    tunnel-interface vxlan1 {
        vxlan-interface 1 {
            type bridged
            ingress {
                vni 1
            }
        }
    }
```

Outer VLAN tagging is supported (one VLAN tag only), assuming that the egress subinterface in the default network-instance uses vlan-tagging. No inner VLAN tags can be pushed or popped on vxlan-interfaces, but vlan tags that are not stripped-off at the ingress bridged subinterfaces are transparently carried over the VXLAN tunnels.

The following applies for MTU and fragmentation for VXLAN interfaces:

- No specific MTU checks are performed in network-instances with VXLAN.
- The default network-instance interface MTU should be made large enough to allow room for the VXLAN overhead.
- The Don't Fragment (DF) flag is always set in the VXLAN outer IP header.
- Reassembly is not supported for VXLAN packets.

Step 3. Configure the network-instance type mac-vrf and associate it with the bridged interfaces and vxlan-interface to.

A bgp-evpn enabled mac-vrf requires the association of at least one bridged subinterface and one bridged vxlan-interface.

Example

mac-vrf configuration and bridged interface association

```
--{ [FACTORY] + candidate shared default }--[ network-instance MAC-VRF-1 ]--
A:dut3# info
    type mac-vrf
    admin-state enable
    interface ethernet-1/2.1 {
    }
    vxlan-interface vxlan1.1 {
    }
```

Step 4. Enable EVPN in the mac-vrf by configuring the bgp-vpn and the bgp-evpn protocol containers:

- bgp-vpn - Provides the configuration of the bgp-instances where the route-distinguisher and the import/export route-targets used for the EVPN routes exist. Import and export policies can be used instead of explicit route-targets. In the current release, only one bgp-instance per network-instance is supported.
- bgp-evpn - Hosts all the commands required to enable EVPN in the network-instance. At a minimum, a reference to bgp-instance 1 is configured, along with the reference to the vxlan-interface (where EVPN is enabled) and the EVI. The EVI or EVPN Instance identifier is a two-byte value that is mandatory, and is used for:
  - The auto-derivation of the route-distinguisher (RD). If a manual RD is not configured, the RD is auto-derived as system-ip:evi. Where the system-ip is the IP address configured in the system0.0 subinterface.
  - The auto-derivation of the route-target (RT). If a manual RT is not configured, the RT is auto-derived as autonomous-system:evi. The autonomous-system is configured in the default network-instance.
  - The value used to represent the MAC-VRF in the DF Election algorithm. See Multi-homing configuration for EVPN broadcast domains.

Example

Configure bgp-vpn and bgp-evpn protocol containers

```
--{ [FACTORY] + candidate shared default }--[ network-instance MAC-VRF-1 ]--
A:dut3# info
    type mac-vrf
    admin-state enable
    interface ethernet-1/2.1 {
    }
    vxlan-interface vxlan1.1 {
    }
    protocols {
        bgp-evpn {
            bgp-instance 1 {
                admin-state enable
                vxlan-interface vxlan1.1
                evi 1
                ecmp 2
            }
        }
        bgp-vpn {
            bgp-instance 1 {
                route-target {
                    export-rt target:1234:1
                    import-rt target:1234:1
```

```
                }
            }
        }
    }
```

Each leaf routers is configured with a different autonomous-system number. Therefore, EVI-based auto-derived RTs cannot be used or the three leaf routers would not produce the same import and export route-targets for the MAC-VRFs of the same BD. Therefore, RTs are configured manually.

Step 5. Review the changes. If correct, commit the changes.

Example

```
A:dut2# commit stay
--{ candidate shared default }--[  ]--
```

6.2.3 Checking the EVPN-VXLAN operation in MAC-VRFs

After all leaf routers attached to the same BD are configured, check the state of the MAC-VRF and connectivity to LEAF-2 and LEAF-3.

6.2.3.1 Checking vxlan-interface configuration

Procedure

Use the **show tunnel-interface vxlan-interface** and **show network-instance vxlan-interface** commands to check that the vxlan-interface is properly configured and associated with the network-instance. If the network-instance vxlan-interface is oper-down, a reason is shown. The egress source-ip shown in the output should match the IPv4 address configured in the subinterface system0.0.

Example: Check vxlan-interface configuration

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show tunnel-interface vxlan1 vxlan-interface 1 brief
-------------------------------------------------------------------------------
Show report for vxlan-tunnels
-------------------------------------------------------------------------------
+------------------+-----------------+---------+-------------+------------------+
| Tunnel Interface | VxLAN Interface |  Type   | Ingress VNI | Egress source-ip |
+==================+=================+=========+=============+==================+
| vxlan1           | vxlan1.1        | bridged | 1           | 3.3.3.3/32       |
+------------------+-----------------+---------+-------------+------------------+
-------------------------------------------------------------------------------
Summary
  1 tunnel-interfaces, 1 vxlan interfaces
  5 vxlan-destinations, 2 unicast, 1 es, 2 multicast, 0 ip
-------------------------------------------------------------
```

```
A:dut3# show network-instance MAC-VRF-1 vxlan-interface vxlan1.1
-------------------------------------------------------------------------------
Show report for network instance "MAC-VRF-1" VxLAN interface table
-------------------------------------------------------------------------------
===============================================================================
Network-instance: MAC-VRF-1
VxLAN-Interface : vxlan1.1
```

```
Type            : bridged
Oper state      : up
Oper-down-reason: None
===============================================================================
```

6.2.3.2 Checking mac-vrf, bgp-vpn, and bgp-evpn parameters

Procedure

Use the **show network-instance protocols bgp-vpn** and **show network-instance protocols bgp-evpn** commands to check that the mac-vrf, bgp-vpn, and bgp-evpn parameters are properly configured. A manual or auto-derived RD/RT must exist, or the bgp-evpn bgp-instance will be oper-down.

Example: Check mac-vrf, bgp-vpn, and bgp-evpn parameters

```
A:dut3# show network-instance MAC-VRF-1 protocols bgp-vpn bgp-instance 1
===============================================================================
Net Instance   : MAC-VRF-1
    bgp Instance 1
-------------------------------------------------------------------------------
        route-distinguisher: 3.3.3.3:1, auto-derived-from-evi
        export-route-target: target:1234:1, manual
        import-route-target: target:1234:1, manual
===============================================================================
===============================================================================
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show network-instance MAC-VRF-1 protocols bgp-evpn bgp-instance 1
===============================================================================
Net Instance   : MAC-VRF-1
    bgp Instance 1 is enabled and None
-------------------------------------------------------------------------------
        VXLAN-Interface   : vxlan1.1
        evi               : 1
        ecmp              : 2
        default-admin-tag : 0
        oper-down-reason  : N/A
        EVPN Routes
            Next hop      : None
            MAC/IP Routes : None
            IMET Routes   : None, originating-ip None
===============================================================================
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.2.3.3 Checking VXLAN tunnels

Procedure

Use the **show tunnel vxlan-tunnel** command to check for the creation of VXLAN tunnels to the remote VTEPs. After receiving EVPN routes from the remote leaf routers with VXLAN encapsulation, the vxlan_mgr creates VTEPs from the EVPN routes next-hops. Each VTEP gets an index allocated by the fib_mgr (per source and destination tunnel IP addresses) if the next-hop is resolved in the default network-instance. The state of the two remote VTEPs is shown with their own indexes. EVPN routes are received with Next Hops 2.2.2.2 and 4.4.4.4 respectively.

Example: Check VXLAN tunnels

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show tunnel vxlan-tunnel all
-------------------------------------------------------------------------------
Show report for vxlan-tunnels
-------------------------------------------------------------------------------
+--------------+--------------+--------------------------+
| VTEP Address |    Index     |       Last Change        |
+==============+==============+==========================+
| 2.2.2.2      | 278779228830 | 2021-02-15T11:07:23.000Z |
| 4.4.4.4      | 278779228829 | 2021-02-15T18:15:28.000Z |
+--------------+--------------+--------------------------+
2 VXLAN tunnels, 2 active, 0 inactive
-------------------------------------------------------------
```

6.2.3.4 Checking tunnel-table entries

Procedure

Use the **show network-instance tunnel-table all** command to display all tunnel-table entries. When a VTEP is created in the vxlan-tunnel table and a non-zero index is allocated, a tunnel-table entry is created in the tunnel-table of the default network-instance.

If the next hop is not resolved to a route in the default network-instance route-table, the index in the vxlan-tunnel table shows as `0` for the VTEP and no tunnel-table is created. If the tunnel prefix in the tunnel-table is resolved, but the system runs out of hardware index resources, the tunnel shows in the tunnel-table, but is not programmed. A non-programmed-reason is displayed.

Example: Check tunnel-table entries

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show network-instance default tunnel-table all
-------------------------------------------------------
Show report for network instance "default" tunnel table
-------------------------------------------------------------------------------------------------------------
+-------------+-----------+-------+-------+--------+------------+----------+-------------------------+
| IPv4 Prefix |   Owner   | Type  | Index | Metric | Preference | Fib-prog |       Last Update       |
+=============+===========+=======+=======+========+============+==========+=========================+
| 2.2.2.2/32  | vxlan_mgr | vxlan | 4     | 0      | 0          | Y        | 2021-03-01T10:41:38.590Z|
| 4.4.4.4/32  | vxlan_mgr | vxlan | 5     | 0      | 0          | Y        | 2021-03-01T10:45:08.633Z|
+-------------+-----------+-------+-------+--------+------------+----------+-------------------------+
-------------------------------------------------------------------------------------------------------------
2 VXLAN tunnels, 2 active, 0 inactive
-------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------
Show report for network instance "default" tunnel table
-------------------------------------------------------------------------------------------------------------
```

6.2.3.5 Checking statistics

About this task

When the three leaf routers exchange packets over the VXLAN, LEAF-3 displays statistics for all individual VTEPs. Statistics include:

- Global-level ingress/egress packets and octets. Global in/out octets and packets are aggregations of the individual statistics per VTEP. "in-discarded-packets" are vxlan packets discarded as a result of a non-existent local VNI, packets from a source VTEP are not discovered in the control plan, and packets are not aggregations of individual per VTEP dropped packets
- Per VTEP packets and octets with in/out discarded packets.

Procedure

Use the **info from state tunnel vxlan-tunnel** command to check the VTEP statistics.

To clear statistics, use the following command: **tools tunnel vxlan-tunnel vtep 2.2.2.2 statistics clear**

Example: Check statistics

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# info from state tunnel vxlan-tunnel
    tunnel {
        vxlan-tunnel {
            vtep 2.2.2.2 {
                index 278779228830
                last-change "8 hours ago"
                statistics {
                    in-octets 0
                    in-packets 0
                    in-discarded-packets 0
                    out-octets 0
                    out-packets 0
                    out-discarded-packets 0
                }
            }
            vtep 4.4.4.4 {
                index 278779228829
                last-change "an hour ago"
                statistics {
                    in-octets 555720
                    in-packets 5052
                    in-discarded-packets 0
                    out-octets 0
                    out-packets 0
                    out-discarded-packets 0
                }
            }
            statistics {
                in-octets 555720
                in-packets 5052
                in-discarded-packets 0
                out-octets 0
                out-packets 0
            }
        }
    }
```

6.2.3.6 Checking for received IMET routes and multicast destination creation

About this task

IMET routes are used for auto-discovery and the creation of the default flood list for vxlan in the MAC-VRF. When LEAF-3 receives and imports the IMET routes from LEAF-2 and LEAF-4, it creates a VXLAN default flood list. BUM frames received on a bridged subinterface are ingress-replicated to the VTEPs on the list.

Procedure

Use the **show** and **info from state** commands shown in the following example to check that the IMET routes for the BD from LEAF-2 and LEAF-4 have been received and they have created multicast destinations in the MAC-VRF. Note that the VNI is received in the PMSI tunnel attribute and not in the route's Network Layer Reachability Information (NLRI).

Example: Check for received IMET routes and multicast destination creation

```
--{ [FACTORY] + candidate shared default }--[ ]--
A:dut3# show network-instance default protocols bgp routes evpn route-type 3 detail
-------------------------------------------------------------------------------
Show report for the EVPN routes to network "*" network-instance  "default"
-------------------------------------------------------------------------------
Route Distinguisher: 2.2.2.2:1
Tag-ID             : 0
Originating router : 2.2.2.2
neighbor           : 2.2.2.2
Received paths     : 1
  Path 1: <Best,Valid,Used,>
    VNI             : 1
    Route source    : neighbor 2.2.2.2 (last modified 9h11m44s ago)
    Route preference: No MED, LocalPref is 100
    Atomic Aggr     : false
    BGP next-hop    : 2.2.2.2
    AS Path         :  i
    Communities     : [target:1234:1, bgp-tunnel-encap:VXLAN]
    RR Attributes   : No Originator-ID, Cluster-List is []
    Aggregation     : None
    Unknown Attr    : None
    Invalid Reason  : None
    Tie Break Reason: none
-------------------------------------------------------------------------------
Route Distinguisher: 4.4.4.4:1
Tag-ID             : 0
Originating router : 4.4.4.4
neighbor           : 4.4.4.4
Received paths     : 1
  Path 1: <Best,Valid,Used,>
    VNI             : 1
    Route source    : neighbor 4.4.4.4 (last modified 9h11m44s ago)
    Route preference: No MED, LocalPref is 100
    Atomic Aggr     : false
    BGP next-hop    : 4.4.4.4
    AS Path         :  i
    Communities     : [target:1234:1, bgp-tunnel-encap:VXLAN]
    RR Attributes   : No Originator-ID, Cluster-List is []
    Aggregation     : None
    Unknown Attr    : None
    Invalid Reason  : None
    Tie Break Reason: none
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# info from state network-instance default bgp-rib evpn rib-in-out rib-in-post imet-
routes * originating-router * ethernet-tag-id * neighbor *
    network-instance default {
        bgp-rib {
            evpn {
                rib-in-out {
                    rib-in-post {
                        imet-routes 2.2.2.2:1 originating-router 2.2.2.2 ethernet- tag-id
 0 neighbor 2.2.2.2 {
```

```
                            attr-id 193
                            last-modified 2021-02-15T11:07:21.500Z
                            used-route true
                            valid-route true
                            best-route true
                            stale-route false
                            pending-delete false
                            tie-break-reason none
                            invalid-reason {
                                rejected-route false
                                as-loop false
                                next-hop-unresolved false
                                cluster-loop false
                            }
                        }
                        imet-routes 4.4.4.4:1 originating-router 4.4.4.4 ethernet-tag-id 0
 neighbor 4.4.4.4 {
                            attr-id 197
                            last-modified 2021-02-15T11:07:21.500Z
                            used-route true
                            valid-route true
                            best-route true
                            stale-route false
                            pending-delete false
                            tie-break-reason none
                            invalid-reason {
                                rejected-route false
                                as-loop false
                                next-hop-unresolved false
                                cluster-loop false
                            }
                        }
                    }
                }
            }
        }
    }
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# info from state network-instance default bgp-rib attr-sets attr-set rib-in index
 {193,197}
    network-instance default {
        bgp-rib {
            attr-sets {
                attr-set rib-in index 193 {
                    origin igp
                    atomic-aggregate false
                    next-hop 2.2.2.2
                    med 0
                    local-pref 100
                    aggregator {
                    }
                    pmsi-tunnel {
                        tunnel-type ingress-replication
                        vni 1
                        tunnel-endpoint 2.2.2.2
                    }
                    communities {
                        ext-community [
                            target:1234:1
                            bgp-tunnel-encap:VXLAN
                        ]
                    }
                    unknown-attributes {
                    }
```

```
                }
                attr-set rib-in index 197 {
                    origin igp
                    atomic-aggregate false
                    next-hop 4.4.4.4
                    med 0
                    local-pref 100
                    aggregator {
                    }
                    pmsi-tunnel {
                        tunnel-type ingress-replication
                        vni 1
                        tunnel-endpoint 4.4.4.4
                    }
                    communities {
                        ext-community [
                            target:1234:1
                            bgp-tunnel-encap:VXLAN
                        ]
                    }
                    unknown-attributes {
                    }
                }
            }
        }
    }
```

6.2.3.7 Checking for multicast-destinations

About this task

If the IMET routes from LEAF-2 and LEAF-4 are imported for MAC-VRF-1, the corresponding multicast VXLAN destinations are added.

Procedure

Use the **show tunnel-interface vxlan-interface bridge-table multicast-destinations** command to check the multicast VXLAN destinations are added.

Example: Check for multicast-destinations

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show tunnel-interface vxlan1 vxlan-interface 1 bridge-table multicast-destinations
 destination *
-------------------------------------------------------------------------------
Show report for vxlan-interface vxlan1.1 multicast destinations (flooding-list)
-------------------------------------------------------------------------------
+--------------+------------+-------------------+----------------------+
| VTEP Address | Egress VNI | Destination-index | Multicast-forwarding |
+==============+============+===================+======================+
| 2.2.2.2      | 1          | 278779228840      | BUM                  |
| 4.4.4.4      | 1          | 278779228838      | BUM                  |
+--------------+------------+-------------------+----------------------+
-------------------------------------------------------------------------
Summary
  2 multicast-destinations
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.2.3.8 Checking mac-table and MAC/IP routes

Procedure

When traffic is exchanged between HOST-3 and HOST-12, the MACs are learned on the access bridged sub-interfaces and advertised in MAC/IP routes. The MAC/IP routes are imported, and the MACs programmed in the mac-table. Use the **show network-instance bridge-table mac-table all** and **show network-instance protocols bgp routes evpn route-type summary** commands to check the MAC/IP routes and the programmed MACs.

Example: Check mac-table and MAC/IP routes

```
--{ [FACTORY] + candidate shared default )--[ ]--
A:dut3# show network-instance MAC-VRF-1 bridge-table mac-table all
-----------------------------------------------------------------------------------------------------
Mac-table of network instance MAC-VRF-1
-----------------------------------------------------------------------------------------------------
+--------------+---------------------------+------------+------+--------+-------+-------------------+
|   Address    |            Destination    | Dest Index | Type | Active | Aging |    Last Update    |
+==============+===========================+============+======+========+=======+===================+
| 00:00:00:00: | vxlan-interface:vxlan1.1  | 2787792288 | evpn | true   | N/A   | 2021-02-16T10:54: |
|  00:01       | esi:01:24:24:24:24:24:    | 46         |      |        |       |  54.000Z          |
|              |  00:00:01                 |            |      |        |       |                   |
| 00:00:00:00: | vxlan-interface:vxlan1.1  | 2787792288 | evpn | true   | N/A   | 2021-02-16T10:54: |
|  00:02       | vtep:2.2.2.2 vni:1        | 40         |      |        |       |  54.000Z          |
| 00:00:00:00: | ethernet-1/2.1            | 12         |learnt| true   | 300   | 2021-02-16T10:54: |
|  00:03       |                           |            |      |        |       |  54.000Z          |
| 00:00:00:00: | vxlan-interface:vxlan1.1  | 2787792288 | evpn | true   | N/A   | 2021-02-16T10:54: |
|  00:04       | vtep:4.4.4.4 vni:1        | 38         |      |        |       |  54.000Z          |
+--------------+---------------------------+------------+------+--------+-------+-------------------+
Total Irb Macs            :    0 Total    0 Active
Total Static Macs         :    0 Total    0 Active
Total Duplicate Macs      :    0 Total    0 Active
Total Learnt Macs         :    1 Total    1 Active
Total Evpn Macs           :    3 Total    3 Active
Total Irb anycast Macs    :    0 Total    0 Active
Total Macs                :    4 Total    4 Active
-----------------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show network-instance default protocols bgp routes evpn route-type 2 summary
-------------------------------------------------------------------------------
Show report for the BGP route table of network-instance "default"
-------------------------------------------------------------------------------
Status codes: u=used, *=valid, >=best, x=stale
Origin codes: i=IGP, e=EGP, ?=incomplete
-------------------------------------------------------------------------------
BGP Router ID: 3.3.3.3      AS: 3333      Local AS: 3333
-------------------------------------------------------------------------------
Type 2 MAC-IP Advertisement Routes
+------+-----------+-----+--------------+---------+---------+---------+---+-------------------+------+
|Status| Route-dis-| Tag | MAC-address  | IP-     | Neighbor|  Next-  |VNI|    ESI            | MAC  |
|      | tinguisher| ID  |              | address |         |   Hop   |   |                   | Mob. |
+======+===========+=====+==============+=========+=========+=========+===+===================+======+
| u*>  | 2.2.2.2:1 | 0   | 00:00:00:00: | 0.0.0.0 | 2.2.2.2 | 2.2.2.2 | 1 | 00:00:00:00:00:00 | -    |
|      |           |     | 00:02        |         |         |         |   | 00:00:00:00       |      |
| u*>  | 4.4.4.4:1 | 0   | 00:00:00:00: | 0.0.0.0 | 4.4.4.4 | 4.4.4.4 | 1 | 01:24:24:24:24:24 | -    |
|      |           |     | 00:01        |         |         |         |   | 24:00:00:01       |      |
| u*>  | 4.4.4.4:1 | 0   | 00:00:00:00: | 0.0.0.0 | 4.4.4.4 | 4.4.4.4 | 1 | 00:00:00:00:00:00:| -    |
|      |           |     | 00:04        |         |         |         |   | 00:00:00:0 0      |      |
+------+-----------+-----+--------------+---------+---------+---------+---+-------------------+------+
-------------------------------------------------------------------------------------------------------
```

```
3 MAC-IP Advertisement routes 3 used, 3 valid
-------------------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.2.3.9 Checking unicast destinations

About this task

The reception of MAC/IP routes also creates unicast destinations in the vxlan-interface. In some cases, the unicast destinations are Ethernet Segment (ES) destinations if the MAC/IP routes are advertised from an ES. See Multi-homing configuration for EVPN broadcast domains for details.

Procedure

Use the **show tunnel-interface vxlan-interface bridge-table unicast-destinations** command to display the unicast destinations.

Example: Check unicast destinations

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show tunnel-interface vxlan1 vxlan-interface 1 bridge-table unicast-destinations destination *
-------------------------------------------------------------------------------------------------------
Show report for vxlan-interface vxlan1.1 unicast destinations
-------------------------------------------------------------------------------------------------------
Destinations
-------------------------------------------------------------------------------
+--------------+------------+-------------------+-----------------------------+
| VTEP Address | Egress VNI | Destination-index | Number MACs (Active/Failed) |
+==============+============+===================+=============================+
| 2.2.2.2      | 1          | 278779228840      | 1(1/0)                      |
| 4.4.4.4      | 1          | 278779228838      | 1(1/0)                      |
+--------------+------------+-------------------+-----------------------------+
-------------------------------------------------------------------------------
Ethernet Segment Destinations
-------------------------------------------------------------------------------------------------------
+-------------------------------+-------------------+------------------+-----------------------------+
|              ESI              | Destination-index |      VTEPs       | Number MACs (Active/Failed) |
+===============================+===================+==================+=============================+
| 01:24:24:24:24:24:24:00:00:01 |                   | 2.2.2.2, 4.4.4.4 | 0(0/0)                      |
+-------------------------------+-------------------+------------------+-----------------------------+
-------------------------------------------------------------------------------------------------------
Summary
  3 unicast-destinations, 2 non-es, 1 es
  2 MAC addresses, 2 active, 0 non-active
-------------------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.2.4 Checking MAC mobility, MAC protection and MAC loop protection in EVPN-VXLAN BDs

MAC mobility and MAC protection are implemented following [RFC7432]. MAC loop protection follows [draft-ietf-bess-rfc7432bis].

6.2.4.1 Checking MAC mobility

About this task

MAC Mobility is an event that triggers the fast move and re-learn of a MAC in a different leaf router. Mobility is common in DCs with some workloads moving between racks in the same DC. EVPN provides tools for fast mobility because MAC/IP routes are advertised with a sequence number that indicates the latest location of a MAC. This sequence number is used by the leaf routers to program the MAC with the correct VXLAN destination.

Procedure

To check MAC mobility, use the **show network-instance bridge-table mac-table** command.

Example: MAC mobility (1 of 2)

Using Figure 8: Example of EVPN-VXLAN broadcast domain as reference, if HOST-2 moves from LEAF-2 to LEAF-3, and you review the programming of the MAC in LEAF-4, MAC 00:00:00:00:00:02 is learned against VXLAN destination vtep:2.2.2.2 vni:1:

```
--{ [FACTORY] + candidate shared default }--[ network-instance MAC-VRF-1 bridge-table ]--
A:dut4# /show network-instance MAC-VRF-1 bridge-table mac-table all
-------------------------------------------------------------------------------------------------
Mac-table of network i
-------------------------------------------------------------------------------------------------
+-------------------+-------------------------+------------+-------+--------+-------+--------------+
|      Address      |   Destination           | Dest Index | Type  | Active | Aging | Last Update  |
+===================+=========================+============+=======+========+=======+==============+
| 00:00:00:00:00:01 |lag1.1                   | 11         | learnt| true   | 300   |2021-02-16T11:|
|                   |                         |            |       |        |       | 32:14.000Z   |
| 00:00:00:00:00:02 |vxlan-interface:vxlan1.1 | 2787793311 | evpn  | true   | N/A   |2021-02-16T11:|
|                   | vtep:2.2.2.2 vni:1      | 82         |       |        |       | 32:15.000z   |
| 00:00:00:00:00:03 |vxlan-interface:vxlan1.1 | 2787793311 | evpn  | true   | N/A   |2021-02-16T11:|
|                   | vtep:3.3.3.3 vni:1      | 84         |       |        |       | 32:15.000Z   |
| 00:00:00:00:00:04 |ethernet-1/13.1          | 13         | learnt| true   | 300   |2021-02-16T11:|
|                   |                         |            |       |        |       | 32:14.000Z   |
| 00:CA:FE:CA:FE:04 |ethernet-1/13.1          | 13         | static| true   | N/A   |2021-02-16T11:|
|                   |                         |            |       |        |       | 10:26.000Z   |
+-------------------+-------------------------+------------+-------+--------+-------+--------------+
Total Irb Macs            :    0 Total    0 Active
Total Static Macs         :    1 Total    1 Active
Total Duplicate Macs      :    0 Total    0 Active
Total Learnt Macs         :    2 Total    2 Active
Total Evpn Macs           :    2 Total    2 Active
Total Evpn static Macs    :    0 Total    0 Active
Total Irb anycast Macs    :    0 Total    0 Active
Total Macs                :    5 Total    5 Active
-------------------------------------------------------------------------------------------------
```

Example: MAC mobility (2 of 2)

After the mobility event, LEAF-4 receives the MAC with a higher sequence number. This makes LEAF-4 reprogram the MAC against LEAF-3 as shown below:

```
2021-02-16T03:33:53.505253-08:00 dut4 local6|DEBU sr_bgp_mgr: bgp|4959|5178|402506|D:
 VR default (1) Peer 1: 3.3.3.3 UPDATE: Peer 1: 3.3.3.3 - Received BGP UPDATE:
    Withdrawn Length = 0
    Total Path Attr Length = 96
    Flag: 0x90 Type: 14 Len: 44 Multiprotocol Reachable NLRI:
        Address Family EVPN
```

```
        NextHop len 4 NextHop 3.3.3.3
        Type: EVPN-MAC Len: 33 RD: 3.3.3.3:1 ESI: ESI-0, tag: 0, mac len: 48 mac: 00:00:00:00:00:02,
              IP len: 0, IP: NULL, label1: 1
    Flag: 0x40 Type: 1 Len: 1 Origin: 0
    Flag: 0x40 Type: 2 Len: 0 AS Path:
    Flag: 0x80 Type: 4 Len: 4 MED: 0
    Flag: 0x40 Type: 5 Len: 4 Local Preference: 100
    Flag: 0xc0 Type: 16 Len: 24 Extended Community:
        target:1234:1
        bgp-tunnel-encap:VXLAN
        mac-mobility:Seq:1
--{ [FACTORY] + candidate shared default }--[  ]--

A:dut4# show network-instance MAC-VRF-1 bridge-table mac-table all
-------------------------------------------------------------------------------------------------------
-
Mac-table of network instance MAC-VRF-1
-------------------------------------------------------------------------------------------------------
-
+--------------------+-------------------------+------------+-------+--------+------+---------------+
|      Address       |       Destination       | Dest Index | Type  | Active | Aging| Last Update   |
+====================+=========================+============+=======+========+======+===============+
| 00:00:00:00:00:01  |lag1.1                   | 11         | learnt| true   | 180  |2021-02-16T11: |
|                    |                         |            |       |        |      | 32:14.000Z    |
| 00:00:00:00:00:02  |vxlan-interface:vxlan1.1 | 2787793311 | evpn  | true   | N/A  |2021-02-16T11: |
|                    | vtep:3.3.3.3 vni:1      | 84         |       |        |      | 33:54.000Z    |
| 00:00:00:00:00:03  |vxlan-interface:vxlan1.1 | 2787793311 | evpn  | true   | N/A  |2021-02-16T11: |
|                    | vtep:3.3.3.3 vni:1      | 84         |       |        |      | 32:15.000Z    |
| 00:00:00:00:00:04  |ethernet-1/13.1          | 13         | learnt| true   | 180  |2021-02-16T11: |
|                    |                         |            |       |        |      | 32:14.000Z    |
| 00:CA:FE:CA:FE:04  |ethernet-1/13.1          | 13         | static| true   | N/A  |2021-02-16T11: |
|                    |                         |            |       |        |      | 10:26.000Z    |
+--------------------+-------------------------+------------+-------+--------+------+---------------+
Total Irb Macs            :    0 Total    0 Active
Total Static Macs         :    1 Total    1 Active
Total Duplicate Macs      :    0 Total    0 Active
Total Learnt Macs         :    2 Total    2 Active
Total Evpn Macs           :    3 Total    3 Active
Total Evpn static Macs    :    0 Total    0 Active
Total Irb anycast Macs    :    0 Total    0 Active
Total Macs                :    5 Total    5 Active

-------------------------------------------------------------------------------------------------------
-
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.2.4.2 Checking MAC protection

About this task

MAC protection refers to the property of a MAC that does not move between leaf routers. It is always learned against a bridged subinterface. You can configure this MAC as static, but be aware of the following:

- When a MAC is programmed as static, the same MAC cannot be learned in another sub-interace or via EVPN. If frames arriving on an interface are different than the ones associated with the static MAC, they are discarded.
- The MAC is now advertised as `static` in EVPN and installed as `evpn-static` in the leaf routers attached to the same BD. If programmed, evpn-static MACs are also protected. Therefore, frames arriving on a local subinterface are discarded if their source MAC matches an evpn-static MAC.

Procedure

To program a MAC as static, use the **network-instance bridge-table static-mac** command.

Example: MAC protection (1 of 2)

Using Figure 8: Example of EVPN-VXLAN broadcast domain as reference, the following example shows MAC 00:ca:fe:ca:fe:04 configured as static in LEAF-4.

```
--{ [FACTORY] +* candidate shared default }--[ network-instance MAC-VRF-1 bridge-table ]--
A:dut4# info
    static-mac {
        mac 00:CA:FE:CA:FE:04 {
            destination ethernet-1/13.1
        }
    }
--{ [FACTORY] +* candidate shared default }--[ network-instance MAC-VRF-1 bridge-table ]--
A:dut4# commit stay
All changes have been committed. Starting new transaction.
--{ [FACTORY] + candidate shared default }--[ network-instance MAC-VRF-1 bridge-table ]--
A:dut4#
--{ [FACTORY] + candidate shared default }--[ network-instance MAC-VRF-1 bridge-table ]--
A:dut4# /show network-instance MAC-VRF-1 bridge-table mac-table all
-------------------------------------------------------------------------------------------
Mac-table of network instance MAC-VRF-1
-------------------------------------------------------------------------------------------
+--------------+--------------------------+------------+-------+--------+-------+------------------+
|      Address |  Destination             | Dest Index | Type  | Active | Aging | Last Update      |
+==============+==========================+============+=======+========+=======+==================+
| 00:00:00:00: | lag1.1                   | 11         | learnt| true   | 180   | 2021-02-16T11:08:|
|  00:01       |                          |            |       |        |       |  10.000Z         |
| 00:00:00:00: | vxlan-interface:vxlan1.1 | 2787793311 | evpn  | true   | N/A   | 2021-02-16T11:08:|
|  00:02       |  vtep:2.2.2.2 vni:1      | 82         |       |        |       |  11.000Z         |
| 00:00:00:00: | vxlan-interface:vxlan1.1 | 2787793311 | evpn  | true   | N/A   | 2021-02-16T11:08:|
|  00:03       |  vtep:3.3.3.3 vni:1      | 84         |       |        |       |  11.000Z         |
| 00:00:00:00: | ethernet-1/13.1          | 13         | learnt| true   | 180   | 2021-02-16T11:08:|
|  00:04       |                          |            |       |        |       |  10.000Z         |
| 00:CA:FE:CA: | ethernet-1/13.1          | 13         | static| true   | N/A   | 2021-02-16T11:10:|
|  FE:04       |                          |            |       |        |       |  26.000Z         |
+--------------+--------------------------+------------+-------+--------+-------+------------------+
Total Irb Macs            :    0 Total    0 Active
Total Static Macs         :    1 Total    1 Active
Total Duplicate Macs      :    0 Total    0 Active
Total Learnt Macs         :    2 Total    2 Active
Total Evpn Macs           :    2 Total    2 Active
Total Evpn static Macs    :    0 Total    0 Active
Total Irb anycast Macs    :    0 Total    0 Active
Total Macs                :    5 Total    5 Active
-------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[ network-instance MAC-VRF-1 bridge-table ]--
```

Example: MAC protection (2 of 2)

On the remote leaf routers, the MAC is received as evpn-static and programmed this way. For example, LEAF-4 receives the route and programs it as follows:

```
2021-02-16T03:10:27.402653-08:00 dut3 local6|DEBU sr_bgp_mgr: bgp|4628|4789|270039|D:
  VR default (1) Peer 1: 4.4.4.4 UPDATE: Peer 1: 4.4.4.4 - Received BGP UPDATE:
    Withdrawn Length = 0
    Total Path Attr Length = 96
    Flag: 0x90 Type: 14 Len: 44 Multiprotocol Reachable NLRI:
        Address Family EVPN
        NextHop len 4 NextHop 4.4.4.4
```

```
        Type: EVPN-MAC Len: 33 RD: 4.4.4.4:1 ESI: ESI-0, tag: 0, mac len: 48 mac:
              00:ca:fe:ca:fe:04, IP len: 0, IP: NULL, label1: 1
    Flag: 0x40 Type: 1 Len: 1 Origin: 0
    Flag: 0x40 Type: 2 Len: 0 AS Path:
    Flag: 0x80 Type: 4 Len: 4 MED: 0
    Flag: 0x40 Type: 5 Len: 4 Local Preference: 100
    Flag: 0xc0 Type: 16 Len: 24 Extended Community:
        target:1234:1
        bgp-tunnel-encap:VXLAN
        mac-mobility:Seq:0/Static

--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show network-instance MAC-VRF-1 bridge-table mac-table all
-------------------------------------------------------------------------------------------------------------
-
Mac-table of network instance MAC-VRF-1
-------------------------------------------------------------------------------------------------------------
-
+--------------+--------------------------+------------+------------+-------+-----+----------------+
|   Address    |      Destination         | Dest Index |  Type      | Active| Aging|  Last Update   |
+==============+==========================+============+============+=======+======+================+
| 00:CA:FE:CA: | vxlan-interface:vxlan1.1 | 2787792288 | evpn-static| true  | N/A  | 2021-02-16T11: |
|  FE:04       |  vtep:4.4.4.4 vni:1      | 38         |            |       |      |  10:27.000Z    |
+--------------+--------------------------+------------+------------+-------+------+----------------+
Total Irb Macs            :    0 Total    0 Active
Total Static Macs         :    0 Total    0 Active
Total Duplicate Macs      :    0 Total    0 Active
Total Learnt Macs         :    0 Total    0 Active
Total Evpn Macs           :    0 Total    0 Active
Total Evpn static Macs    :    1 Total    1 Active
Total Irb anycast Macs    :    0 Total    0 Active
Total Macs                :    1 Total    1 Active
-------------------------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[
```

Note that the static MACs state depends on the state of the subinterface which they are configured against. If the subinterface goes `oper-down`, the static MAC and EVPN route are removed. Static Blackhole MACs (where the configured destination is `blackhole`) also behave as static MACs and are advertised as `evpn-static`.

6.2.4.3 MAC loop protection

MAC loop protection in EVPN BDs is based on the SR Linux MAC Duplication feature. This feature detects MAC duplication for MACs moving:

- among bridge sub-interfaces of the same MAC-VRF
- between bridge sub-interfaces and EVPN (in the same MAC-VRF)

It does not detect MAC duplication for MACs moving from one VTEP to a different VTEP in the same MAC-VRF. In addition, when a MAC is declared as a duplicate:

- If the blackhole configuration option is added to the interface, incoming frames on bridged sub-interfaces are discarded if their MAC SA or DA match the blackhole MAC. Frames encapsulated in VXLAN packets are discarded if their inner source MAC or destination MAC match the blackhole MAC in the mac-table.
- The "duplicate" MAC can be overwritten by a higher priority type (for example, static or evpn-static) or flushed by a tools command. Blackhole MACs that result out of duplicate MACs are advertised as regular MACs (non-static).

6.3 Multi-homing configuration for EVPN broadcast domains

SR Linux supports all-active multi-homing for multi-homed peers connected using VXLAN, as per [RFC8365].

Using Figure 8: Example of EVPN-VXLAN broadcast domain as a reference, LEAF-2 and LEAF-3 are multi-homed to server-1 using all-active multi-homing. The representation of the multi-homed device in the EVPN control plane is referred to as an Ethernet Segment (ES). It is considered "all-active" and not "active-active", because SR Linux supports up to four leaf routers multi-homed to the same CE or server with all links being active (not just two).

The all-active multi-homing function relies on three different procedures to handle multi-homing in the ES:

- Designated Forwarder (DF) election
- Split-Horizon (also known as Local-Bias)
- Aliasing

The DF is the leaf that forwards BUM traffic received from the VXLAN into the ES (to the server). Only one DF exists per ES and network-instance, and it is elected based on the exchange of ES routes (EVPN routes type 4) and the subsequent DF election algorithm. All leaf routers, DF and non-DF, forward known-unicast traffic to the multi-homed server.

The split-horizon or local bias is the procedure that avoids looped packets on the server. If server-1 hashes the BUM traffic to the non-DF leaf (for example, LEAF-2), without any split-horizon technique, the flooded BUM packets move to the DF (LEAF-4) and back to server-1. Split-horizon prevents these flooded packets from forwarding back to server-1. When the data plane is VXLAN, the split-horizon mechanism is based on a "local-bias" forwarding mode as defined in RFC8365. This implies that:

- BUM traffic from a local subinterface is always forwarded to the ES, irrespective of the PE being DF. For example, if HOST-2 sends a broadcast frame, it is sent to the ES (lag1.1) even though LEAF- is non-DF for ES-1.
- BUM traffic received over VXLAN is never be forwarded to the ES if the source VTEP matches a leaf that is attached to the same ES. For example, BUM traffic from HOST-2 that is forwarded via VXLAN to LEAF-4 is not forwarded to lag1.1, only to Ethernet-1/13.1.

Aliasing is the procedure that allows ecmp (load-balancing) from remote leaf routers (LEAF-3) to all leaf routers attached to the same ES, even though the MAC is only advertised by one of the leaf routers in the ES. For example, in Figure 8: Example of EVPN-VXLAN broadcast domain, flows from 00:00:00:00:00:01 can only be hashed to LEAF-2. LEAF-2 is the only router in the ES advertising the MAC. However, because LEAF-2 and LEAF-4 advertise the association to the same Ethernet Segment Identifier (ESI), and the MAC/IP route for 00:00:00:00:00:01 is tagged with ESI-1, LEAF-3 can "alias" the unicast traffic to both leaf routers.

Note that a leaf advertises its association to an ES via AD per ES routes, and its association to an ES for a specified MAC-VRF via AD per EVI routes. Both are EVPN routes type 1.

6.3.1 All-active multi-homing configurations

Configuration of all-active multi-homing involves four major steps:

- Configuring the server/CE with a single LAG that connects it to the leaf routers.
- Configuring an ES (ES-1) on the leaf routers (LEAF-2 and LEAF-4)

- Associating the ES interface with the MAC-VRF.
- Optional: Configuring the ecmp with a value greater than 1 in all the leaf routers attached to the same BD (for aliasing). This step is only required if multi-homing is used in an EVPN-VXLAN BD distributed among multiple leaf routers.

6.3.1.1 Ethernet segment configuration details

With SR Linux, ESs are control plane entities that reside in the system network-instance. The system network-instance contains a BGP-VPN instance similar to the one in mac-vrfs. This instance hosts the bgp information used by EVPN for multi-homing routes, and the ES configuration and state.

The following example provides ES configuration details.

```
--{ [FACTORY] + candidate shared default }--
    [ system network-instance protocols evpn ethernet-segments ]--
A:dut4# tree detail
ethernet-segments!+    evpn_mgr
+-- timers    evpn_mgr
|   +-- boot-timer?    evpn_mgr
|   +-- activation-timer?    evpn_mgr
+-- bgp-instance* [id]    evpn_mgr
    +-- ethernet-segment* [name]    evpn_mgr
        +-- admin-state?    evpn_mgr
        +-- esi?    evpn_mgr
        +-- interface?    evpn_mgr
        +-- multi-homing-mode?    evpn_mgr
        +-- df-election    evpn_mgr
        |   +-- timers    evpn_mgr
        |   |   +-- activation-timer?    evpn_mgr
```

The ES model uses a BGP-VPN instance where the route-distinguisher and export/import route-targets are taken by BGP and used for the ES routes. Only one instance is allowed, and all ESs live under this BGP instance. The default route-distinguisher for the instance is automatically derived from system-ip:0 and used in ES routes.

The default import/export route-target is automatically derived from the ESI (bytes 1 to 6; from the second highest order byte up to the seventh byte). This route-target is of type ESI-import route-target (as per [RFC7432]) and is used in ES routes to ensure they are imported on Leaf routers attached to the ES.

ESs have an admin-state this is disabled by default. It must be toggled to change any of the parameters affecting the EVPN control plane.

The following timers can be configures for ESs: general boot, per ES boot, and activation:

- The boot-timer is configured globally for all ESs. This allows the system to synchronize with the rest of the network at reboot, and before the ES is brought up and its route is advertised.
- Before a boot-timer expires, the ES subinterfaces are oper-up and the AD routes advertised. In all-active mode, they forward unicast traffic; BUM is not forwarded until the ES subinterfaces become DF. When the boot-timer expires, the ES route is advertised, and the DF election takes place.
- The boot-timer can be configured with a value of 0-6000 seconds. Because it is linked to the evpn_mgr application, the boot-timer kicks in when the evpn_mgr restarts. It is recommended that you configure a timer that is long enough for the node to establish its BGP sessions and underlay connectivity before it expires, use some transient BUM duplication).and ES routes are exchanged.
- The ES activation timer allows collecting ES routes for the same ES from other leaf routers before promoting a node subinterface as DF. This prevents multiple transient DF leaf routers on the same ES,

and BUM duplication to the server/CE. The ES activation timer defaults to 3 seconds, but can be set to 0 if fast convergence is needed (although this may cause some transient BUM duplication).

The ES requires a manual 10-byte ESI configuration. Reserved ESI values such as ESI-0 or MAX-ESI (0xFF..FF) are not allowed. ESI values with 00-00-00-00-00-00 in bytes 1-6 are not allowed. This prevents the auto-derivation of ESI-import route-targets as all 0s.

SR Linux supports the default DF election algorithm, as per [RFC8584]. No configuration is required.

- The algorithm (also known as type Default or type 0) is a modulo-based operation that uses the number of leafs in the ES and the configured EVI values in the contained mac-vrfs.
- The default alg orders the candidate list from lowest to highest IP address (where the IP address is taken from the originating-ip of the ES routes), and picks up an ordinal of the list based on the outcome of the modulo operation.
- If the mac-vrf instances in the ES have consecutive EVI values, load balancing of the DF function occurs. For example, if mac-vrf-1 has a value of EVI=1, mac-vrf-2 is EVI=2. Both have subinterfaces in lag1 that belong to ES-1; one of the mac-vrfs is DF and the other is non-DF for ES-1.

The ES association to an interface must be configured. The interface type can be Ethernet or LAG. If LACP is used on the CE, as shown in Figure 8: Example of EVPN-VXLAN broadcast domain, only a LAG can be associated.

6.3.2 Configuring LEAF-2 and LEAF-4 as multi-homed nodes to server-1

About this task

LEAF-2 and LEAF-4 behave as a single system to server-1. Therefore, they must be configured with the same LACP parameters for the LAG on server-1 to come up. The admin-key, system-id-mac, and system-priority must match on both leaf routers so that the LAG comes up.

Procedure

Step 1. In candidate mode, configure the LAG that connects to server-1.

The LAG can be LACP enabled or static. In this example, LACP is used.

Example

LAG configuration (LAG1 on LEAF-4)

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut4# interface ethernet-1/4
--{ [FACTORY] + candidate shared default }--[ interface ethernet-1/4 ]--
A:dut4# info
    description ES-1
    ethernet {
        aggregate-id lag1
    }
--{ [FACTORY] + candidate shared default }--[ interface ethernet-1/4 ]--
A:dut4# /interface lag1
--{ [FACTORY] + candidate shared default }--[ interface lag1 ]--
A:dut4# info
    admin-state enable
    vlan-tagging true
    subinterface 1 {
        type bridged
        vlan {
            encap {
                single-tagged {
```

```
                    vlan-id 1
                }
            }
        }
    }
    lag {
        lag-type lacp
        member-speed 100G
        lacp {
            interval FAST
            lacp-mode ACTIVE
            admin-key 24
            system-id-mac 00:00:00:00:00:24
            system-priority 24
        }
    }
```

Example

LAG configuration (LAG1 on LEAF-2)

```
--{ [FACTORY] + candidate shared default }--[ interface ethernet-1/11 ]--
A:dut2# info
    description ES-1
    ethernet {
        aggregate-id lag1
    }
--{ [FACTORY] + candidate shared default }--[ interface ethernet-1/11 ]--
A:dut2# /interface lag1
--{ [FACTORY] + candidate shared default }--[ interface lag1 ]--
A:dut2# info
    admin-state enable
    vlan-tagging true
    subinterface 1 {
        type bridged
        vlan {
            encap {
                single-tagged {
                    vlan-id 1
                }
            }
        }
    }
    lag {
        lag-type lacp
        member-speed 100G
        lacp {
            interval FAST
            lacp-mode ACTIVE
            admin-key 24
            system-id-mac 00:00:00:00:00:24
            system-priority 24
        }
    }
```

Step 2. Configure Ethernet Segment (ES-1) on LEAF-2 and LEAF-4.

See Ethernet segment configuration details for an in-depth overview of ES functionality and configuration.

Example

ES configuration (ES-1 on LEAF-2)

```
--{ [FACTORY] + candidate shared default }--[ interface lag1 ]--
A:dut2# /system network-instance
--{ [FACTORY] + candidate shared default }--[ system network-instance ]--
A:dut2# info
    protocols {
        evpn {
            ethernet-segments {
                bgp-instance 1 {
                    ethernet-segment ES-1 {
                        admin-state enable
                        esi 01:24:24:24:24:24:24:00:00:01
                        interface lag1
                        multi-homing-mode all-active
                    }
                }
            }
        }
        bgp-vpn {
            bgp-instance 1 {
            }
        }
    }
```

The ESI and mode must match on both Leaf routers. The following is the minimum configuration for ES-1 to function across the two leaf routers.

Example

ES configuration (ES-1 on LEAF-4)

```
--{ [FACTORY] + candidate shared default }--[ interface lag1 ]--
A:dut4#  /system network-instance
--{ [FACTORY] + candidate shared default }--[ system network-instance ]--
A:dut4# info
    protocols {
        evpn {
            ethernet-segments {
                bgp-instance 1 {
                    ethernet-segment ES-1 {
                        admin-state enable
                        esi 01:24:24:24:24:24:24:00:00:01
                        interface lag1
                        multi-homing-mode all-active
                    }
                }
            }
        }
        bgp-vpn {
            bgp-instance 1 {
            }
        }
    }
```

Step 3. Configure the association of the ES interface with the MAC-VRF.

In this example, interface lag1.1 is added to the MAC-VRF. The association is based on the configuration under the ES and no further configuration is needed at the MAC-VRF level.

Example

ES interface association with the MAC-VRF

```
A:dut2# /network-instance MAC-VRF-1
--{ [FACTORY] + candidate shared default }--[ network-instance MAC-VRF-1 ]--
A:dut2# info
    type mac-vrf
    admin-state enable
    interface ethernet-1/12.1 {
    }
    interface lag1.1 {
    }
    vxlan-interface vxlan1.1 {
    }
    protocols {
        bgp-evpn {
            bgp-instance 1 {
                admin-state enable
                vxlan-interface vxlan1.1
                evi 1
            }
        }
        bgp-vpn {
            bgp-instance 1 {
                route-target {
                    export-rt target:1234:1
                    import-rt target:1234:1
                }
            }
        }
    }
A:dut4# /network-instance MAC-VRF-1
--{ [FACTORY] + candidate shared default }--[ network-instance MAC-VRF-1 ]--
A:dut4# info
    type mac-vrf
    admin-state enable
    interface ethernet-1/13.1 {
    }
    interface lag1.1 {
    }
    vxlan-interface vxlan1.1 {
    }
    protocols {
        bgp-evpn {
            bgp-instance 1 {
                admin-state enable
                vxlan-interface vxlan1.1
                evi 1
            }
        }
        bgp-vpn {
            bgp-instance 1 {
                route-target {
                    export-rt target:1234:1
                    import-rt target:1234:1
                }
            }
        }
    }
    bridge-table {
        static-mac {
            mac 00:CA:FE:CA:FE:04 {
                destination ethernet-1/13.1
```

```
            }
        }
    }
```

Step 4. Configure the ecmp with a value greater than 1 in all the leaf routers attached to the same BD to allow for aliasing.

Note:
This step is only required if Multi-Homing is used in an EVPN-VXLAN BD distributed among multiple Leaf routers. If the Multi-Homing ES is used locally as a Layer-2 MLAG (Multi-chassis Link Aggregation Group) technique, this step can be skipped.

In the following example, LEAF-3 is configured with ecmp 2.

Example

Configure ecmp

```
--{ [FACTORY] + candidate shared default }--[ network-instance MAC-VRF-1 ]--
A:dut3# info detail flat | grep ecmp
set / network-instance MAC-VRF-1 protocols bgp-evpn bgp-instance 1 ecmp 2
```

Step 5. Review the configuration and commit the changes.

Example

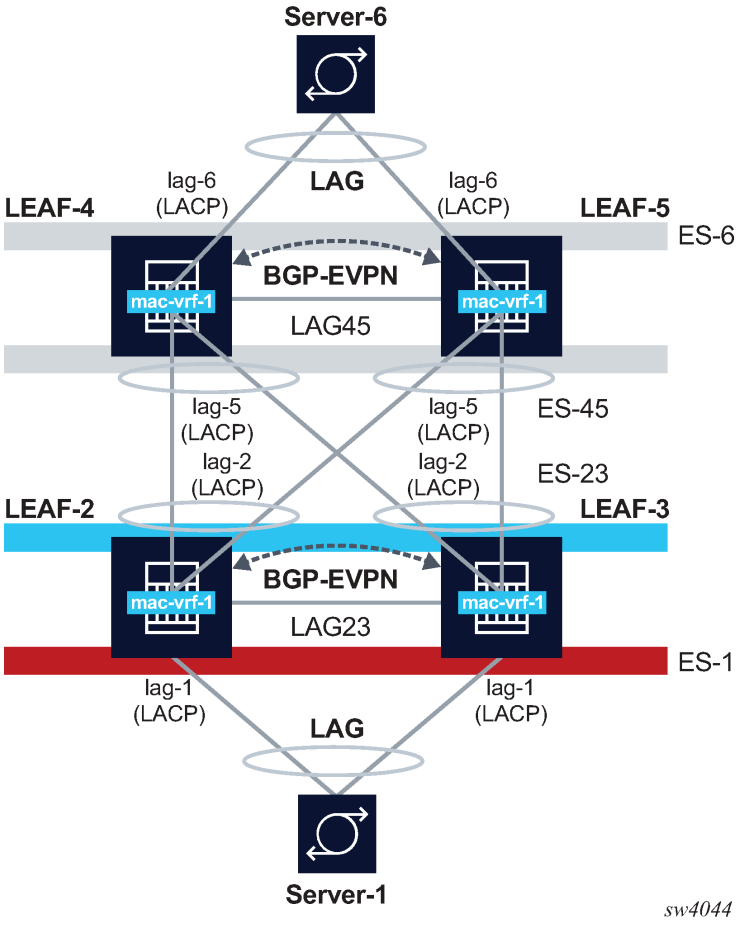
```
--{ candidate shared default }--[  ]--
A:dut2# commit stay
```

6.3.2.1 Use of multi-homing as all-active MLAG for non-EVPN layer-2 BDs

An example of ESs in a non-EVPN layer-2 BD is shown in the following diagram. In this scenario, EVPN only runs locally between the leaf routers of the two pairs, but not globally in the network. The two leaf tiers (LEAF-4/5 and LEAF-2/3) are connected via layer-2 sub-interfaces, and not VXLAN. Each leaf is configured with two ESs. LEAF-4 is configured with ES-6 for multi-homing to server-6, and ES-45 for multi-homing to the LEAF-2/3 tier. The configuration of the ES previously described also apply to these topologies, with the exception that each ES would use a different name, ESI, and lag interface.

As noted in the multi-homing configuration procedure, configuring the ecmp with a value greater than 1 in all the leaf routers attached to the same BD is not required If the multi-homing ES is used locally as a layer-2 MLAG.

Figure 9: Use of ES for layer-2 MLAG scenarios



6.3.3 Checking the multi-homing operation

After the multi-homed leaf routers and the remote leaf are configured, the ES operation must be checked.

6.3.3.1 Checking the ES status

Procedure

Use the **show system network-instance ethernet-segments** command to check the status of the ES on LEAF-2 and LEAF-4. The output from this command must show the same DF for the same mac-vrf on both leaf routers, and the same candidate list for the ES on both leaf routers. The detail form of this command also provides information about timers and the DF election.

Example: Check the ES status

```
// Leaf-4
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut4# show system network-instance ethernet-segments ES-1
-------------------------------------------------------------------------------
```

```
ES-1 is up, all-active
  ESI  : 01:24:24:24:24:24:24:00:00:01
  Alg  : default
  Peers: 2.2.2.2
  Interface: lag1
  Network-instances:
     MAC-VRF-1
      Candidates : 2.2.2.2, 4.4.4.4 (DF)
      Interface : lag1.1
-------------------------------------------------------------------------------
Summary
 1 Ethernet Segments Up
 0 Ethernet Segments Down
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[ ]--
A:dut4# show system network-instance ethernet-segments ES-1 detail
===============================================================================
Ethernet Segment
===============================================================================
Name                : ES-1
4.4.4.4 (DF)
Admin State         : enable             Oper State        : up
ESI                 : 01:24:24:24:24:24:24:00:00:01
Multi-homing        : all-active         Oper Multi-homing : all-active
Interface           : lag1
ES Activation Timer : None
DF Election         : default            Oper DF Election  : default
Last Change         : 2021-02-15T11:07:01.412Z
===============================================================================
MAC-VRF   Actv Timer Rem   DF
ES-1      0                Yes
-------------------------------------------------------------------------------
DF Candidates
-------------------------------------------------------------------------------
Network-instance       ES Peers
MAC-VRF-1              2.2.2.2
MAC-VRF-1              4.4.4.4 (DF)
===============================================================================
--{ [FACTORY] + candidate shared default }--[  ]—
// Leaf-2

--{ [FACTORY] + candidate shared default }--[  ]--
A:dut2# show system network-instance ethernet-segments ES-1
-------------------------------------------------------------------------------
ES-1 is up, all-active
  ESI  : 01:24:24:24:24:24:24:00:00:01
  Alg  : default
  Peers: 4.4.4.4
 show system network-instance ethernet-segments ES-1
  Network-instances:
     MAC-VRF-1
      Candidates : 2.2.2.2, 4.4.4.4 (DF)
      Interface : lag1.1
-------------------------------------------------------------------------------
Summary
 1 Ethernet Segments Up
 0 Ethernet Segments Down
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.3.3.2 Checking ES and EVI routes

Procedure

Use the **show network-instance protocols bgp routes evpn route-type summary** command to check the exchange of ES routes (used for DF election and ES discovery) and AD per ES/EVI routes (used to indicate the association of Leaf services to ES).

Note that LEAF-2 should have a type 4 route for the ES originating from LEAF-4. There should also be one AD per EVI and one AD per ES route from LEAF-4 for MAC-VRF-1. AD routes are advertised for each MAC-VRF that are part of the ES.

Example: Check ES and EVI routes

```
// Received ES routes or routes type 4 on Leaf-2
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut2# show network-instance default protocols bgp routes evpn route-type 4 summary
-------------------------------------------------------------------------------
Show report for the BGP route table of network-instance "default"
-------------------------------------------------------------------------------
Status codes: u=used, *=valid, >=best, x=stale
Origin codes: i=IGP, e=EGP, ?=incomplete
-------------------------------------------------------------------------------
BGP Router ID: 2.2.2.2      AS: 2222      Local AS: 2222
-------------------------------------------------------------------------------
Type 4 Ethernet Segment Routes
+--------+---------------+-------------------+--------------+---------+-----------+
| Status |  Route-       |          ESI      | originating  | neighbor| Next-Hop  |
|        | distinguisher |                   |  -router     |         |           |
+========+===============+===================+==============+=========+===========+
| u*>    | 4.4.4.4:0     | 01:24:24:24:24:24:| 4.4.4.4      | 4.4.4.4 | 4.4.4.4   |
|        |               |  24:00:00:01      |              |         |           |
+--------+---------------+-------------------+--------------+---------+-----------+
-------------------------------------------------------------------------------
1 Ethernet Segment routes 1 used, 1 valid
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut2#
/* Received AD routes or routes type 1 on Leaf-2. The AD per ES route uses Eth-Tag= MAX-ET
 (all FFs). */


--{ [FACTORY] + candidate shared default }--[  ]--
A:dut2# show network-instance default protocols bgp routes evpn route-type 1 summary
Show report for the BGP route table of network-instance "default"
-------------------------------------------------------------------------------
Status codes: u=used, *=valid, >=best, x=stale
Origin codes: i=IGP, e=EGP, ?=incomplete
-------------------------------------------------------------------------------
BGP Router ID: 2.2.2.2      AS: 2222      Local AS: 2222
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
Type 1 Ethernet Auto-Discovery Routes
+--------+---------------+-------------------+------------+---------+---------+-----+
| Status |     Route-    |     ESI           |   Tag-ID   | neighbor|Next-hop | VNI |
|        | distinguisher |                   |            |         |         |     |
+========+===============+===================+============+=========+=========+=====+
| u*>    | 4.4.4.4:1     | 01:24:24:24:24:   | 0          | 4.4.4.4 | 4.4.4.4 | -   |
|        |               |  24:24:00:00:01   |            |         |         |     |
| u*>    | 4.4.4.4:1     | 01:24:24:24:24:   | 4294967295 | 4.4.4.4 | 4.4.4.4 | -   |
|        |               |  24:24:00:00:01   |            |         |         |     |
```

```
+--------+--------------+-----------------+------------+---------+---------+-----+
2 Ethernet Auto-Discovery routes 2 used, 2 valid
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut2# show network-instance default protocols bgp routes evpn route-type 1 detail
-------------------------------------------------------------------------------
Show report for the EVPN routes to network "*" network-instance  "default"
-------------------------------------------------------------------------------
Route Distinguisher: 4.4.4.4:1
Tag-ID             : 0
ESI                : 01:24:24:24:24:24:24:00:00:01
neighbor           : 4.4.4.4
Received paths     : 1
  Path 1: <Best,Valid,Used,>
    ESI             : 01:24:24:24:24:24:24:00:00:01
    Route source    : neighbor 4.4.4.4 (last modified 4h38m27s ago)
    Route preference: No MED, LocalPref is 100
    Atomic Aggr     : false
    BGP next-hop    : 4.4.4.4
    AS Path         :  i
    Communities     : [target:1234:1, bgp-tunnel-encap:VXLAN]
    RR Attributes   : No Originator-ID, Cluster-List is []
    Aggregation     : None
    Unknown Attr    : None
    Invalid Reason  : None
    Tie Break Reason: none
-------------------------------------------------------------------------------
Route Distinguisher: 4.4.4.4:1
Tag-ID             : 4294967295
ESI                : 01:24:24:24:24:24:24:00:00:01
neighbor           : 4.4.4.4
Received paths     : 1
  Path 1: <Best,Valid,Used,>
    ESI             : 01:24:24:24:24:24:24:00:00:01
    Route source    : neighbor 4.4.4.4 (last modified 4h38m27s ago)
    Route preference: No MED, LocalPref is 100
    Atomic Aggr     : false
    BGP next-hop    : 4.4.4.4
    AS Path         :  i
    Communities     : [target:1234:1, esi-label:0/All-Active]
    RR Attributes   : No Originator-ID, Cluster-List is []
    Aggregation     : None
    Unknown Attr    : None
    Invalid Reason  : None
    Tie Break Reason: none
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.3.3.3 Checking the MAC/IP route

About this task

MAC/IP routes advertised for MACs learned on the ES sub-interfaces are advertised with the ESI of ES-1. The RIB state for the MAC/IP routes can be used to check this.

Procedure

Use the **show network-instance protocols bgp routes evpn route-type summary** command to check the MAC/IP route for MAC 00:00:00:00:00:01 on LEAF-3:

Example: Check the MAC/IP route

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show network-instance default protocols bgp routes evpn route-type 2 summary
-------------------------------------------------------------------------------------------------------
Show report for the BGP route table of network-instance "default"
-------------------------------------------------------------------------------------------------------
Status codes: u=used, *=valid, >=best, x=stale
Origin codes: i=IGP, e=EGP, ?=incomplete
-------------------------------------------------------------------------------------------------------
BGP Router ID: 3.3.3.3      AS: 3333      Local AS: 3
-------------------------------------------------------------------------------------------------------
Type 2 MAC-IP Advertisement Routes
+--------+-----------+-----+-------------+--------+---------+---------+---+-----------------+-------+
| Status |Route-dis- | Tag |MAC-address  |IP-     | neighbor| Next-Hop|VNI|         ESI     | MAC   |
|        |tinguisher | -ID |             |address |         |         |   |                 | Mob.  |
+========+===========+=====+=============+========+=========+=========+===+=================+=======+
| u*>    |2.2.2.2:1  | 0   |00:00:00:00: |0.0.0.0 | 2.2.2.2 | 2.2.2.2 | 1 | 00:00:00:00:00: | -     |
|        |           |     | 00:02       |        |         |         |   |  00:00:00:00:0 0|       |
| u*>    |4.4.4.4:1  | 0   |00:00:00:00: |0.0.0.0 | 4.4.4.4 | 4.4.4.4 | 1 | 01:24:24:24:24: | -     |
|        |           |     | 00:01       |        |         |         |   |  24:24:00:00:01 |       |
| u*>    |4.4.4.4:1  | 0   |00:00:00:00: |0.0.0.0 | 4.4.4.4 | 4.4.4.4 | 1 | 00:00:00:00:00: | -     |
|        |           |     | 00:0 4      |        |         |         |   |  00:00:00:00:00 |       |
| u*>    |4.4.4.4:1  | 0   |00:CA:FE:CA: |0.0.0.0 | 4.4.4.4 | 4.4.4.4 | 1 | 00:00:00:00:00: |Seq:0/ |
|        |           |     | FE:04       |        |         |         |   |  00:00:00:00:00 |Static |
+--------+-----------+-----+-------------+--------+---------+---------+---+-----------------+-------+
-------------------------------------------------------------------------------------------------------
4 MAC-IP Advertisement routes 4 used, 4 valid
-------------------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.3.3.4 Checking the ES destination

About this task

When AD routes are received from LEAF-2 and LEAF-4, and the MAC/IP route is tagged with the ESI, LEAF-3 creates an ES destination resolved to as many VTEPs as leafs advertising the AD routes (up to a maximum of the ecmp setting on LEAF-3).

Procedure

Use the **show tunnel-interface vxlan-interface bridge-table unicast-destinations** command to check the ES destination for ES-1 created on LEAF-3.

Example: Check the ES destination

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show tunnel-interface vxlan1 vxlan-interface 1 bridge-table unicast-destinations destination *
-------------------------------------------------------------------------------------------------------
Show report for vxlan-interface vxlan1.1 unicast destinations
-------------------------------------------------------------------------------------------------------
Destinations
-------------------------------------------------------------------------
+--------------+------------+-------------------+-----------------------------+
| VTEP Address | Egress VNI | Destination-index | Number MACs (Active/Failed) |
+==============+============+===================+=============================+
| 2.2.2.2      | 1          | 278779228840      | 1(1/0)                      |
| 4.4.4.4      | 1          | 278779228838      | 2(2/0)                      |
+--------------+------------+-------------------+-----------------------------+
-------------------------------------------------------------------------
```

```
Ethernet Segment Destinations
-------------------------------------------------------------------------------------------------------
+------------------------------+------------------+------------------+----------------------------+
|              ESI             | Destination-index |      VTEPs       | Number MACs (Active/Failed) |
+==============================+==================+==================+============================+
| 01:24:24:24:24:24:24:00:00:01 |                  | 2.2.2.2, 4.4.4.4 | 0(0/0)                     |
+------------------------------+------------------+------------------+----------------------------+
-------------------------------------------------------------------------------------------------------
Summary
  3 unicast-destinations, 2 non-es, 1 es
  3 MAC addresses, 3 active, 0 non-active
-------------------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.3.3.5 Checking MAC programming

Procedure

Use the **show network-instance bridge-table mac-table mac** command to show how LEAF-3 programs the MACs received for the ES as associated with an ES destination

Example: Check MAC programming

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut3# show network-instance MAC-VRF-1 bridge-table mac-table mac 00:00:00:00:00:01
-------------------------------------------------------------------------------
Mac-table of network instance MAC-VRF-1
-------------------------------------------------------------------------------
Mac                     : 00:00:00:00:00:01
Destination             : vxlan-interface:vxlan1.1 esi:01:24:24:24:24:24:24:00:00:01
Dest Index              : 278779228850
Type                    : evpn
Programming Status      : Success
Aging                   : N/A
Last Update             : 2021-02-16T15:51:09.000Z
Duplicate Detect time   : N/A
Hold down time remaining: N/A
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

6.3.3.6 Checking subinterface ES association (LEAF-2)

About this task

On the non-DF (in this example, LEAF-2), the MAC-VRF interface included in ES-1 (lag1.1) shows the **multicast-forwarding** flag as none. This means that the interface does not forward BUM traffic to the CE/server when it is received on the VXLAN.

Procedure

Use the **info from state** command for the subinterface itself to show the association with ES-1 and the DF state.

Example: Check subinterface ES association (LEAF-2)

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut2# info from state network-instance MAC-VRF-1 interface lag1.1
```

```
    network-instance MAC-VRF-1 {
        interface lag1.1 {
            oper-state up
            oper-mac-learning up
            index 12
            multicast-forwarding none
        }
    }
--{ [FACTORY] + candidate shared default }--[  ]--
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut2# info from state interface lag1 subinterface 1 ethernet-segment-association
    interface lag1 {
        subinterface 1 {
            ethernet-segment-association {
                ethernet-segment ES-1
                es-managed true
                designated-forwarder false
            }
        }
```

6.3.3.7 Checking subinterface ES association (LEAF-4)

About this task

On the DF (in this example, LEAF-4), the MAC-VRF interface in ES-1 (lag1.1) shows the **multicast-forwarding** flag as BUM.

Procedure

Use the **info from state** command for the subinterface itself to show the association with ES-1 and the DF state.

Example: Check subinterface ES association (LEAF-4)

```
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut4# info from state network-instance MAC-VRF-1 interface lag1.1
    network-instance MAC-VRF-1 {
        interface lag1.1 {
            oper-state up
            oper-mac-learning up
            index 11
            multicast-forwarding BUM
        }
    }
--{ [FACTORY] + candidate shared default }--[  ]--
--{ [FACTORY] + candidate shared default }--[  ]--
A:dut4#   info from state interface lag1 subinterface 1 ethernet-segment-association
    interface lag1 {
        subinterface 1 {
            ethernet-segment-association {
                ethernet-segment ES-1
                es-managed true
                designated-forwarder true
            }
        }
    }
```

6.3.3.8 EVPN related logs

The evpn_mgr application has logs that are triggered when the DF state changes on an ES as shown in the following example:

Example: EVPN related logs

```
[root@dut2 srlinux]#
2021-02-15T02:59:41.888505-08:00 dut2 local6|NOTI sr_evpn_mgr: evpn|1905|1905|00086|N:
 BGP-EVPN attachment circuit on ethernet segment ES-1 on network instance MAC-VRF-1
 and bgp instance 1 is now a non-designated forwarder.

2021-02-15T02:59:44.859295-08:00 dut2 local6|NOTI sr_evpn_mgr: evpn|1905|1905|00087|N:
 BGP-EVPN attachment circuit on ethernet segment ES-1 on network instance MAC-VRF-1
 and bgp instance 1 is now a designated forwarder.
```

7 EVPN-VXLAN for layer 3

The EVPN Layer 3 configuration model builds on the model for EVPN routes described in EVPN-VXLAN for layer-2 and multi-homing. Understanding the concepts in the EVPN-VXLAN Layer-2 chapter is required to understand this chapter.

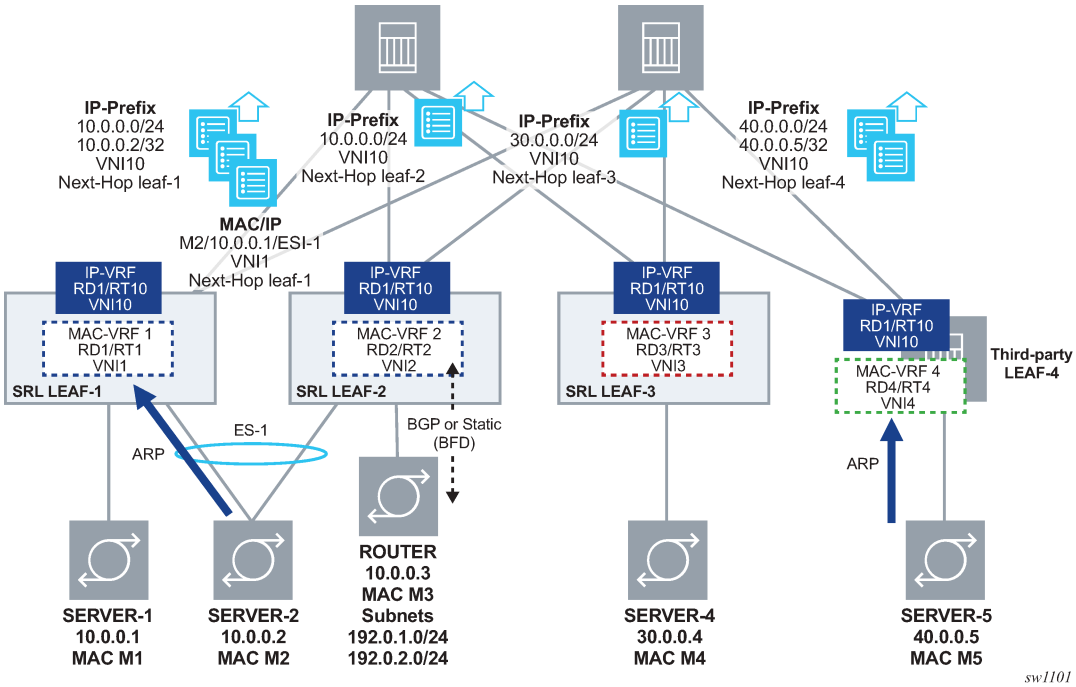
This chapter addresses connectivity between subnets across multiple Broadcast Domains (BDs) of the same tenant as defined in the EVPN Interface-less (IFL) model [draft-ietf-bess-evpn-prefix-advertisement]. It is based on the advertisement and processing of IP prefixes using EVPN type 5 routes. This chapter defines how CEs or servers can be multi-homed to multiple leaf nodes in an EVPN IFL network. It also describes other EVPN L3 topics such as:

- IRB subinterface extensions for EVPN-VXLAN Layer 3
- unicast routing PE-CE
- layer 3 host mobility

7.1 Overview

Figure 10: EVPN IP-VRF domain in a multi-tenant DC shows four leaf routers attached to the same tenant or IP-VRF domain. Servers are connected to different subnets and, therefore, different BDs. The leaf routers provide inter-subnet forwarding by using the EVPN IFL model as defined in [draft-ietf-bess-evpn-prefix-advertisement]. The SR Linux implementation is fully standard and third-party routers, such as LEAF-4, can be connected to the same IP-VRF domain as SR Linux routers.

Figure 10: EVPN IP-VRF domain in a multi-tenant DC



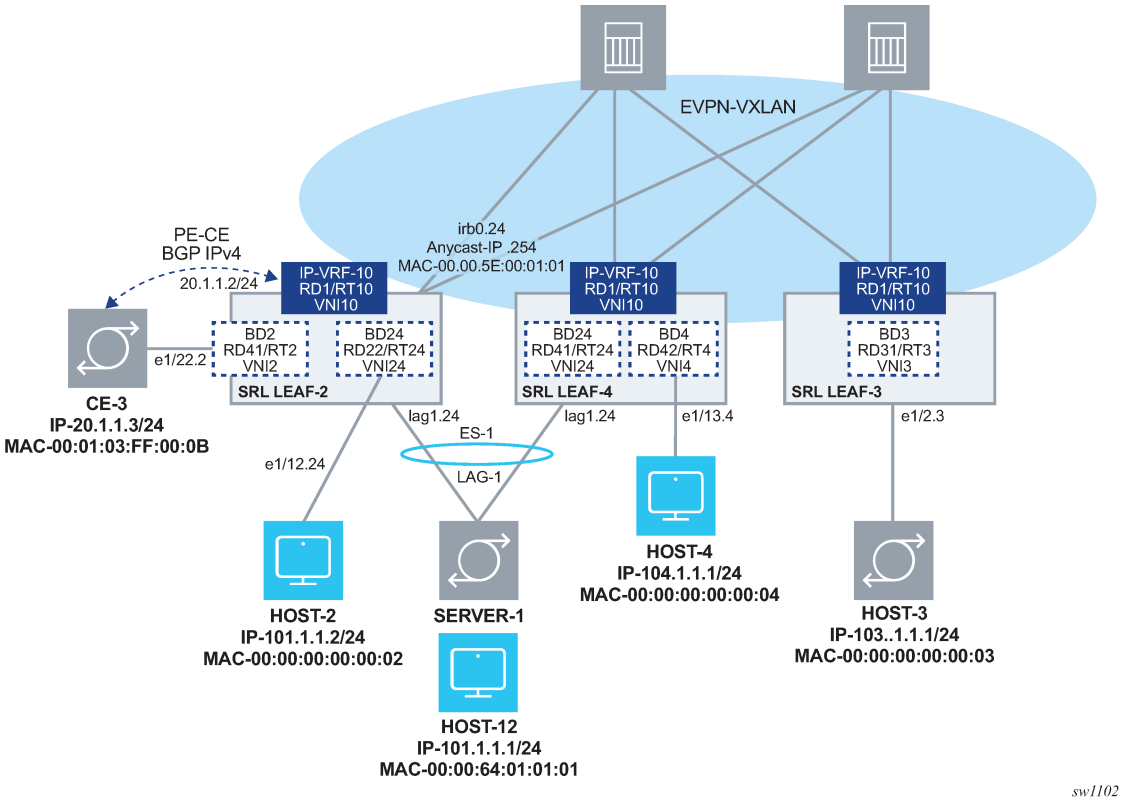
The procedures in this chapter define the configuration and operation for:

- the EVPN IFL model for EVPN-VXLAN Layer 3 and the EVPN IP prefix routes
- multi-homing in an EVPN-VXLAN Layer 3 solution
- host route mobility aspects
- PE-CE unicast routing on EVPN-VXLAN Layer 3 networks
- EVPN-VXLAN Layer 3 feature parity for IPv6 prefixes

7.2 Configuration of EVPN-VXLAN IP-VRF domains

The following figure shows the configuration of an EVPN-VXLAN IP-VRF-10 distributed in three leaf routers, with different subnets, and multi-homing for SERVER-1.

Figure 11: Example of EVPN-VXLAN IP-VRF domain



7.2.1 Preconfiguring the underlay network

Before configuring the overlay BD, the underlay connectivity must be configured.

This chapter uses the same underlay configuration defined for EVPN-VXLAN Layer-2 and Multi-Homing. See Configuring the underlay network and review this section to understand the underlay configuration before proceeding.

7.2.2 Configuring the LEAF-3 IP-VRF domain

About this task

After LEAF-3 is pre-configured as defined in Configuring the underlay network, use the following steps to enable EVPN-VXLAN on LEAF-3.

As shown in Figure 11: Example of EVPN-VXLAN IP-VRF domain, LEAF-3 is attached to IP-VRF-10 and HOST-3 is connected to BD3. BD3 is mapped to subnet 103.1.1.0/24 and its IRB subinterface is the default-gateway to all hosts in BD3.

Procedure

Step 1. In candidate mode, create the interfaces and bridged subinterfaces that connect LEAF-3 BD3 to HOST-3.

In this example:

- Ethernet-1/2 connects HOST-3 to LEAF-3. Although this interface could be defined untagged, this example configures the interface as tagged (**vlan-tagging true**).
- A subinterface with index 3 is created under the interface and must be configured as **type bridged**. Bridged subinterfaces can be associated with MAC-VRF instances as described in EVPN-VXLAN for layer-2 and multi-homing.
- The subinterface uses **vlan-id optional**, which captures any traffic that is not specified in other subinterfaces of the same interface.

Note: The IRB subinterface expects no vlan tags so that traffic forwarded from HOST-3 can be routed. If HOST-3 sends frames tagged with a vlan-id, the frames would be classified in the BD3 context, but the subinterface does not strip off the vlan tag, and frames are not routed.

Example

```
--{ [FACTORY] + candidate shared default }--[ interface ethernet-1/2 ]--
# info
    admin-state enable
    vlan-tagging true
    subinterface 3 {
        type bridged
        admin-state enable
        vlan {
            encap {
                single-tagged {
                    vlan-id optional
                }
            }
        }
    }
```

Step 2. After creating the access subinterfaces, create the vxlan-interfaces.

This allows MAC-VRFs of the same BD to be connected throughout the IP fabric.

In this example, no other leaf router is attached to BD3, so no vxlan-interface is needed in BD3. The configuration of the vxlan-interface is only shown for completeness. See EVPN-VXLAN for layer-2 and multi-homing for details on vxlan-interfaces and their characteristics.

Example

vxlan1 vxlan-interface 3 configuration

```
--{ [FACTORY] + candidate shared default }--[ tunnel-interface vxlan1 ]--
# info
    vxlan-interface 3 {
        type bridged
        ingress {
            vni 3
        }
    }
```

Step 3. IP-VRF instances in the leaf routers are also connected by VXLAN tunnels, therefore, vxlan-interfaces of type routed must be created.

In this example, tunnel-interface vxlan2 vxlan-interface 10 is configured. While the configuration of the routed vxlan-interface is similar to the bridged vxlan-interface, this type ensures a routed

vxlan-interface only attaches to an ip-vrf, and a bridged vxlan-interface only attaches to a mac-vrf.

Example

VXLAN tunnel configuration

```
--{ [FACTORY] + candidate shared default }--[ tunnel-interface vxlan2 ]--
# info
    vxlan-interface 10 {
        type routed
        ingress {
            vni 10
        }
    }
```

Step 4. Configure the IRB interface and subinterface that links BD3 and IP-VRF-10 together to allow packets from/to subnet 103.1.1.0/24 to route to/from remote subnets in the local or remote leaf routers of the same tenant.

Note that because BD3 is not present in another leaf, the IRB subinterface is not configured as an anycast-gw subinterface. However, an operator may want to configure all IRB subinterfaces as anycast-gw in case the BD is extended later. See Configuring the IP-VRF Domain on LEAF-2 and LEAF-4 for anycast-gw configuration details.

Example

IRB configuration

```
--{ [FACTORY] + candidate shared default }--[ interface irb0 ]--
# info
    subinterface 3 {
        ipv4 {
            admin-state enable
            address 103.1.1.254/24 {
            }
        }
    }
```

Step 5. Configure the network-instance type mac-vrf and associate it with the bridged IRB interfaces and the vxlan-interface.

In the example that follows, BD3 is connected to HOST-3 and to the IRB subinterface that is also attached to IP-VRF-10.

Although the B is not needed, in this example, the bgp-evpn and vxlan configuration is shown for completeness. For details about bgp-vpn, bgp-evpn, and vxlan-interface configuration, see EVPN-VXLAN for layer-2 and multi-homing.

Example

mac-vrf configuration and bridged interface association

```
--{ [FACTORY] + candidate shared default }--[ network-instance BD3 ]--
# info
    type mac-vrf
    interface ethernet-1/2.3 {
    }
    interface irb0.3 {
    }
    vxlan-interface vxlan1.3 {
    }
    protocols {
```

```
        bgp-evpn {
            bgp-instance 1 {
                admin-state enable
                vxlan-interface vxlan1.3
                evi 3
                ecmp 2
            }
        }
        bgp-vpn {
            bgp-instance 1 {
                route-target {
                    export-rt target:64500:3
                    import-rt target:64500:3
                }
            }
        }
    }
```

Step 6. Configure IP-VRF-10 with bgp-evpn enabled using the EVPN IFL model.

In this example, IP-VRF is configured with the irb0.3 interface for connectivity to BD3 and vxlan2.10. This allows the extension of IP-VRF-10 to remote leaf routers. A loopback interface is configured in the IP-VRF to test connectivity among IP-VRFs of the same tenant.

When configured, all local routes learned on IP-VRF-10 route-table are advertised in IP Prefix routes (or IPv6 Prefix routes for local IPv6 routes).

Example

Enable EVPN IFL model on IP-VRF-10

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF* ]--
# info
    network-instance IP-VRF-10 {
        type ip-vrf
        interface irb0.3 {
        }
        interface lo10.2 {
        }
        vxlan-interface vxlan2.10 {
        }
        protocols {
            bgp-evpn {
                bgp-instance 1 {
                    vxlan-interface vxlan2.10
                    evi 10
                    ecmp 2
                }
            }
            bgp-vpn {
                bgp-instance 1 {
                    route-target {
                        export-rt target:64500:10
                        import-rt target:64500:10
                    }
                }
            }
        }
    }
```

The bgp-vpn instance is configured as described in Chapter EVPN-VXLAN for layer-2 and multi-homing (with a network-instance of type ip-vrf). Likewise, the bgp-evpn container enables EVPN in the ip-vrf and associates it to the routed vxlan-interface. The RD and RT can be auto-derived

from the evi just like they can in mac-vrfs. Explicitly configured RD/RTs can override the auto-configured ones. Import and export policies are supported.

Step 7. Review the changes. If correct, commit the changes.

Example

```
# commit stay
--{ candidate shared default }--[  ]--
```

7.2.3 Configuring the IP-VRF Domain on LEAF-2 and LEAF-4

About this task

LEAF-2 and LEAF-4 are configured in the same way as LEAF-3, but with the addition of multi-homing, anycast-gw interfaces, and related configurations.

Use the following procedure to enable EVPN-VXLAN Layer 3 on LEAF-2 and LEAF-4. Considerations for configuring the IRB subinterfaces (Step 4) are provided in IRB subinterface considerations, if needed.

Procedure

Step 1. In candidate mode, create the interfaces, and bridged subinterfaces (including LAG) to connect HOST-2, HOST-4, SERVER-1, and CE-3.

In this example, Ethernet Segment ES-1 is associated with lag1 and is multi-homed to SERVER-1 lag. LACP is enabled on lag1 (but can be disabled) and the admin-key, system-id-mac, and system-priority match on both LEAF-2 and LEAF-4.

Example

Interfaces and bridged subinterfaces configuration (LEAF-2)

```
// interfaces in Leaf-2
--{ [FACTORY] + candidate shared default }--[ interface * ]--
# info
    interface ethernet-1/11 {
        description ES-1
        ethernet {
            aggregate-id lag1
        }
    }
    interface ethernet-1/12 {
        description to-host-2
        admin-state enable
        vlan-tagging true
        subinterface 24 {
            type bridged
            vlan {
                encap {
                    single-tagged {
                        vlan-id optional
                    }
                }
            }
        }
    }
    interface ethernet-1/22 {
        description to-CE-3
        vlan-tagging true
        subinterface 2 {
```

```
            type bridged
            admin-state enable
            vlan {
                encap {
                    single-tagged {
                        vlan-id 2
                    }
                }
            }
        }
    }
    interface lag1 {
        admin-state enable
        vlan-tagging true
        subinterface 24 {
            type bridged
            vlan {
                encap {
                    single-tagged {
                        vlan-id 24
                    }
                }
            }
        }
        lag {
            lag-type lacp
            member-speed 100G
            lacp {
                interval FAST
                lacp-mode ACTIVE
                admin-key 24
                system-id-mac 00:00:00:00:00:24
                system-priority 24
            }
        }
    }
```

Example

Interfaces and bridged subinterfaces configuration (LEAF-4)

```
// Interfaces in Leaf-4
--{ [FACTORY] + candidate shared default }--[ interface * ]--
# info
    interface ethernet-1/4 {
        description ES-1
        ethernet {
            aggregate-id lag1
        }
    }
    interface ethernet-1/13 {
        description to-host-4
        admin-state enable
        vlan-tagging true
        subinterface 4 {
            type bridged
            admin-state enable
            vlan {
                encap {
                    single-tagged {
                        vlan-id optional
                    }
                }
            }
```

```
        }
    }
    interface lag1 {
        admin-state enable
        vlan-tagging true
        subinterface 24 {
            type bridged
            vlan {
                encap {
                    single-tagged {
                        vlan-id 24
                    }
                }
            }
        }
        lag {
            lag-type lacp
            member-speed 100G
            lacp {
                interval FAST
                lacp-mode ACTIVE
                admin-key 24
                system-id-mac 00:00:00:00:00:24
                system-priority 24
            }
        }
    }
```

Step 2. Create the all-active Ethernet Segment ES-1 that is attached to LEAF-2 and LEAF-4.

Details about the ES configuration and operation can be found in EVPN-VXLAN for layer-2 and multi-homing. Note that the following example only shows the Ethernet Segment configuration. The bgp-vpn>bgp-instance 1 must also be configured as described in EVPN-VXLAN for layer-2 and multi-homing.

Example

ES configuration

```
// ES-1 on Leaf-2
--{ [FACTORY] + candidate shared default }--[ system network-instance protocols
 evpn ethernet-segments ]--
# info
    bgp-instance 1 {
        ethernet-segment ES-1 {
            admin-state enable
            esi 01:24:24:24:24:24:24:00:00:01
            interface lag1
            multi-homing-mode all-active
        }
    }
// ES-1 on Leaf-4
--{ [FACTORY] + candidate shared default }--[ system network-instance protocols
 evpn ethernet-segments ]--
A:dut4# info
    bgp-instance 1 {
        ethernet-segment ES-1 {
            admin-state enable
            esi 01:24:24:24:24:24:24:00:00:01
            interface lag1
            multi-homing-mode all-active
        }
    }
```

Step 3. After the access bridged subinterfaces are created, create the vxlan-interfaces to facilitate connectivity between network-instances across the IP fabric.

The mac-vrf network-instances require both vxlan-interfaces of type bridged and ip-vrfs of type routed.

In the following example, all the vxlan-interfaces for all network-instances on LEAF-2 and LEAF-4 nodes are configured as follows:

Example

vxlan-interface configuration

```
// vxlan-interfaces on Leaf-2
--{ [FACTORY] + candidate shared default }--[ tunnel-interface * ]--
# info
    tunnel-interface vxlan1 {
        vxlan-interface 2 {
            type bridged
            ingress {
                vni 2
            }
        }
        vxlan-interface 24 {
            type bridged
            ingress {
                vni 24
            }
        }
    }
    tunnel-interface vxlan2 {
        vxlan-interface 10 {
            type routed
            ingress {
                vni 10
            }
        }
    }
// vxlan-interfaces on Leaf-4
--{ [FACTORY] + candidate shared default }--[ tunnel-interface * ]--
# info
    tunnel-interface vxlan1 {
        vxlan-interface 4 {
            type bridged
            ingress {
                vni 4
            }
        }
        vxlan-interface 24 {
            type bridged
            ingress {
                vni 24
            }
        }
    }
    tunnel-interface vxlan2 {
        vxlan-interface 10 {
            type routed
            ingress {
                vni 10
            }
        }
    }
```

Step 4. Configure the IRB subinterfaces that link the mac-vrf and ip-vrf network-instances for inter-subnet-forwarding.

See IRB subinterface considerations, for details on configuring IRB subinterfaces.

Example

IRB subinterface configuration

```
// IRB interfaces in Leaf-2
--{ [FACTORY] + candidate shared default }--[ interface irb* ]--
# info
    interface irb0 {
        subinterface 2 {
            ipv4 {
                admin-state enable
                address 20.1.1.2/24 {
                }
                arp {
                    learn-unsolicited true
                    ]
                }
            }
            anycast-gw {
            }
        }
        subinterface 24 {
            ipv4 {
                admin-state enable
                address 101.1.1.2/24 {
                }
                address 101.1.1.254/24 {
                    anycast-gw true
                    primary
                }
                address 102.1.1.254/24 {
                }
                arp {
                    learn-unsolicited true
                    debug [
                        messages
                    ]
                    host-route {
                        populate dynamic {
                        }
                    }
                    evpn {
                        advertise dynamic {
                        }
                    }
                }
            }
            anycast-gw {
            }
        }
    }
// IRB interfaces in Leaf-4
--{ [FACTORY] + candidate shared default }--[ interface irb* ]--
# info
    interface irb0 {
        subinterface 4 {
            ipv4 {
                admin-state enable
                address 104.1.1.4/24 {
                }
```

```
                address 104.1.1.254/24 {
                    anycast-gw true
                    primary
                }
                arp {
                    learn-unsolicited true
                    debug [
                        messages
                    ]
                }
            }
            anycast-gw {
            }
        }
        subinterface 24 {
            ipv4 {
                admin-state enable
                address 101.1.1.4/24 {
                }
                address 101.1.1.254/24 {
                    anycast-gw true
                    primary
                }
                arp {
                    learn-unsolicited true
                    debug [
                        messages
                    ]
                    host-route {
                        populate dynamic {
                        }
                    }
                    evpn {
                        advertise dynamic {
                        }
                    }
                }
            }
            anycast-gw {
            }
        }
```

Step 5. Configure the network-instances of type mac-vrf and associate the bridged subinterfaces, irb subinterfaces, and vxlan-interfaces. Then enable bgp-evpn.

Example

network instance configuration and association

```
// MAC-VRFs in Leaf-2
--{ [FACTORY] + candidate shared default }--[ network-instance BD* ]--
# info
    network-instance BD2 {
        type mac-vrf
        interface ethernet-1/22.2 {
        }
        interface irb0.2 {
        }
        vxlan-interface vxlan1.2 {
        }
        protocols {
            bgp-evpn {
                bgp-instance 1 {
                    admin-state enable
```

```
                    vxlan-interface vxlan1.2
                    evi 2
                    ecmp 2
                }
            }
            bgp-vpn {
                bgp-instance 1 {
                    route-target {
                        export-rt target:64500:2
                        import-rt target:64500:2
                    }
                }
            }
        }
    }
    network-instance BD24 {
        type mac-vrf
        interface ethernet-1/12.24 {
        }
        interface irb0.24 {
        }
        interface lag1.24 {
        }
        vxlan-interface vxlan1.24 {
        }
        protocols {
            bgp-evpn {
                bgp-instance 1 {
                    admin-state enable
                    vxlan-interface vxlan1.24
                    evi 24
                    ecmp 2
                }
            }
            bgp-vpn {
                bgp-instance 1 {
                    route-target {
                        export-rt target:64500:24
                        import-rt target:64500:24
                    }
                }
            }
        }
    }
// MAC-VRFs in Leaf-4
--{ [FACTORY] + candidate shared default }--[ network-instance BD* ]--
# info
    network-instance BD24 {
        type mac-vrf
        interface irb0.24 {
        }
        interface lag1.24 {
        }
        vxlan-interface vxlan1.24 {
        }
        protocols {
            bgp-evpn {
                bgp-instance 1 {
                    admin-state enable
                    vxlan-interface vxlan1.24
                    evi 24
                    ecmp 2
                }
            }
```

```
            bgp-vpn {
                bgp-instance 1 {
                    route-target {
                        export-rt target:64500:24
                        import-rt target:64500:24
                    }
                }
            }
        }
    }
    network-instance BD4 {
        type mac-vrf
        interface ethernet-1/13.4 {
        }
        interface irb0.4 {
        }
        vxlan-interface vxlan1.4 {
        }
        protocols {
            bgp-evpn {
                bgp-instance 1 {
                    admin-state enable
                    vxlan-interface vxlan1.4
                    evi 4
                    ecmp 2
                }
            }
            bgp-vpn {
                bgp-instance 1 {
                    route-target {
                        export-rt target:64500:4
                        import-rt target:64500:4
                    }
                }
            }
        }
    }
```

Step 6. Configure IP-VRF-10 with bgp-evpn enabled with the EVPN IFL model.

The IP-VRF is configured with the IRB subinterfaces previously created for BD2, BD4, and BD24. The IP-VRF instances are connected VXLAN tunnels, so routed vxlan-interfaces need to be associated with IP-VRF-10. A loopback interface is configured in the IP-VRF to test connectivity among IP-VRFs of the same tenant.

In the following example, LEAF-2's IP-VRF is configured with a BGP PE-CE neighbor to CE-3.

Example

IP-VRF-10 configuration

```
// IP-VRF-10 in Leaf-2
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF* ]--
# info
    network-instance IP-VRF-10 {
        type ip-vrf
        interface irb0.2 {
        }
        interface irb0.24 {
        }
        interface lo10.2 {
        }
        vxlan-interface vxlan2.10 {
        }
```

```
        protocols {
            bgp-evpn {
                bgp-instance 1 {
                    vxlan-interface vxlan2.10
                    evi 10
                    ecmp 2
                }
            }
            bgp {
                admin-state enable
                afi-safi ipv4-unicast {
                    admin-state enable
                }
                autonomous-system 645002
                router-id 2.2.2.2
                group eBGP-PE-CE {
                    admin-state enable
                    export-policy export-all
                    import-policy import-all
                    afi-safi ipv4-unicast {
                        admin-state enable
                    }
                }
                neighbor 20.1.1.3 {
                    peer-as 645003
                    peer-group eBGP-PE-CE
                    local-as as-number 645002 {
                    }
                    transport {
                        local-address 20.1.1.2
                    }
                }
            }
            bgp-vpn {
                bgp-instance 1 {
                    route-target {
                        export-rt target:64500:10
                        import-rt target:64500:10
                    }
                }
            }
        }
    }
// IP-VRF-10 in Leaf-4
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF* ]--
# info
    network-instance IP-VRF-10 {
        type ip-vrf
        interface irb0.4 {
        }
        interface irb0.24 {
        }
        interface lo10.2 {
        }
        vxlan-interface vxlan2.10 {
        }
        protocols {
            bgp-evpn {
                bgp-instance 1 {
                    vxlan-interface vxlan2.10
                    evi 10
                    ecmp 2
                }
            }
```

```
            bgp-vpn {
                bgp-instance 1 {
                    route-target {
                        export-rt target:64500:10
                        import-rt target:64500:10
                    }
                }
            }
        }
    }
```

Step 7. Review the changes, and if correct, commit the changes.

Example

```
A:dut2# commit stay
--{ candidate shared default }--[  ]--
```

7.2.3.1 IRB subinterface considerations

The following are considerations for configuring IRB subinterfaces (performed in Step 4).

IRB subinterfaces on BDs that are distributed to multiple leaf nodes must be configured with at least one anycast-gw IP address and an anycast-gw MAC address. When the anycast-gw container is configured, the anycast-gw MAC address is auto-derived as 00:00:5E:00:01:01 in all the leaf nodes. The MAC address can also be explicitly configured if needed. In addition:

- The same anycast-gw IP and MAC address must be configured on all IRBs of the same BD.
- All the hosts attached to the same BD use the same default-gateway (that is, the anycast-gw IP) irrespective of the leaf they are connected to. For example, irb0 subinterfaces 24 are configured with the same anycast-gw IP on LEAF-2 and LEAF-4 (101.1.1.254) in the configuration example.
- Default gateway redundancy in DCs is realized using anycast-gws, and not VRRP. Anycast-gws avoid upstream tromboning for hosts that are multi-homed to multiple leaf nodes or for single-homed hosts that move to other leaf nodes of the same BD.

IRB subinterfaces on BDs that are distributed may also be configured with non-anycast-gw IP addresses. This is only done when separate IPs are needed to check connectivity per leaf. For example, when LEAF-2 is configured with non-anycast-gw IPs 101.1.1.2 and 102.1.1.254, and LEAF-4 is configured with 104.1.1.4. and anycast-gw IPs exist in multiple nodes, the anycast-gw IPs should not be used in ICMP tools to check the availability of a leaf. Non-anycast-gw IPs should be used instead.

IRB subinterfaces on distributed BDs should be configured with the following commands, as shown for subinterface 24 in LEAF-2 and LEAF-4 in the configuration example:

- **arp learn-unsolicited true** - Triggers the learning of ARP entries out of any ARP packet arriving at the IRB subinterface, regardless of whether there was an ARP-Request issued from the IRB.
- **arp host-route populate dynamic** - Creates host routes (arp-nd) in the IP-VRF route-table from learned dynamic ARP entries in the IRB. The arp-nd host routes are then advertised to the remote leaf nodes. This assists the routing of downstream traffic to a specified host without hair-pinning traffic via another leaf connected to the same BD of the host, but not connected to the host directly.
- **arp evpn advertise dynamic** - Advertises EVPN MAC/IP routes that include the MAC and the IP of the dynamic ARP entries. The advertisement of these routes synchronizes the ARP caches in all the IRB subinterfaces of the same BD.

IRB subinterfaces on BDs that are *not* distributed (that is, BDs attached to only one Leaf node) do *not* need to be configured with the following:

- **arp host-route-populate dynamic** as downstream routing is always direct to the connected leaf
- **arp evpn advertise dynamic** as ARP entries do not need to be synchronized with any other node

Examples of non-distributed BDs are BD2, BD4, and BD3 as shown in Figure 11: Example of EVPN-VXLAN IP-VRF domain. Their corresponding IRB subinterfaces do not create host-routes or advertise EVPN MAC/IP routes for the ARP entries.

7.2.4 Configuring EVPN IFL interoperability to EVPN IFF unnumbered model

About this task

While EVPN IFL for VXLAN is supported by most DC vendors, Nuage WBX or VSC/VRS use the EVPN IFF Unnumbered model. By default, the SR Linux EVPN IFL (interface-less) model does not inter-operate with the EVPN IFF (interface-full) model. However, it is possible to configure the SR Linux EVPN IFL model to inter-operate with the EVPN IFF model.

For more information about EVPN IFL vs EVPN IFF models, see the *SR Linux VPN Services Guide* and *draft-ietf-bess-evpn-prefix-advertisement*.

Procedure

To configure inter-operability in IP-VRF-10, configure the **advertise-gateway-mac** command as shown in the following example.

Example: EVPN IFF inter-operability in IP-VRF-10 configuration

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# protocols bgp-evpn bgp-instance 1 routes route-table mac-ip advertise-gateway-mac
 <value> ?
usage: advertise-gateway-mac <true|false>

If set to true in an ip-vrf where bgp-evpn is enabled, a MAC/IP route
containing the gateway-MAC is advertised.

This gateway-MAC matches the MAC advertised along with the EVPN IFL routes
type 5 for the ip-vrf network-instance. This advertisement is needed so that
the EVPN IFL (Interface-Less) model in the ip-vrf can interoperate with a remote
system working in EVPN IFF (Interface-ful) Unnumbered mode.

Positional arguments:
  value             [true|false, default false]
```

When set to true, the node advertises a MAC/IP route using all of the following:

- Gateway-mac for IP-VRF-10 (that is, the system-mac)
- RD/RT, next-hop, and VNI of IP-VRF-10
- Null IP address, ESI or Ethernet Tag ID

Example: MAC/IP route advertisement

In the following example, the MAC/IP route advertised is from LEAF-3. The MAC address matches the system-mac advertised in any local RT5s.

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
```

```
# protocols bgp-evpn bgp-instance 1 routes route-table mac-ip advertise-gateway-mac true


--{ [FACTORY] +* candidate shared default }--[ network-instance IP-VRF-10 ]--
# commit stay
All changes have been committed. Starting new transaction.
2021-04-15T01:18:24.688185-07:00 dut3 local6|DEBU sr_bgp_mgr: bgp|4942|5135|1393922|D:
 VR default (1) Peer 1: 1.1.1.1 UPDATE: Peer 1: 1.1.1.1 - Send BGP UPDATE:
    Withdrawn Length = 0
    Total Path Attr Length = 81
    Flag: 0x90 Type: 14 Len: 44 Multiprotocol Reachable NLRI:
        Address Family EVPNandidate shared default
           root (8)  Thu 01:18AM
        NextHop len 4 NextHop 3.3.3.3
        Type: EVPN-MAC Len: 33 RD: 3.3.3.3:10 ESI: ESI-0, tag: 0, mac len: 48 mac:
              00:01:03:ff:00:00, IP len: 0, IP: NULL, label1: 10
    Flag: 0x40 Type: 1 Len: 1 Origin: 0
    Flag: 0x40 Type: 2 Len: 0 AS Path:
    Flag: 0x40 Type: 5 Len: 4 Local Preference: 100
    Flag: 0xc0 Type: 16 Len: 16 Extended Community:
        target:64500:10
        bgp-tunnel-encap:VXLAN
```

For IPv6, Nuage WBX devices support two EVPN L3 IPv6 modes: IFF unnumbered and IFF numbered. The SR Linux interoperability mode enabled by the advertise-gateway-mac command only works with devices that use EVPN IFF unnumbered. This is because EVPN IFL and EVPN IFF unnumbered models both use the same format in the IP prefix route, and differ only in the additional MAC/IP route for the gateway-mac. EVPN IFL and EVPN IFF numbered models have different IP prefix route formats, and cannot inter-operate.

7.2.5 Checking the EVPN IFL model in IP-VRFs

When configured, the state of the IP-VRF-10 on the three leaf nodes and basic connectivity should be checked.

When the leaf nodes attached to IP-VRF-10 exchange at least one EVPN IP-Prefix route on all leaf nodes of the tenant, the bgp_mgr requests the fib_mgr to create a VXLAN tunnel to each next-hop of the received EVPN routes type 5 (RT5s). This assumes the tunnel had not already been created.

When a VXLAN tunnel to the remote VTEP exists, the bgp_mgr requests the next-hop resolution to the fib_mgr, and if it resolves, the RT5 is installed in the IP-VRF route-table. Using LEAF-3 as a reference, you can check that RT5s are received from the two remote leaf nodes, and then verify that VXLAN tunnels exist to their VTEPs and the RT5s are installed in the route-table. Loopbacks are configured on each IP-VRF-10 instance to verify reachability.

7.2.5.1 Checking IP-VRF-10 state and connectivity

Procedure

Use the **show network-instance protocols bgp routes evpn route-type prefix** command to check RT5s for the loopbacks 22.22.22.22 and 44.44.44.44 advertised by the remote leaf nodes. You can check that the routes contain the expected IP-VRF-10 VNI, route-target, and the mac-nh which is used as the inner destination MAC when sending VXLAN packets to the prefix.

Example: Check IP-VRF-10 state and connectivity

```
--{ [FACTORY] + candidate shared default }--[  ]--
# show network-instance default protocols bgp routes evpn route-type 5 prefix 22.22.22.22/32 detail
-------------------------------------------------------------------------------------------------
Show report for the EVPN routes in network-instance  "default"
-------------------------------------------------------------------------------------------------
Route Distinguisher: 2.2.2.2:10
Tag-ID             : 0
ip-prefix-len      : 32
ip-prefix          : 22.22.22.22/32
neighbor           : 2.2.2.2
Gateway IP         : 0.0.0.0
Received paths     : 1
  Path 1: <Best,Valid,Used,>
    ESI             : 00:00:00:00:00:00:00:00:00:00
    VNI             : 10
    Route source    : neighbor 2.2.2.2 (last modified 46m16s ago)
    Route preference: No MED, LocalPref is 100
    Atomic Aggr     : false
    BGP next-hop    : 2.2.2.2
    AS Path         :  i
    Communities     : [target:64500:10, mac-nh:00:01:02:ff:00:00, bgp-tunnel-encap:VXLAN]
    RR Attributes   : No Originator-ID, Cluster-List is []
    Aggregation     : None
    Unknown Attr    : None
    Invalid Reason  : None
    Tie Break Reason: none
-------------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
# show network-instance default protocols bgp routes evpn route-type 5 prefix 44.44.44.44/32 summary
-------------------------------------------------------------------------------------------------
Show report for the BGP route table of network-instance "default"
-------------------------------------------------------------------------------------------------
Status codes: u=used, *=valid, >=best, x=stale
Origin codes: i=IGP, e=EGP, ?=incomplete
-------------------------------------------------------------------------------------------------
BGP Router ID: 3.3.3.3      AS: 3333      Local AS: 3333
-------------------------------------------------------------------------------------------------
Type 5 IP Prefix Routes
+--------+---------------+-----+----------------+----------+----------+-----+---------+
| Status |   Route-      | Tag | IP-address     | neighbor | Next-Hop | VNI | Gateway |
|        | distinguisher | -ID |                |          |          |     |         |
+========+===============+=====+================+==========+==========+=====+=========+
| u*>    | 4.4.4.4:10    | 0   | 44.44.44.44/32 | 4.4.4.4  | 4.4.4.4  | 10  | 0.0.0.0 |
+--------+---------------+-----+----------------+----------+----------+-----+---------+
-------------------------------------------------------------------------------------------
1 IP Prefix routes 1 used, 1 valid
-------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

7.2.5.2 Checking for VXLAN tunnel creation

Procedure

When the routes are correct, the VXLAN tunnels are created. Use the **show network-instance tunnel-table all** command to verify that the VXLAN tunnels are created.

Example: Check for VXLAN tunnel creation

```
--{ [FACTORY] + candidate shared default }--[  ]--
# show network-instance default tunnel-table all
-----------------------------------------------------------------------------------------------
Show report for network instance "default" tunnel table
-----------------------------------------------------------------------------------------------
+-------------+-----------+-------+-------+--------+------------+---------+-------------------------+
| IPv4 Prefix |   Owner   | Type  | Index | Metric | Preference |Fib-prog |       Last Update       |
+=============+===========+=======+=======+========+============+=========+=========================+
| 2.2.2.2/32  | vxlan_mgr | vxlan | 7     | 0      | 0          | Y       | 2021-04-13T10:43:09.483Z |
| 4.4.4.4/32  | vxlan_mgr | vxlan | 6     | 0      | 0          | Y       | 2021-04-13T10:43:09.144Z |
+-------------+-----------+-------+-------+--------+------------+---------+-------------------------+
-----------------------------------------------------------------------------------------------
2 VXLAN tunnels, 2 active, 0 inactive
-----------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------
Show report for network instance "default" tunnel table
-----------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

7.2.5.3 Checking for remote VTEPS and associated destinations

Procedure

Use the **show tunnel vxlan-tunnel vtep** command to show the remote VTEPs and the associated destinations. A destination is the combination of the VTEP and VNI that is created when the EVPN routes are received and the VXLAN tunnel is created. IP destinations are created from RT5s.

Example: Check for remote VTEPs and associated destinations

```
# show tunnel vxlan-tunnel vtep 2.2.2.2
-------------------------------------------------------------------------
Show report for vxlan-tunnels vtep
-------------------------------------------------------------------------
VTEP Address: 2.2.2.2
Index       : 202418627561
Last Change : 2021-04-13T11:47:09.000Z
-------------------------------------------------------------------------
Destinations
-------------------------------------------------------------------------
+------------------+-----------------+------------+-----------------------+
| Tunnel Interface | VXLAN Interface | Egress VNI |         Type          |
+==================+=================+============+=======================+
| vxlan1           | 1               | 1          | multicast-destination |
| vxlan2           | 10              | 10         | ip-destination        |
+------------------+-----------------+------------+-----------------------+
-------------------------------------------------------------------------
1 bridged destinations, 1 multicast, 0 unicast, 0 es
1 routed destinations
-------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
# show tunnel vxlan-tunnel vtep 4.4.4.4
-------------------------------------------------------------------------
Show report for vxlan-tunnels vtep
-------------------------------------------------------------------------
VTEP Address: 4.4.4.4
Index       : 202418627553
Last Change : 2021-04-14T15:40:23.000Z
```

```
-------------------------------------------------------------------------
Destinations
-------------------------------------------------------------------------
+------------------+-----------------+------------+----------------------+
| Tunnel Interface | VXLAN Interface | Egress VNI |         Type         |
+==================+=================+============+======================+
| vxlan1           | 1               | 1          | multicast-destination |
| vxlan1           | 1               | 1          | unicast-destination   |
| vxlan2           | 10              | 10         | ip-destination        |
+------------------+-----------------+------------+----------------------+
-------------------------------------------------------------------------
2 bridged destinations, 1 multicast, 1 unicast, 0 es
1 routed destinations
-------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

7.2.5.4 Checking IP-VRF-10 route table

Procedure

Use the **show route-table ipv4-unicast summary** command to check the IP-VRF-10 route table to ensure all the remote subnets and hosts are received and installed. All interface and local routes are automatically advertised in RT5s. Because ECMP=2 is configured in the IP-VRF-10, there are two ECMP paths for the 101.1.1.0/24 subnet, which is attached to both LEAF-2 and LEAF-4.

Example: Check IP-VRF-10 route table

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# show route-table ipv4-unicast summary
-------------------------------------------------------------------------------------------------
IPv4 Unicast route table of network instance IP-VRF-10
-------------------------------------------------------------------------------------------------
+-----------------+-----+--------+------------+--------+------+--------------------+-----------+
|     Prefix      | ID  | Active | Route Type | Metric | Pref |  Next-hop (Type)   | Next-hop  |
|                 |     |        |            |        |      |                    | Interface |
+=================+=====+========+============+========+======+====================+===========+
| 31.31.31.31/32  | 0   | true   | bgp-evpn   | 0      | 170  | 2.2.2.2 (indirect) | None      |
| 20.1.1.0/24     | 0   | true   | bgp-evpn   | 0      | 170  | 2.2.2.2 (indirect) | None      |
| 20.1.1.3/32     | 0   | true   | bgp-evpn   | 0      | 170  | 2.2.2.2 (indirect) | None      |
| 22.22.22.22/32  | 0   | true   | bgp-evpn   | 0      | 170  | 2.2.2.2 (indirect) | None      |
| 33.33.33.33/32  | 0   | true   | host       | 0      | 0    | None (extract)     | None      |
| 44.44.44.44/32  | 0   | true   | bgp-evpn   | 0      | 170  | 4.4.4.4 (indirect) | None      |
| 101.1.1.0/24    | 0   | true   | bgp-evpn   | 0      | 170  | 2.2.2.2 (indirect) | None      |
|                 |     |        |            |        |      | 4.4.4.4 (indirect) | None      |
| 101.1.1.1/32    | 0   | true   | bgp-evpn   | 0      | 170  | 2.2.2.2 (indirect) | None      |
| 102.1.1.0/24    | 0   | true   | bgp-evpn   | 0      | 170  | 2.2.2.2 (indirect) | None      |
| 103.1.1.0/24    | 0   | true   | local      | 0      | 0    | 103.1.1.3 (direct) | irb0.3    |
| 103.1.1.1/32    | 0   | true   | arp-nd     | 0      | 1    | 103.1.1.1 (direct) | irb0.3    |
| 103.1.1.3/32    | 0   | true   | host       | 0      | 0    | None (extract)     | None      |
| 103.1.1.254/32  | 0   | true   | host       | 0      | 0    | None (extract)     | None      |
| 103.1.1.255/32  | 0   | true   | host       | 0      | 0    | None (broadcast)   | None      |
| 104.1.1.0/24    | 0   | true   | bgp-evpn   | 0      | 170  | 4.4.4.4 (indirect) | None      |
+-----------------+-----+--------+------------+--------+------+--------------------+-----------+
-------------------------------------------------------------------------------------------------
15 IPv4 routes total
15 IPv4 prefixes with active routes
1 IPv4 prefixes with active ECMP routes
-------------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
```

7.2.5.5 Checking route-table state for a RT5

Procedure

Use the **info from state route-table** command to check the route-table state for a RT5. This can be useful to understand how the RT5 is resolved to a vxlan tunnel and what vxlan VNI, inner source, and destination MACs are be used when sending VXLAN packets to that route. The following uses ECMP route 101.1.1.0/24 on LEAF-3. The route's next-hop group has two separate next-hops pointing at the remote LEAF-2 and LEAF-4 VTEPs:

Example: Check route-table state for a RT5

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# info from state route-table ipv4-unicast route 101.1.1.0/24 id 0
    route-table {
        ipv4-unicast {
            route 101.1.1.0/24 id 0 {
                route-type bgp-evpn
                route-owner bgp_evpn_mgr
                metric 0
                preference 170
                active true
                last-app-update "a day ago"
                next-hop-group 202418627581
                resilient-hash false
                fib-programming {
                    status success
                }
            }
        }
    }
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# info from state route-table next-hop-group 202418627581 next-hop *
    route-table {
        next-hop-group 202418627581 {
            next-hop 0 {
                next-hop 202418627569
                resolved true
            }
            next-hop 1 {
                next-hop 202418627565
                resolved true
            }
        }
    }
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# info from state route-table next-hop 202418627569
    route-table {
        next-hop 202418627569 {
            type indirect
            ip-address 2.2.2.2
            resolving-tunnel {
                ip-prefix 2.2.2.2/32
                tunnel-type vxlan
                tunnel-owner vxlan_mgr
            }
            vxlan {
                vni 10
                source-mac 00:01:03:FF:00:00
                destination-mac 00:01:02:FF:00:00
            }
```

```
        }
    }
```

7.2.5.6 Monitoring pings

Procedure

Use the **tools system traffic-monitor** command to monitor pings between the local LEAF-3 loopback and LEAF-2's loopback (22.22.22.22), the inner source, and destination MACs that are associated to the RT5's next-hop that are used in the actual packets. Note that the source-mac is the chassis MAC advertised in the mac-nh of the local RT5s:

Example: Monitor pings

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
// a ping is sent from Leaf-3 to 22.22.22.22 (the loopback on Leaf-2’s IP-VRF-10)
# network-instance IP-VRF-10

--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# ping 22.22.22.22
Using network instance IP-VRF-10
PING 22.22.22.22 (22.22.22.22) 56(84) bytes of data.
64 bytes from 22.22.22.22: icmp_seq=1 ttl=64 time=4.88 ms
64 bytes from 22.22.22.22: icmp_seq=2 ttl=64 time=4.76 ms
^C
--- 22.22.22.22 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1000ms
rtt min/avg/max/mdev = 4.767/4.827/4.888/0.092 ms
// the monitor command catches the inner packet sent on VXLAN
--{ [FACTORY] +! candidate shared default }--[ network-instance IP-VRF-10 ]--
# /tools system traffic-monitor destination-address 33.33.33.33 protocol icmp
Running as user "root" and group "root". This could be dangerous.
Capturing on 'monit'
1       0.000000000     ethernet-1/1    00:01:02:ff:00:00       00:01:03:ff:00:00
         22.22.22.22     33.33.33.33    ICMP    146     Echo (ping) reply    id=0x580c,
         seq=1/256, ttl=64

// the source MAC is the local chassis mac:

--{ [FACTORY] + candidate shared default }--[  ]--
# info from state platform chassis mac-address
    platform {
        chassis {
            mac-address 00:01:03:FF:00:00
        }
    }

// that source MAC is also advertised in the RT5’s mac-nh

--{ [FACTORY] + candidate shared default }--[  ]--
# info from state network-instance default bgp-rib evpn rib-in-out rib-out-post ip-prefix-routes
 3.3.3.3:10 ethernet-tag-id 0 ip-prefix-length 32 ip-prefix 33.33.33.33/32 neighbor 2.2.2.2
    network-instance default {
        bgp-rib {
            evpn {
                rib-in-out {
                    rib-out-post {
                        ip-prefix-routes 3.3.3.3:10 ethernet-tag-id 0 ip-prefix-length 32
                        ip-prefix 33.33.33.33/32 neighbor 2.2.2.2 {
                            esi 00:00:00:00:00:00:00:00:00:00
```

```
                            gateway-ip 0.0.0.0
                            vni 10
                            attr-id 132
                            next-hop 3.3.3.3
                        }
                    }
                }
            }
        }
    }
--{ [FACTORY] + candidate shared default }--[  ]--
# info from state network-instance default bgp-rib attr-sets attr-set rib-out index 132
    network-instance default {
        bgp-rib {
            attr-sets {
                attr-set rib-out index 132 {
                    origin igp
                    atomic-aggregate false
                    next-hop 3.3.3.3
                    med 0
                    local-pref 100
                    aggregator {
                    }
                    pmsi-tunnel {
                    }
                    communities {
                        ext-community [
                            target:64500:10
                            mac-nh:00:01:03:ff:00:00
                            bgp-tunnel-encap:VXLAN
                        ]
                    }
                    unknown-attributes {
                    }
                }
            }
        }
    }
```

The received EVPN IFL IP Prefix routes are only installed in the IP-VRF-10 route-table if:

- the import route-target matches the RT5 route-target
- the RT5's VNI matches the VNI of the vxlan-interface in the IP-VRF-10
- the RT5's gateway-ip is zero

Additional guidelines:

- Importing an RT5 into multiple ip-vrf network-instances is not supported due to the VNI restriction: an ip-vrf can only use a single VNI for ingress and egress VXLAN packets. This is a TD3 limitation.
- The route next-hop cannot be changed in ip-vrf network-instances. It is always the system-ip in this release.
- The ip-vrf bgp-evpn bgp instance can be oper-down for the same reasons as the bgp-evpn bgp instance can be down in mac-vrfs. See EVPN-VXLAN for layer-2 and multi-homing for details.
- VXLAN statistics are also accounted for when EVPN-IFL is used.
- No MTU checks are done for VXLAN in EVPN-IFL. If the routed packet plus the VXLAN overhead exceeds the underlay interface MTU of the egress interface in the default network-instance, the packet is still encapsulated and sent to the remote leaf. No statistics increment or drops occur.

- Outer TTL for VXLAN packets is always initialized to 255 and not copied or propagated from or to the inner IP packet.

7.2.6 Checking PE-CE routing on an IP-VRF with EVPN-IFL

In an EVPN-VXLAN Layer 3 network, PE-CE routing refers to the unicast routing between a CE connected to a BD in a leaf node and the IRB subinterface of the IP-VRF connected to the same BD. Static or BGP routing is supported in SR Linux. BFD can also be used between the IRB and the CE.

7.2.6.1 Checking PC-CE routing on IP-VRF

Procedure

Figure 11: Example of EVPN-VXLAN IP-VRF domain depicts a PE-CE BGP session between CE-3 and IP-VRF-10 in LEAF-2. Use the following configuration in IP-VRF-10 to enable a PE-CE BGP session to CE-3.

Example: Check PE-CE routing on IP-VRF

```
// IP-VRF-10 in Leaf-2
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF* ]--
# info
    network-instance IP-VRF-10 {
        type ip-vrf
        interface irb0.2 {
        }
        interface irb0.24 {
        }
        interface lo10.2 {
        }
        vxlan-interface vxlan2.10 {
        }
        protocols {
            bgp-evpn {
                bgp-instance 1 {
                    vxlan-interface vxlan2.10
                    evi 10
                    ecmp 2
                }
            }
            bgp {
                admin-state enable
                afi-safi ipv4-unicast {
                    admin-state enable
                }
                autonomous-system 645002
                router-id 2.2.2.2
                group eBGP-PE-CE {
                    admin-state enable
                    export-policy export-all
                    import-policy import-all
                    afi-safi ipv4-unicast {
                        admin-state enable
                    }
                }
                neighbor 20.1.1.3 {
                    peer-as 645003
                    peer-group eBGP-PE-CE
                    local-as as-number 645002 {
```

```
                    }
                    transport {
                        local-address 20.1.1.2
                    }
                }
            }
            bgp-vpn {
                bgp-instance 1 {
                    route-target {
                        export-rt target:64500:10
                        import-rt target:64500:10
                    }
                }
            }
        }
    }
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# show protocols bgp neighbor 20.1.1.3
-------------------------------------------------------------------------------------------------
BGP neighbor summary for network-instance "IP-VRF-10"
Flags: S static, D dynamic, L discovered by LLDP, B BFD enabled, - disabled, * slow
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
+-----------+----------+------------+--------+---------+------------+---------+---------+------------+
|  Net-Inst |    Peer  |   Group    |  Flags | Peer-AS |   State    |  Uptime | AFI/    | [Rx/Active |
|           |          |            |        |         |            |         | SAFI    |    /Tx]    |
+===========+==========+============+========+=========+============+=========+=========+============+
| IP-VRF-10 | 20.1.1.3 | eBGP-PE-CE | S      | 645003  | established| 1d:21h: | ipv4-   | [2/1/11]   |
|           |          |            |        |         |            | 46m:56s | unicast |            |
+-----------+----------+------------+--------+---------+------------+---------+---------+------------+
-------------------------------------------------------------------------------------------------
1 configured neighbors, 1 configured sessions are established,0 disabled peers
0 dynamic peers
```

7.2.6.2 PE-CE EBGP session: import and export policies

By default, all local routes to the IP-VRF route-table are automatically advertised in EVPN-IFL routes. This includes static routes, local routes, IGP routes, arp-nd host routes, and so on. Consider the following for routes coming from or going to a PE-CE EBGP session.

- EVPN-IFL to PE-CE EBGP: An export policy must be configured so that EVPN IFL routes can be re-advertised to a CE on the PE-CE BGP session.
- PE-CE EBGP to EVPN-IFL: Either an import policy to accept the routes or **ebgp-default-policy import-reject-all false** must be configured so that the BGP routes are re-advertised to EVPN-IFL.

For example, the following two policies are configured to import and export all routes:

Example: PE-CE EBGP session: import and export policies

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# /info routing-policy policy import-all
    routing-policy {
        policy import-all {
            statement 1 {
                action {
                    accept {
                    }
                }
            }
        }
```

```
    }
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# /info routing-policy policy export-all
    routing-policy {
        policy export-all {
            statement 1 {
                action {
                    accept {
                    }
                }
            }
        }
    }
```

7.2.6.3 Additional PE-CE considerations

BGP PE-CE sessions can only be established with primary IP addresses. Therefore, in an IRB with both an anycast-gw-ip and a non-anycast-gw-ip, the BGP session can be setup against the non-anycast-gw-ip only if it is configured as primary.

A BGP session is not established if the configured BGP local-address for that session is a non-primary address. Adding a secondary address on an interface where the primary address has established a BGP session is supported.

Example: BGP PE-CE sessions and primary IP addresses

In the following, the local IP address is primary, but not an anycast-gw IP:

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# /info from state interface irb0 subinterface 2
    interface irb0 {
        subinterface 2 {
            admin-state enable
            ip-mtu 1500
            name irb0.2
            ifindex 1082130435
            oper-state up
            last-change "a day ago"
            ipv4 {
                allow-directed-broadcast false
                address 20.1.1.2/24 {
                    anycast-gw false
                    origin static
                    primary
                    status preferred
                }
                arp {
                    duplicate-address-detection true
                    timeout 14400
                    learn-unsolicited true
                    debug [
                        messages
                    ]
                    neighbor 20.1.1.3 {
                        link-layer-address 00:01:03:FF:00:0B
                        origin dynamic
                        expiration-time "an hour from now"
                    }
                    host-route {
                        populate dynamic {
                        }
```

```
                }
                evpn {
                }
            }
        }
        anycast-gw {
            virtual-router-id 1
            anycast-gw-mac 00:00:5E:00:01:01
            anycast-gw-mac-origin vrid-auto-derived
        }
```

7.2.6.3.1 Changing the route preference

Procedure

In SR Linux, the route selection across BGP families (EVPN-IFL vs PE-CE IPv4/v6) occurs based on the route-table preference. For example, if the same prefix 31.31.31.31/32 is received on the IP-VRF-10's route-table via BGP PE-CE (ipv4 family) and via EVPN-IFL, the route with the lowest route-table preference wins. By default, the preference for both EVPN-IFL and BGP PE-CE is set to 170. Therefore, for the PE-CE route to be selected, use the **protocols bgp preference ebgp** command to change the preference for the PE-CE routes to a value lower than 170 as shown in the following example.

Example: Changing the route preference

```
--{ [FACTORY] +* candidate shared default }--[ network-instance IP-VRF-10 ]--
# diff
    protocols {
        bgp {
            preference {
+               ebgp 160
            }
        }
    }
--{ [FACTORY] +* candidate shared default }--[ network-instance IP-VRF-10 ]--
# commit stay
All changes have been committed. Starting new transaction.
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# show route-table ipv4-unicast prefix 31.31.31.31/32 detail
-------------------------------------------------------------------------------
IPv4 Unicast route table of network instance IP-VRF-10
-------------------------------------------------------------------------------
Destination   : 31.31.31.31/32
ID            : 0
Route Type    : bgp
Metric        : 0
Preference    : 160
Active        : true
Last change   : 2021-04-15T09:05:53.745Z
Resilient hash: false
-------------------------------------------------------------------------------
Next hops: 1 entries
20.1.1.3 (indirect) resolved by 20.1.1.3/32 (arp-nd)
  via 20.1.1.3 (direct) via [irb0.2]
-------------------------------------------------------------------------------
Destination   : 31.31.31.31/32
ID            : 1
Route Type    : bgp-evpn
Metric        : 0
Preference    : 170
Active        : false
```

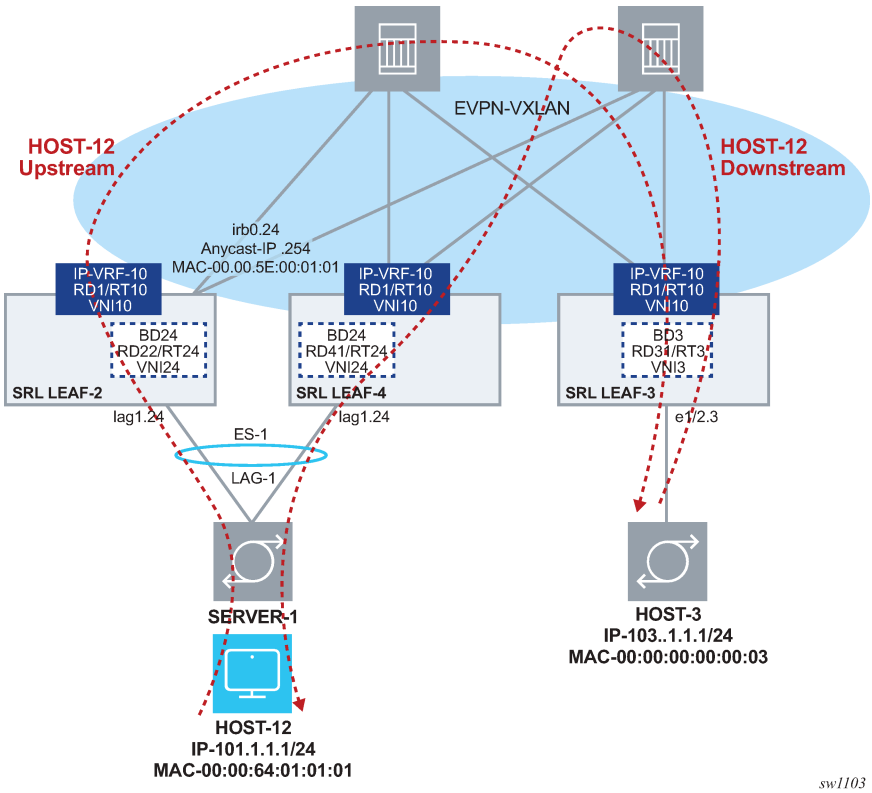
```
Last change   : 2021-04-15T08:58:50.600Z
Resilient hash: false
-------------------------------------------------------------------------------
Next hops: 1 entries
3.3.3.3 (indirect) resolved by None (None)
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
```

In the current release, there is no ECMP across different owners (for instance across EVPN-IFL and PE-CE BGP), only within the same routing owner.

7.2.7 Checking multi-homing in an EVPN-VXLAN Layer 3 network

An EVPN-VXLAN Layer 3 network needs to provide a multi-homing solution where upstream and downstream traffic is always routed efficiently, without hair-pinning. As shown in Figure 12: Example of EVPN-VXLAN layer 3 multi-homing, LEAF-2 and LEAF-4 are all-active multi-homed to SERVER-1. The use of IRB anycast-gw IP and MAC addresses, along with the synchronization of MACs and ARPs on the multi-homed leaf nodes, provides efficient routing.

Figure 12: Example of EVPN-VXLAN layer 3 multi-homing



7.2.7.1 Consistency check for anycast-gw IPs

The configuration of the anycast-gw must be consistent in the IRB sub-interfaces of LEAF-2 and LEAF-4.

7.2.7.1.1 Checking anycast-gw IP address consistency

Procedure

Use the **info from state** command for the subinterface to check the consistency of the anycast-gw configuration.

Example: Check configuration consistency

```
// Leaf-2 irb0.24 subinterface
--{ [FACTORY] + candidate shared default }--[  ]--
# info from state interface irb0 subinterface 24
    interface irb0 {
        subinterface 24 {
            admin-state enable
            ip-mtu 1500
            name irb0.24
            ifindex 1082130457
            oper-state up
            last-change "2 days ago"
            ipv4 {
                allow-directed-broadcast false
                address 101.1.1.254/24 {
                    anycast-gw true
                    origin static
                    primary
                    status preferred
                }
            anycast-gw {
                virtual-router-id 1
                anycast-gw-mac 00:00:5E:00:01:01
                anycast-gw-mac-origin vrid-auto-derived
            }
// Leaf-4 irb.024 subinterface
--{ [FACTORY] + candidate shared default }--[  ]--
# info from state interface irb0 subinterface 24
    interface irb0 {
        subinterface 24 {
            admin-state enable
            ip-mtu 1500
            name irb0.24
            ifindex 1082130457
            oper-state up
            last-change "2 days ago"
            ipv4 {
                allow-directed-broadcast false
                address 101.1.1.254/24 {
                    anycast-gw true
                    origin static
                    primary
                    status preferred
                }
            anycast-gw {
                virtual-router-id 1
                anycast-gw-mac 00:00:5E:00:01:01
                anycast-gw-mac-origin vrid-auto-derived
            }
```

The anycast-gw-mac address is automatically derived by default as 00:00:5e:00:01:VRID per draft-ietf-bess-evpn-inter-subnet-forwarding. It can also be manually configured. Either way, the anycast-gw IP and MAC must match in the two leaf nodes.

7.2.7.1.2 Checking anycast-gw IP address resolution

About this task

In the next example, HOST-12 is configured with default-gw 101.1.1.254 (the anycast-gw IP address of BD24). When HOST-12 ARPs for the default-gw IP, the ARP Request can be hashed to either leaf. Regardless which leaf gets the ARP Request, the ARP reply contains the anycast-gw MAC. Unicast traffic from HOST-12 can now be hashed to either leaf (for example, LEAF-2 in Figure 12: Example of EVPN-VXLAN layer 3 multi-homing) and the receiving leaf node always routes the traffic directly to LEAF-3 without sending it to the peer leaf first (LEAF-4 in the example). Using no anycast-gw IPs or MAC addresses causes hair-pinning and uses unnecessary spine bandwidth.

Procedure

Use the **arp** and **ping** commands to show the resolution of the anycast-gw IP from HOST-12 and upstream routed traffic.

Example: anycast-gw IP address resolution

```
[:host-12]$ arp -n -I veth2
[:host-12]$
[:host-12]$
[:host-12]$ ping 33.33.33.33
PING 33.33.33.33 (33.33.33.33) 56(84) bytes of data.
02:58:15.782587 00:00:64:01:01:01 > Broadcast, ethertype ARP (0x0806), length 42:
  Request who-has 101.1.1.254 tell 101.1.1.1, length 28

02:58:15.787404 00:00:5e:00:01:01 > 00:00:64:01:01:01, ethertype ARP (0x0806),
  length 60: Reply 101.1.1.254 is-at 00:00:5e:00:01:01, length 46

02:58:15.787436 00:00:64:01:01:01 > 00:00:5e:00:01:01, ethertype IPv4 (0x0800),
  length 98: 101.1.1.1 > 33.33.33.33: ICMP echo request, id 3140, seq 1, length 64

02:58:15.791393 00:00:5e:00:01:01 > 00:00:64:01:01:01, ethertype IPv4 (0x0800),
  length 98: 33.33.33.33 > 101.1.1.1: ICMP echo reply, id 3140, seq 1, length 64

64 bytes from 33.33.33.33: icmp_seq=1 ttl=63 time=8.96 ms

--- 33.33.33.33 ping statistics ---
9 packets transmitted, 9 received, 0% packet loss, time 8008ms
rtt min/avg/max/mdev = 2.362/3.792/8.962/1.907 ms
[:host-12]$ arp -n -i veth2
Address                  HWtype  HWaddress           Flags Mask            Iface
101.1.1.254              ether   00:00:5e:00:01:01   C                     veth2
```

7.2.7.1.3 Checking synchronization in both multi-home leaf nodes

About this task

As shown in Figure 12: Example of EVPN-VXLAN layer 3 multi-homing, downstream routed traffic from LEAF-3 to HOST-12 is routed directly by LEAF-2 or LEAF-4 without hair-pinning, regardless of who gets the packets. This occurs because HOST-12's ARP and the MAC entries are synchronized in both multi-homed leaf nodes. LEAF-2 learns 101.1.1.1->00:00:64:01:01:01 (host-12 ip and mac) as dynamic and advertises both in MAC/IP routes that are imported by LEAF-4. LEAF-4 installs the HOST-12 ARP and MAC entries as evpn. However, the MAC points at the local ES lag interface, and forwarding is direct to HOST-12.

Procedure

To verify the synchronization in both multi-home leaf nodes, show the ARP entries for the IRB subinterface and show the MAC table report for the network-instance.

Example: Synchronization in both multi-home leaf nodes

```
--{ [FACTORY] + candidate shared default }--[  ]--
# show arpnd arp-entries interface irb0 subinterface 24
+-----------+-----------+----------------+-----------+----------------------+-----------------+
| Interface | Subinterf |    Neighbor    |  Origin   |  Link layer address  | Expiry          |
|           |    ace    |                |           |                      |                 |
+===========+===========+================+===========+======================+=================+
| irb0      |        24 |      101.1.1.1 |   dynamic | 00:00:64:01:01:01    | 3 hours from now|
| irb0      |        24 |      101.1.1.4 |      evpn | 00:01:04:FF:00:41    |                 |
+-----------+-----------+----------------+-----------+----------------------+-----------------+
-------------------------------------------------------------------------------------------
  Total entries : 2 (0 static, 2 dynamic)
-------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
# show network-instance BD24 bridge-table mac-table all
-------------------------------------------------------------------------------------------
Mac-table of network instance BD24
-------------------------------------------------------------------------------------------
+--------------+---------------------+-------+--------+------+-----+--------------------------+
|   Address    | Destination         | Dest- |  Type  |Active|Aging|      Last Update         |
|              |                     | Index |        |      |     |                          |
+==============+=====================+=======+========+======+=====+==========================+
| 00:00:5E:00: | irb                 | 0     | irb-int| true | N/A | 2021-04-13T10:42:14.000Z |
|  01:01       |                     |       | erface-|      |     |                          |
|              |                     |       | anycast|      |     |                          |
| 00:00:64:01: | lag1.24             | 20    | learnt | true | 285 | 2021-04-15T10:13:11.000Z |
|  01:01       |                     |       |        |      |     |                          |
| 00:00:66:01: | ethernet-1/12.24    | 17    | learnt | true | 285 | 2021-04-15T10:13:11.000Z |
|  01:01       |                     |       |        |      |     |                          |
| 00:01:02:FF: | irb                 | 0     | irb-int| true | N/A | 2021-04-13T10:42:14.000Z |
|  00:41       |                     |       | erface |      |     |                          |
| 00:01:04:FF: | vxlan-interface:    | 202418| evpn-  | true | N/A | 2021-04-13T10:42:54.000Z |
|  00:41       |  vxlan1.24          |       |        |      |     |                          |
|              | vtep:4.4.4.4 vni:24 | 653897| static |      |     |                          |
+--------------+---------------------+-------+--------+------+-----+--------------------------+
Total Irb Macs            :    1 Total    1 Active
Total Static Macs         :    0 Total    0 Active
Total Duplicate Macs      :    0 Total    0 Active
Total Learnt Macs         :    2 Total    2 Active
Total Evpn Macs           :    0 Total    0 Active
Total Evpn static Macs    :    1 Total    1 Active
Total Irb anycast Macs    :    1 Total    1 Active
Total Macs                :    5 Total    5 Active
-------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--

// ARP and MAC entries for Leaf-4

--{ [FACTORY] + candidate shared default }--[  ]--
# show arpnd arp-entries interface irb0 subinterface 24
+-----------+-----------+----------------+-----------+----------------------+-------+
| Interface | Subinterf |    Neighbor    |  Origin   |  Link layer address  | Expiry|
|           |    ace    |                |           |                      |       |
+===========+===========+================+===========+======================+=======+
| irb0      |        24 |      101.1.1.1 |      evpn | 00:00:64:01:01:01    |       |
| irb0      |        24 |      101.1.1.2 |      evpn | 00:01:02:FF:00:41    |       |
+-----------+-----------+----------------+-----------+----------------------+-------+
```

```
-------------------------------------------------------------------------------
  Total entries : 2 (0 static, 2 dynamic)
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
# show network-instance BD24 bridge-table mac-table all
-------------------------------------------------------------------------------
Mac-table of network instance BD24
-------------------------------------------------------------------------------
+-------------------+-------------------------+------+--------+------+-----+-----------------+
|      Address      |        Destination      |Dest  | Type   |Active|Aging|   Last Update   |
|                   |                         |Index |        |      |     |                 |
+===================+=========================+======+========+======+=====+=================+
| 00:00:5E:00:01:01 | irb                     | 0    |irb-int | true | N/A |2021-04-13T10:42:|
|                   |                         |      |erface- |      |     |  38.000Z        |
|                   |                         |      |anycast |      |     |                 |
| 00:00:64:01:01:01 | lag1.24                 | 18   |evpn    | true | N/A |2021-04-15T10:04:|
|                   |                         |      |        |      |     |  12.000Z        |
| 00:00:66:01:01:01 |vxlan-interface:vxlan1.24 |202418|evpn    | true | N/A |2021-04-15T10:13:|
|                   |vtep:2.2.2.2 vni:24      |654989|        |      |     |  12.000Z        |
| 00:01:02:FF:00:41 |vxlan-interface:vxlan1.24 |202418|evpn-   | true | N/A |2021-04-13T10:42:|
|                   |vtep:2.2.2.2 vni:24      |654989|static  |      |     |  54.000Z        |
| 00:01:04:FF:00:41 |irb                      |0     |irb-int | true | N/A |2021-04-13T10:42:|
|                   |                         |      |erface  |      |     | 38.000Z         |
+-------------------+-------------------------+------+--------+------+-----+-----------------+
Total Irb Macs            :    1 Total    1 Active
Total Static Macs         :    0 Total    0 Active
Total Duplicate Macs      :    0 Total    0 Active
Total Learnt Macs         :    0 Total    0 Active
Total Evpn Macs           :    2 Total    2 Active
Total Evpn static Macs    :    1 Total    1 Active
Total Irb anycast Macs    :    1 Total    1 Active
Total Macs                :    5 Total    5 Active
-------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

7.2.7.2 Non-anycast-gw IP addresses

In addition to using anycast-gw IPs for the routed traffic, the multi-homed leaf nodes also have non-anycast-gw IPs that can be used for ICMP. The examples that follow check the availability of each individual Leaf IRB (LEAF-2 and LEAF-4).

7.2.7.2.1 Checking LEAF-2 IRB availability

Procedure

Use the **show interfaces** command to check the LEAF-2 IRB availability. LEAF-2 has a non-anycast-gw IP of 101.1.1.2.

Example: Check LEAF-2 IRB availability

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# show interfaces irb0.24
===============================================================================
Net instance    : IP-VRF-10
Interface       : irb0.24
Oper state      : up
Ip mtu          : 1500
  Prefix                                  Origin       Status
```

```
  ===============================================================================
  101.1.1.2/24                              static       preferred
  101.1.1.254/24                            static       preferred, primary, anycast
  102.1.1.254/24                            static       preferred
  2001:db8:24::254/64                       static       preferred, primary, anycast
  fe80::200:5eff:fe00:101/64                link-layer   preferred, anycast
  fe80::201:2ff:feff:41/64                  link-layer   preferred
===============================================================================
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
```

7.2.7.2.2 Checking LEAF-4 IRB availability

Procedure

Use the **show interfaces** command to check the LEAF-4 IRB availability. LEAF-4 has a non-anycast-gw IP of 101.1.1.4 in the same IRB:

Example: Check LEAF-4 IRB availability

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# show interfaces irb0.24
===============================================================================
Net instance    : IP-VRF-10
Interface       : irb0.24
Oper state      : up
Ip mtu          : 1500
  Prefix                                  Origin       Status
  ===============================================================================
  101.1.1.4/24                            static       preferred
  101.1.1.254/24                          static       preferred, primary, anycast
  fe80::200:5eff:fe00:101/64              link-layer   preferred, anycast
  fe80::201:4ff:feff:41/64                link-layer   preferred
===============================================================================
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
```

7.2.7.2.3 Checking non-anycast-gw IPs reachability

Procedure

Use the **arp** and **ping** commands to check the non-anycast-gw IPs reachability.

Both non-anycast-gw IPs are reachable from HOST-12. ARP Requests to non-anycast-gw IPs reply with the chassis MAC of the leaf and not with the anycast-gw MAC of the IRB. This allows using the non-anycast-gw IPs for troubleshooting purposes when there are anycast-gw IPs on the same IRBs. The example output from HOST-12 demonstrates this:

Example: non-anycast-gw IPs reachability from host

```
[:host-12]$ arp -n -i veth2
Address                  HWtype  HWaddress           Flags Mask            Iface
101.1.1.254              ether   00:00:5e:00:01:01   C                     veth2

[:host-12]$ ping 101.1.1.2
PING 101.1.1.2 (101.1.1.2) 56(84) bytes of data.

03:25:41.291765 00:00:64:01:01:01 > Broadcast, ethertype ARP (0x0806), length 42:
  Request who-has 101.1.1.2 tell 101.1.1.1, length 28
```

```
03:25:41.295105 00:01:02:ff:00:41 > 00:00:64:01:01:01, ethertype ARP (0x0806),
   length 60: Reply 101.1.1.2 is-at 00:01:02:ff:00:41, length 46

03:25:41.295130 00:00:64:01:01:01 > 00:01:02:ff:00:41, ethertype IPv4 (0x0800),
   length 98:101.1.1.1 > 101.1.1.2: ICMP echo request, id 3307, seq 1, length 64

03:25:41.299204 00:01:02:ff:00:41 > 00:00:64:01:01:01, ethertype IPv4 (0x0800),
   length 98: 101.1.1.2 > 101.1.1.1: ICMP echo reply, id 3307, seq 1, length 64

64 bytes from 101.1.1.2: icmp_seq=1 ttl=64 time=7.59 ms

--- 101.1.1.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 2.073/3.684/7.596/2.269 ms

[:host-12]$ arp -n -i veth2
Address                  HWtype  HWaddress           Flags Mask            Iface
101.1.1.254              ether   00:00:5e:00:01:01   C                     veth2
101.1.1.2                ether   00:01:02:ff:00:41   C                     veth2
[:host-12]$ ping 101.1.1.4
PING 101.1.1.4 (101.1.1.4) 56(84) bytes of data.

03:25:52.696934 00:00:64:01:01:01 > Broadcast, ethertype ARP (0x0806), length 42:
   Request who-has 101.1.1.4 tell 101.1.1.1, length 28

03:25:52.700615 00:01:04:ff:00:41 > 00:00:64:01:01:01, ethertype ARP (0x0806),
   length 60: Reply 101.1.1.4 is-at 00:01:04:ff:00:41, length 46

03:25:52.700649 00:00:64:01:01:01 > 00:01:04:ff:00:41, ethertype IPv4 (0x0800),
   length 98: 101.1.1.1 > 101.1.1.4: ICMP echo request, id 3318, seq 1, length 64

03:25:52.703463 00:01:04:ff:00:41 > 00:00:64:01:01:01, ethertype IPv4 (0x0800),
   length 98: 101.1.1.4 > 101.1.1.1: ICMP echo reply, id 3318, seq 1, length 64

64 bytes from 101.1.1.4: icmp_seq=1 ttl=64 time=6.64 ms

--- 101.1.1.4 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2003ms
rtt min/avg/max/mdev = 2.200/3.821/6.648/2.006 ms

[:host-12]$ arp -n -i veth2
Address                  HWtype  HWaddress           Flags Mask            Iface
101.1.1.4                ether   00:01:04:ff:00:41   C                     veth2
101.1.1.254              ether   00:00:5e:00:01:01   C                     veth2
101.1.1.2                ether   00:01:02:ff:00:41   C                     veth2
```

7.2.7.3 Additional anycast gateway considerations

The following guidelines also apply for using anycast-gw in SR Linux.

In a bgp-evpn-enabled MAC-VRF with an IRB subinterface, the following applies whether the IPs are configured as primary, anycast-gw, or neither of these.

- All IPv4 and IPv6 addresses associated with the IRB subinterface are advertised in separate MAC/IP routes.
- The anycast-gw-mac and its corresponding anycast-gw IP address are advertised in a MAC/IP route.
- Any other existing non-anycast-gw IP is advertised along with the interface MAC (hw-mac) in a MAC/IP route.

For example, if irb0.24 is configured in LEAF-2 with anycast-gw (ip,mac)=(101.1.1.254/24, 00:5e:00:00:01:01), and 101.1.1.2/24 is also configured as non-anycast-gw IP, two MAC/IP routes are advertised in the context of BD24: MAC/IP route (101.1.1.254, 00:5e:00:00:01:01), and MAC/IP route (101.1.1.2, hw-mac-1).

For IPv6, Local Link Addresses (LLDs) are also advertised in addition to global addresses.

When the IRB subinterface is admin disabled, the IRB MAC addresses are removed from the mac-table (and withdrawn from EVPN). ARP Requests and Neighbor Solicitation messages for the IRB subinterface IP addresses from the hosts connected to the Broadcast Domain are only processed when coming from local subinterfaces. These messages cannot be processed when received over VXLAN, so each of the Leaf routers attached to the same BD need to have their anycast IRB subinterface operationally up to process the requests for the local hosts.

7.2.7.3.1 Checking protection flags per MAC address

About this task

The IRB MAC addresses are protected in the mac-table if they are not anycast-gw-MACs. Protection means that received frames are dropped if their MAC SA match a protected MAC. The mac-table state shows the protection flag per MAC.

Procedure

Use the **info from state network-instance bridge-table mac-table** to check the protection flags per MAC address.

Example: mac-table state

```
--{ [FACTORY] + candidate shared default }--[  ]--
# info from state network-instance BD24 bridge-table mac-table mac *
    network-instance BD24 {
        bridge-table {
            mac-table {
                mac 00:00:5E:00:01:01 {
                    destination-type irb-interface
                    destination-index 0
                    type irb-interface-anycast
                    last-update "2 days ago"
                    destination irb
                    is-protected false
                }
                mac 00:01:02:FF:00:41 {
                    destination-type irb-interface
                    destination-index 0
                    type irb-interface
                    last-update "2 days ago"
                    destination irb
                    is-protected true
                }
                mac 00:01:04:FF:00:41 {
                    destination-type vxlan
                    destination-index 202418653897
                    type evpn-static
                    last-update "2 days ago"
                    destination "vxlan-interface:vxlan1.24 vtep:4.4.4.4 vni:24"
                    is-protected true
                }
            }
```

```
        }
    }
```

7.3 Testing and checking Layer 3 host mobility

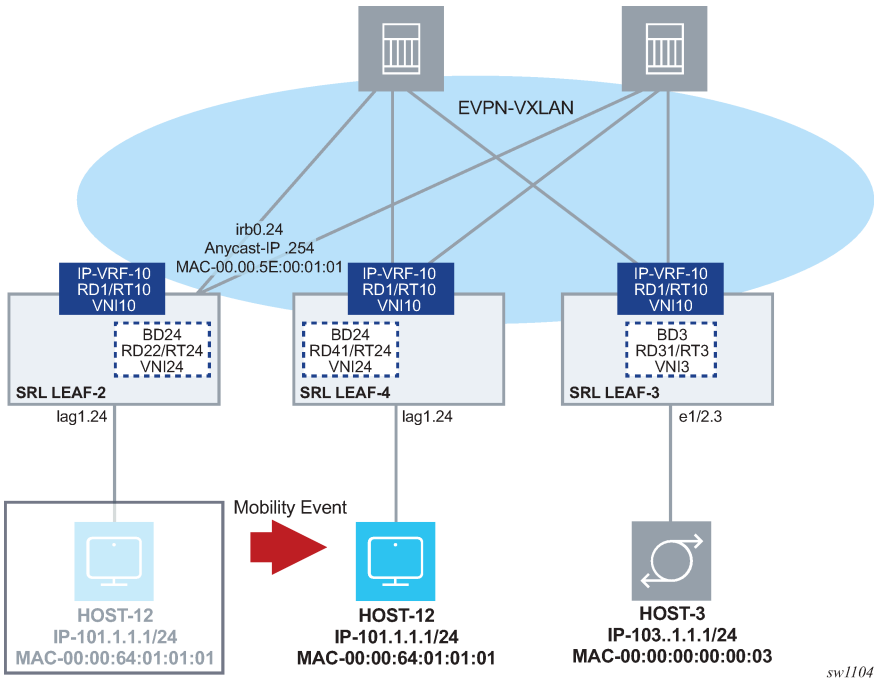
In EVPN-VXLAN Layer 3 networks, multiple leaf nodes are attached to the same BD. Hosts of the same subnet can be connected to any of those leaf nodes. They can also move between leaf nodes of the same BD. In either case, the upstream and downstream traffic must be efficient and avoid hair-pinning. This is shown in the following figure, where LEAF-2 and LEAF-4 configurations are modified (no ES) and HOST-12 was originally connected to LEAF-2.

Upstream traffic from HOST-12 to HOST-3 must be routed by LEAF-2 to LEAF-3 directly. If HOST-12 later moves to LEAF-4, upstream traffic to HOST-3 must be routed by LEAF-4 to LEAF-3 directly. This is accomplished using anycast-gw IPs and MACs on the IRB interfaces.

When HOST-12 is attached to LEAF-2, downstream traffic from HOST-3 must be sent from LEAF-3 to LEAF-2 directly. If HOST-12 later moves to LEAF-4, the routers need to update their tables quickly so that LEAF-3 routes the traffic to LEAF-4 directly, and no bandwidth is wasted on the spines because of unnecessary hair-pinning. This is achieved by learning HOST-12's IP address in the route-table of the connected leaf as a /32 route and advertising that host route in an EVPN IFL route.

Upon a mobility event to LEAF-4, LEAF-2 withdraws the host route as fast as possible and LEAF-4 then advertises the HOST-12 host route in an EVPN IFL route.

Figure 13: Example of L3 host mobility



7.3.1 Configuring efficient host routing

About this task

In the initial configuration, HOST-12 is connected to LEAF-2. For LEAF-3 to route traffic (to HOST-12) directly to LEAF-2, LEAF-2 needs to learn HOST-12's IP and advertise its host route in an EVPN-IFL route.

Procedure

To configure efficient host routing, set the following parameter definitions as shown in the example.

- **learn-unsolicited true** - Triggers the node to snoop/process all solicited and unsolicited ARP messages received on sub-interfaces (no vxlan) and learns the corresponding ARP/ND entries as 'dynamic'. By default, the command is false and only solicited entries are learned, which does not guarantee host mobility.

  When enabled, dynamic ARP/ND entries are learned from the following messages received on the sub-interfaces (if the IPs fall into the local subnets):

  – ARP and Neighbor Solicitation requests

  – Gratuitous ARP requests and unsolicited neighbor advertisements

- **host-route populate dynamic** -Triggers the creation of arp-nd host routes in the IP-VRF-10 route-table out of dynamic ARP entries. These are disabled by default. The arp-nd host routes are *not* installed in the FIB. They are only used in the control plane and advertised to the EVPN-IFL network to attract traffic from LEAF-3. The arp-nd host routes can be exported in any routing protocol, such as EVPN-IFL routes, BGP IPv4/IPv6 routes, OSPF, and ISIS. They are supported in network-instances ip-vrf and default.

- **evpn advertise dynamic** - Triggers the advertisement of EVPN MAC/IP routes for the dynamic learned ARP entries and allows the synchronization of the ARP entries in all IRB sub-interfaces of the same BD. This is only supported on IRB sub-interfaces.

  The MAC/IP routes that are advertised for ARP/ND entries contain the S bit set if the corresponding MAC entry in the mac-table is static.

Note that an equivalent command can be used for ND entries.

Example: Efficient host routing model

```
# subinterface 24
--{ [FACTORY] + candidate shared default }--[ interface irb0 subinterface 24 ]--
# info
    ipv4 {
        admin-state enable
        address 101.1.1.2/24 {
        }
        address 101.1.1.254/24 {
            anycast-gw true
            primary
        }
        arp {
            learn-unsolicited true
            debug [
                messages
            ]
            host-route {
                populate dynamic {
                }
            }
```

```
            evpn {
                advertise dynamic {
                }
            }
        }
    }
    anycast-gw {
    }
```

The next examples show how an ARP Request from HOST-12 to a random IP in the subnet is enough for the irb0.24 to learn the dynamic ARP. It can then create a host route that is advertised as an EVPN IFL route, and imported by LEAF-3.

Example: LEAF-2 - HOST-12 unsolicited ARP Request

```
--{ [FACTORY] + candidate shared default }--[  ]--
# show arpnd arp-entries interface irb0 subinterface 24
+-----------+--------------+----------+-------+--------------------+------+
| Interface | Subinterface | Neighbor | Origin| Link layer address |Expiry|
+===========+==============+==========+=======+====================+======+
| irb0      |      24      |101.1.1.4 |  evpn | 00:01:04:FF:00:41  |      |
+-----------+--------------+----------+-------+--------------------+------+
-------------------------------------------------------------------------
  Total entries : 1 (0 static, 1 dynamic)
-------------------------------------------------------------------------
```

Example: Debug messages - ARP request received

```
2021-04-15T04:58:05.651861-07:00 dut2 local6|INFO sr_arp_nd_mgr: arpnd|1773|1773|19334|I:
  Received ARP request on interface irb0.24 (10247 - 22) from datapath. Source Mac :
  00:00:64:01:01:01 Source IP : 101.1.1.1 Target Mac : 00:00:00:00:00:00 Target IP :
  101.1.1.200
```

Example: Triggered learning of RT5 and RT2 advertisements

```
2021-04-15T04:58:06.019955-07:00 dut2 local6|DEBU sr_bgp_mgr: bgp|4933|5176|2128215|D:
  VR default (1) Peer 1: 3.3.3.3 UPDATE: Peer 1: 3.3.3.3 - Send BGP UPDATE:
    Withdrawn Length = 0
    Total Path Attr Length = 85
    Flag: 0x90 Type: 14 Len: 48 Multiprotocol Reachable NLRI:
        Address Family EVPN
        NextHop len 4 NextHop 2.2.2.2
        Type: EVPN-IP-PREFIX Len: 34 RD: 2.2.2.2:10, tag: 0, ip_prefix: 101.1.1.1/32
          gw_ip 0.0.0.0 Label: 10
    Flag: 0x40 Type: 1 Len: 1 Origin: 0
    Flag: 0x40 Type: 2 Len: 0 AS Path:
    Flag: 0x80 Type: 4 Len: 4 MED: 0
    Flag: 0x40 Type: 5 Len: 4 Local Preference: 100
    Flag: 0xc0 Type: 16 Len: 24 Extended Community:
        target:64500:10
        mac-nh:00:01:02:ff:00:00
        bgp-tunnel-encap:VXLAN
2021-04-15T04:58:06.020003-07:00 dut2 local6|DEBU sr_bgp_mgr: bgp|4933|5176|2128216|D:
  VR default (1) Peer 1: 3.3.3.3 UPDATE: Peer 1: 3.3.3.3 - Send BGP UPDATE:
    Withdrawn Length = 0
    Total Path Attr Length = 97
    Flag: 0x90 Type: 14 Len: 45 Multiprotocol Reachable NLRI:
        Address Family EVPN
        NextHop len 4 NextHop 2.2.2.2
        Type: EVPN-MAC Len: 37 RD: 2.2.2.2:24 ESI: ESI-0, tag: 0, mac len: 48 mac:
        00:00:64:01:01:01, IP len: 4, IP: 101.1.1.1, label1: 24
```

```
    Flag: 0x40 Type: 1 Len: 1 Origin: 0
    Flag: 0x40 Type: 2 Len: 0 AS Path:
    Flag: 0x40 Type: 5 Len: 4 Local Preference: 100
    Flag: 0xc0 Type: 16 Len: 16 Extended Community:
        target:64500:24
        bgp-tunnel-encap:VXLAN
--{ [FACTORY] + candidate shared default }--[  ]--
# show arpnd arp-entries interface irb0 subinterface 24
+---------+----------+----------+---------+-------------------+------------------+
|Interface| Sub-     | Neighbor | Origin  | Link layer        |    Expiry        |
|         |interface |          |         |  address          |                  |
+=========+==========+==========+=========+===================+==================+
| irb0    |   24     |101.1.1.1 | dynamic | 00:00:64:01:01:01 | 3 hours from now |
| irb0    |   24     |101.1.1.4 |  evpn   | 00:01:04:FF:00:41 |                  |
+---------+----------+----------+---------+-------------------+------------------+
-------------------------------------------------------------------------------
  Total entries : 2 (0 static, 2 dynamic)
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# show route-table ipv4-unicast prefix 101.1.1.1/32 detail
-------------------------------------------------------------------------------
IPv4 Unicast route table of network instance IP-VRF-10
-------------------------------------------------------------------------------
Destination   : 101.1.1.1/32
ID            : 0
Route Type    : arp-nd
Metric        : 0
Preference    : 1
Active        : true
Last change   : 2021-04-15T11:58:05.653Z
Resilient hash: false
-------------------------------------------------------------------------------
Next hops: 1 entries
101.1.1.1 (direct) via [irb0.24]
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]—
```

Example: LEAF-3 imports routes as bgp-evpn host route

```
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
# show route-table ipv4-unicast summary
-------------------------------------------------------------------------------------------
IPv4 Unicast route table of network instance IP-VRF-10
-------------------------------------------------------------------------------------------
+----------------+------+-------+----------+-------+-----+--------------------+----------+
|     Prefix     |  ID  |Active | Route    | Metric| Pref|  Next-hop          | Next-hop |
|                |      |       |  Type    |       |     |   (Type)           |Interface |
+================+======+=======+==========+=======+=====+====================+==========+
| 20.1.1.0/24    | 0    | true  | bgp-evpn | 0     | 170 | 2.2.2.2 (indirect) | None     |
| 20.1.1.3/32    | 0    | true  | bgp-evpn | 0     | 170 | 2.2.2.2 (indirect) | None     |
| 22.22.22.22/32 | 0    | true  | bgp-evpn | 0     | 170 | 2.2.2.2 (indirect) | None     |
| 31.31.31.31/32 | 0    | true  | host     | 0     | 0   | None (extract)     | None     |
| 31.31.31.31/32 | 1    | false | bgp-evpn | 0     | 170 | 2.2.2.2 (indirect) | None     |
| 33.33.33.33/32 | 0    | true  | host     | 0     | 0   | None (extract)     | None     |
| 44.44.44.44/32 | 0    | true  | bgp-evpn | 0     | 170 | 4.4.4.4 (indirect) | None     |
| 101.1.1.0/24   | 0    | true  | bgp-evpn | 0     | 170 | 2.2.2.2 (indirect) | None     |
|                |      |       |          |       |     | 4.4.4.4 (indirect) | None     |
| 101.1.1.1/32   | 0    | true  | bgp-evpn | 0     | 170 | 2.2.2.2 (indirect) | None     |
| 102.1.1.0/24   | 0    | true  | bgp-evpn | 0     | 170 | 2.2.2.2 (indirect) | None     |
| 103.1.1.0/24   | 0    | true  | local    | 0     | 0   | 103.1.1.3 (direct) | irb0.3   |
| 103.1.1.1/32   | 0    | true  | arp-nd   | 0     | 1   | 103.1.1.1 (direct) | irb0.3   |
| 103.1.1.3/32   | 0    | true  | host     | 0     | 0   | None (extract)     | None     |
```

```
| 103.1.1.254/32 | 0    | true  | host      | 0    | 0   | None (extract)     | None     |
| 103.1.1.255/32 | 0    | true  | host      | 0    | 0   | None (broadcast)   | None     |
| 104.1.1.0/24   | 0    | true  | bgp-evpn  | 0    | 170 | 4.4.4.4 (indirect) | None     |
+----------------+------+-------+-----------+------+-----+--------------------+----------+
-------------------------------------------------------------------------------------------
16 IPv4 routes total
15 IPv4 prefixes with active routes
1 IPv4 prefixes with active ECMP routes
-------------------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[ network-instance IP-VRF-10 ]--
```

7.3.2 Mobility event - efficient host routing

When HOST-12 is attached to LEAF-2, the ARP entry must be maintained even if HOST-12 does not send any traffic. If the entry is removed or ages out, the associated arp-nd host route in IP-VRF-10 is removed and the EVPN-IFL route withdrawn. This can cause hair-pinning for traffic routed from LEAF-3. To maintain the HOST-12 ARP entry (and other dynamic ARP/ND entries), the system supports timer-based ARP/ND refreshes (ARP-Request for the host IP).

Timer-based refreshes are triggered 30 seconds before the ARP age-out timer expires, and irrespective of the arrival of packets requiring resolution for the entry. Note that in SR OS, the **arp-proactive-refresh** command is needed so that entries are always refreshed irrespective of the arrival of packets that hit the entry. In SR Linux, this is the default behavior, so there is no command to enable the timer-based refreshes.

When HOST-12 moves from LEAF-2 to LEAF-4, LEAF-4 must advertise the host route for 101.1.1.1/32 in EVPN-IFL as fast as possible and LEAF-2 withdraws its EVPN-IFL route for it. The process used by LEAF-2 and LEAF-4 to update their ARP/route-tables when HOST-12 moves between them is called "EVPN Layer 3 host mobility". SR Linux provides this support per section 4 of draft-ietf-bess-evpn-inter-subnet-forwarding. EVPN Layer 3 host mobility supports the three cases specified in the draft:

- HOST-12 moves to LEAF-4 and generates a GARP
- HOST-12 moves to LEAF-4 and generates traffic, but not ARP
- HOST-12 moves to LEAF-4 and remains silent

To support fast mobility, SR Linux supports triggered refreshes. Triggered refreshes (ARP-Requests on events and not based on timer expiration) are issued from irb0.24 leaf nodes, for the existing dynamic ARP entry 101.1.1.1>00:00:64:01:01:01. The following events apply:

- an EVPN MAC/IP route for 101.1.1.1-> 00:00:64:01:01:01 is received
- an EVPN route for 00:00:64:01:01:01 (no IP) is received
- 00:00:64:01:01:01 ages out in the mac-table (or the entry in the MAC table is cleared manually)

As shown in Figure 13: Example of L3 host mobility, when HOST-12 moves to LEAF-4, and if it issues a GARP or ethernet traffic, the advertised routes immediately updates the ARP/route tables on both leaf nodes. LEAF-3 then changes its next-hop for HOST-12 from LEAF-2 to LEAF-4.

Example: Silent move - HOST-2 initially attached to LEAF-2

```
--{ [FACTORY] + candidate shared default }—[  ]--
# show arpnd arp-entries interface irb0 subinterface 24 ipv4-address 101.1.1.1

+---------+----------+-----------+---------+-------------------+-----------------+
|Interface| Sub-     |  Neighbor | Origin  | Link layer        |     Expiry      |
|         |interface |           |         |  address          |                 |
```

```
+=========+==========+==========+=========+==================+=================+
| irb0    |  24      | 101.1.1.1 | dynamic | 00:00:64:01:01:01 | 3 hours from now|
+---------+----------+----------+---------+------------------+-----------------+
-------------------------------------------------------------------------------
  Total entries : 1 (0 static, 1 dynamic)
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
# show network-instance BD24 bridge-table mac-table mac 00:00:64:01:01:01
-------------------------------------------------------------------------------
Mac-table of network instance BD24
-------------------------------------------------------------------------------
Mac                     : 00:00:64:01:01:01
Destination             : lag1.24
Dest Index              : 20
Type                    : learnt
Programming Status      : Success
Aging                   : 2680
Last Update             : 2021-04-15T14:32:45.000Z
Duplicate Detect time   : N/A
Hold down time remaining: N/A
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

Example: Silent move - initial LEAF-4

```
 --{ [FACTORY] + candidate shared default }--[  ]--
# show arpnd arp-entries interface irb0 subinterface 24 ipv4-address 101.1.1.1
+---------+----------+----------+---------+------------------+-----------------+
|Interface| Sub-     |  Neighbor | Origin  | Link layer       |     Expiry      |
|         |interface |           |         |  address         |                 |
+=========+==========+==========+=========+==================+=================+
| irb0    |  24      | 101.1.1.1 | evpn    | 00:00:64:01:01:01 |                 |
+---------+----------+----------+---------+------------------+-----------------+
-------------------------------------------------------------------------------
  Total entries : 1 (0 static, 1 dynamic)
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
# show network-instance BD24 bridge-table mac-table mac 00:00:64:01:01:01
-------------------------------------------------------------------------------
Mac-table of network instance BD24
-------------------------------------------------------------------------------
Mac                     : 00:00:64:01:01:01
Destination             : vxlan-interface:vxlan1.24 vtep:2.2.2.2 vni:24
Dest Index              : 202418654989
Type                    : evpn
Programming Status      : Success
Aging                   : N/A
Last Update             : 2021-04-15T14:15:00.000Z
Duplicate Detect time   : N/A
Hold down time remaining: N/A
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]—
```

Example: Silent move - watch command output for LEAF-3

```
Every 2.0s: show route-table ipv4-unicast prefix 101.1.1.1/32 detail
 (Executions 903, Thu 07:41:40AM)

-------------------------------------------------------------------
IPv4 Unicast route table of network instance IP-VRF-10
-------------------------------------------------------------------
Destination   : 101.1.1.1/32
```

```
ID            : 0
Route Type    : bgp-evpn
Metric        : 0
Preference    : 170
Active        : true
Last change   : 2021-04-15T14:15:00.450Z
Resilient hash: false
-------------------------------------------------------------------
Next hops: 1 entries
2.2.2.2 (indirect) resolved by None (None)
-------------------------------------------------------------------
```

Example: Silent move - move HOST-12 to LEAF-2

In this example, HOST-12 is moved to LEAF-4 to simulate a silent move. Immediately after flushing MAC 00:00:64:01:01:01 in LEAF-2, the MAC/IP routes are withdrawn and LEAF-2 issues three triggered refreshes.

```
--{ [FACTORY] + candidate shared default }--[  ]--
#  2021-04-15T07:43:16.422816-07:00 dut2 local6|INFO sr_arp_nd_mgr: arpnd|1773|1773|20438|
I:
  Sending ARP request on interface irb0.24 (10247 - 22). Source Mac : 00:00:5E:00:01:01
  Source IP : 101.1.1.254 Target Mac : 00:00:00:00:00:00 Target IP : 101.1.1.1 Ethernet
  SA 00:00:5E:00:01:01 Ethernet DA FF:FF:FF:FF:FF:FF

2021-04-15T07:43:16.422816-07:00 dut2 local6|INFO sr_arp_nd_mgr: arpnd|1773|1773|20438|I:
  Sending ARP request on interface irb0.24 (10247 - 22). Source Mac : 00:00:5E:00:01:01
  Source IP : 101.1.1.254 Target Mac : 00:00:00:00:00:00 Target IP : 101.1.1.1 Ethernet
  SA 00:00:5E:00:01:01 Ethernet DA FF:FF:FF:FF:FF:FF

2021-04-15T07:43:16.422816-07:00 dut2 local6|INFO sr_arp_nd_mgr: arpnd|1773|1773|20438|I:
  Sending ARP request on interface irb0.24 (10247 - 22). Source Mac : 00:00:5E:00:01:01
  Source IP : 101.1.1.254 Target Mac : 00:00:00:00:00:00 Target IP : 101.1.1.1 Ethernet
  SA 00:00:5E:00:01:01 Ethernet DA FF:FF:FF:FF:FF:FF

    Flag: 0x90 Type: 15 Len: 77 Multiprotocol Unreachable NLRI:
        Address Family EVPN
        Type: EVPN-MAC Len: 37 RD: 2.2.2.2:24 ESI: ESI-0, tag: 0, mac len: 48 mac:
           00:00:64:01:01:01, IP len: 4, IP: 101.1.1.1, label1: 0
        Type: EVPN-MAC Len: 33 RD: 2.2.2.2:24 ESI: ESI-0, tag: 0, mac len: 48 mac:
           00:00:64:01:01:01, IP len: 0, IP: NULL, label1: 0
```

Example: Silent move - LEAF-2 updates

When the refreshes arrive at HOST-12 in LEAF-4, the ARP reply is consumed by LEAF-4 (since the MAC destination address matches the anycast-gw MAC address). LEAF-4 then advertises the MAC/IP routes and IP Prefix route for HOST-12.

```
 Type: EVPN-IP-PREFIX Len: 34 RD: 4.4.4.4:10, tag: 0, ip_prefix: 101.1.1.1/32
          gw_ip 0.0.0.0 Label: 10
    Flag: 0x40 Type: 1 Len: 1 Origin: 0
    Flag: 0x40 Type: 2 Len: 0 AS Path:
    Flag: 0x80 Type: 4 Len: 4 MED: 0
    Flag: 0x40 Type: 5 Len: 4 Local Preference: 100
    Flag: 0xc0 Type: 16 Len: 24 Extended Community:
        target:64500:10
        mac-nh:00:01:04:ff:00:00
        bgp-tunnel-encap:VXLAN
2021-04-15T07:43:18.763551-07:00 dut2 local6|DEBU sr_bgp_mgr: bgp|4933|5176|2169872|D:
   VR default (1) Peer 1: 4.4.4.4 UPDATE: Peer 1: 4.4.4.4 - Received BGP UPDATE:
    Withdrawn Length = 0
    Total Path Attr Length = 97
```

```
    Flag: 0x90 Type: 14 Len: 45 Multiprotocol Reachable NLRI:
        Address Family EVPN
        NextHop len 4 NextHop 4.4.4.4
        Type: EVPN-MAC Len: 37 RD: 4.4.4.4:24 ESI: ESI-0, tag: 0, mac len: 48 mac:
          00:00:64:01:01:01, IP len: 4, IP: 101.1.1.1, label1: 24
        Type: EVPN-MAC Len: 33 RD: 4.4.4.4:24 ESI: ESI-0, tag: 0, mac len: 48 mac:
          00:00:64:01:01:01, IP len: 0, IP: NULL, label1: 24
    Flag: 0x40 Type: 1 Len: 1 Origin: 0
    Flag: 0x40 Type: 2 Len: 0 AS Path:
    Flag: 0x40 Type: 5 Len: 4 Local Preference: 100
    Flag: 0xc0 Type: 16 Len: 16 Extended Community:
        target:64500:24
        bgp-tunnel-encap:VXLAN
        Type: EVPN-IP-PREFIX Len: 34 RD: 4.4.4.4:10, tag: 0, ip_prefix:
          101.1.1.1/32 gw_ip 0.0.0.0 Label: 10
    Flag: 0x40 Type: 1 Len: 1 Origin: 0
    Flag: 0x40 Type: 2 Len: 0 AS Path:
    Flag: 0x80 Type: 4 Len: 4 MED: 0
    Flag: 0x40 Type: 5 Len: 4 Local Preference: 100
    Flag: 0xc0 Type: 16 Len: 24 Extended Community:
        target:64500:10
        mac-nh:00:01:04:ff:00:00
        bgp-tunnel-encap:VXLAN
2021-04-15T07:43:18.766923-07:00 dut2 local6|INFO sr_arp_nd_mgr:
   arpnd|1773|1773|20450|I: The ARP entry for 101.1.1.1 has been updated.
```

After the move, LEAF-2 and LEAF-4 tables are updated, and LEAF-3 points at LEAF-4 as the next-hop for the HOST-12 route.

Example: Silent move - LEAF-2 tables

```
 --{ [FACTORY] + candidate shared default }--[  ]--
# show arpnd arp-entries interface irb0 subinterface 24 ipv4-address 101.1.1.1

+---------+----------+-----------+---------+-------------------+-----------------+
|Interface| Sub-     |  Neighbor | Origin  | Link layer        |     Expiry      |
|         |interface |           |         |  address          |                 |
+=========+==========+===========+=========+===================+=================+
| irb0    |  24      | 101.1.1.1 | evpn    | 00:00:64:01:01:01 |                 |
+---------+----------+-----------+---------+-------------------+-----------------+
-------------------------------------------------------------------------------
  Total entries : 1 (0 static, 1 dynamic)
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
# show network-instance BD24 bridge-table mac-table mac 00:00:64:01:01:01

-------------------------------------------------------------------------------
Mac-table of network instance BD24
-------------------------------------------------------------------------------
Mac                     : 00:00:64:01:01:01
Destination             : vxlan-interface:vxlan1.24 vtep:4.4.4.4 vni:24
Dest Index              : 202418653897
Type                    : evpn
Programming Status      : Success
Aging                   : N/A
Last Update             : 2021-04-15T14:43:18.000Z
Duplicate Detect time   : N/A
Hold down time remaining: N/A
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

Example: Silent move - LEAF-4 tables

```
--{ [FACTORY] + candidate shared default }--[  ]--
# show arpnd arp-entries interface irb0 subinterface 24 ipv4-address 101.1.1.1

+---------+----------+-----------+---------+-----------------+------------------+
|Interface| Sub-     |  Neighbor | Origin  | Link layer      |     Expiry       |
|         |interface |           |         |  address        |                  |
+=========+==========+===========+=========+=================+==================+
| irb0    |  24      | 101.1.1.1 | dynamic | 00:00:64:01:01:01| 3 hrs from now   |
+---------+----------+-----------+---------+-----------------+------------------+
-------------------------------------------------------------------------------
  Total entries : 1 (0 static, 1 dynamic)
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
--{ [FACTORY] + candidate shared default }--[  ]--
# show network-instance BD24 bridge-table mac-table mac 00:00:64:01:01:01

-------------------------------------------------------------------------------
Mac-table of network instance BD24
-------------------------------------------------------------------------------
Mac                    : 00:00:64:01:01:01
Destination            : lag1.24
Dest Index             : 18
Type                   : learnt
Programming Status     : Success
Aging                  : 2875
Last Update            : 2021-04-15T14:43:18.000Z
Duplicate Detect time  : N/A
Hold down time remaining: N/A
-------------------------------------------------------------------------------
--{ [FACTORY] + candidate shared default }--[  ]--
```

Example: Silent move - watch command output for LEAF-3

```
Every 2.0s: show route-table ipv4-unicast prefix 101.1.1.1/32 detail
  (Executions 976, Thu 07:44:30AM)

-------------------------------------------------------------------
IPv4 Unicast route table of network instance IP-VRF-10
-------------------------------------------------------------------
Destination   : 101.1.1.1/32
ID            : 0
Route Type    : bgp-evpn
Metric        : 0
Preference    : 170
Active        : true
Last change   : 2021-04-15T14:43:19.767Z
Resilient hash: false
-------------------------------------------------------------------
Next hops: 1 entries
4.4.4.4 (indirect) resolved by None (None)
-------------------------------------------------------------------
```

7.4 EVPN-VXLAN Layer 3 feature parity for IPv6 prefixes

All the features discussed in this chapter are supported for IPv6 prefixes and hosts. EVPN IFL works for Prefix IPv6 routes without enabling a separate BGP family. EVPN supports IPv4 and IPv6 routes. In

addition, all IRB sub-interfaces must be configured with the IPv6 container using the same commands used earlier in this chapter, but performed under "neighbor-discovery".

7.4.1 Configuring IPv6 Container

Procedure

See the following example to configure the IPv6 container.

Example: IPv6 container configuration

```
--{ [FACTORY] + candidate shared default }--[ interface irb0 subinterface 24 ]--
# info
    ipv4 {
        admin-state enable
        address 101.1.1.2/24 {
        }
        address 101.1.1.254/24 {
            anycast-gw true
            primary
        }
        address 102.1.1.254/24 {
        }
        arp {
            learn-unsolicited true
            debug [
                messages
            ]
            host-route {
                populate dynamic {
                }
            }
            evpn {
                advertise dynamic {
                }
            }
        }
    }
    ipv6 {
        admin-state enable
        address 2001:db8:24::254/64 {
            anycast-gw true
        }
        neighbor-discovery {
            learn-unsolicited both
            host-route {
                populate dynamic {
                }
            }
            evpn {
                advertise dynamic {
                }
            }
        }
    anycast-gw {
    }
```

7.4.2 Additional feature parity considerations

The anycast-gw container is common for IPv4 and IPv6. Therefore, the anycast-gw mac is the same for both families. Only one anycast-gw MAC is programmed in the interface, and IPv4 and IPv6 packets use this anycast-gw-mac as MAC SA when sourcing packets to the BD.

LLA and global addresses are advertised in EVPN. The command **neighbor-discovery learn-unsolicited both** includes global and link local addresses.

The following example shows that when anycast-gw is enabled, an anycast-gw LLA is automatically generated. The anycast-gw ipv6 link local address is based off the anycast-gw-mac when the anycast-gw and the ipv6 containers are present. The logic to compute this new anycast-gw ipv6 link local address is the same as is used for computing the regular ipv6 LLA except the anycast-gw-mac is used instead of the interface mac. This new ipv6 LLA appears in the list of ipv6 addresses associated with the subinterface, but with the attribute **anycast-gw true**.

Multicast NS messages use the anycast-gw LLA and anycast-gw MAC. Unicast NS use the global IPv6 and hw-address.

Example: LLA generation

```
--{ [FACTORY] + candidate shared default }--[ interface irb0 subinterface 24 ipv6 ]--
# info from state
    address 2001:db8:24::254/64 {
        anycast-gw true
        origin static
        primary
        status preferred
    }
    address fe80::200:5eff:fe00:101/64 {
        anycast-gw true
        origin link-layer
        status preferred
    }
    address fe80::201:2ff:feff:41/64 {
        origin link-layer
        status preferred
    }
    neighbor-discovery {
        duplicate-address-detection true
        reachable-time 30
        stale-time 14400
        learn-unsolicited both
        neighbor fe80::201:4ff:feff:41 {
            link-layer-address 00:01:04:FF:00:41
            origin evpn
        }
        host-route {
            populate dynamic {
            }
        }
        evpn {
            advertise dynamic {
                admin-tag 0
            }
        }
    }
    router-advertisement {
        router-role {
            current-hop-limit 64
```

```
            managed-configuration-flag false
            other-configuration-flag false
            max-advertisement-interval 600
            min-advertisement-interval 200
            reachable-time 0
            retransmit-time 0
            router-lifetime 1800
        }
    }
```

8 LDP Point-to-Point LSPs

This chapter provides information about Label Distribution Protocol (LDP) point-to-point Label Switched Paths (LSPs)

Topics in this chapter include:

8.1 Applicability

This chapter is applicable to SR Linux 25.7.R1. There are no prerequisites or conditions on the hardware for this configuration.

8.2 Overview

Because of the connectionless nature of the network layer protocol, IP packets travel through the network on a hop-by-hop basis with routing decisions made at each node. As a result, hyper aggregation of data on specific links may occur and it may impact the provider's ability to provide guaranteed service levels across the network end-to-end. To address these shortcomings, Multi-Protocol Label Switching (MPLS) was developed.

MPLS provides the capability to establish connection-oriented paths, called Label Switched Paths (LSPs), over a connectionless (IP) network. The LSP offers a mechanism to engineer network traffic independently from the underlying network routing protocol (mostly IP) to improve the network resiliency and recovery options and to permit delivery of services that are not readily supported by conventional IP routing techniques, such as Layer 2 Virtual Private Networks (VPNs). These benefits are essential for today's communication network explaining the wide deployment base of the MPLS technology.

RFC 3031 specifies the MPLS architecture whereas this chapter describes the configuration and troubleshooting of point-to-point LSPs on SR Linux.

8.2.1 Packet forwarding

When a packet of a connectionless network layer protocol travels from one router to the next, each router in the network makes an independent forwarding decision by performing the following basic tasks:

1. analyzing the packet header
2. referencing the local routing table to find the longest prefix match based on the destination address in the IP header
3. sending out the packet on the corresponding interface

The first function partitions the entire set of incoming packets into a set of Forwarding Equivalence Classes (FECs). All packets mapped to a particular FEC are forwarded along the same path to the same destination. The second function maps each FEC to a next hop destination router. Each router along the path performs these actions.

In MPLS, the assignment of a packet to a particular FEC is done only when the packet enters the network. The FEC is mapped to an LSP, which must be established before the packets can be forwarded.

An MPLS egress label, representing the FEC to which the packet is assigned, is attached to the packet (push operation) and the labeled packet is forwarded to the next hop router along that LSP path.

At subsequent hops, the packet IP header is not analyzed. Instead, the ingress label is used as an index into a table which specifies the next hop and a new egress label. The ingress label is replaced with the new egress label (swap operation), and the packet is forwarded to the specified next hop.

At the MPLS network egress, the ingress label is removed from the packet (pop operation). If this router is the destination of the packet (based on the remaining packet), the packet is handed to the receiving application, such as a MAC VRF. If this router is not the destination of the packet, the packet is sent into a new MPLS tunnel or forwarded by conventional IP forwarding toward the Layer 3 destination.

8.2.2 Terminology

Figure 14: Generic MPLS network, MPLS label operations

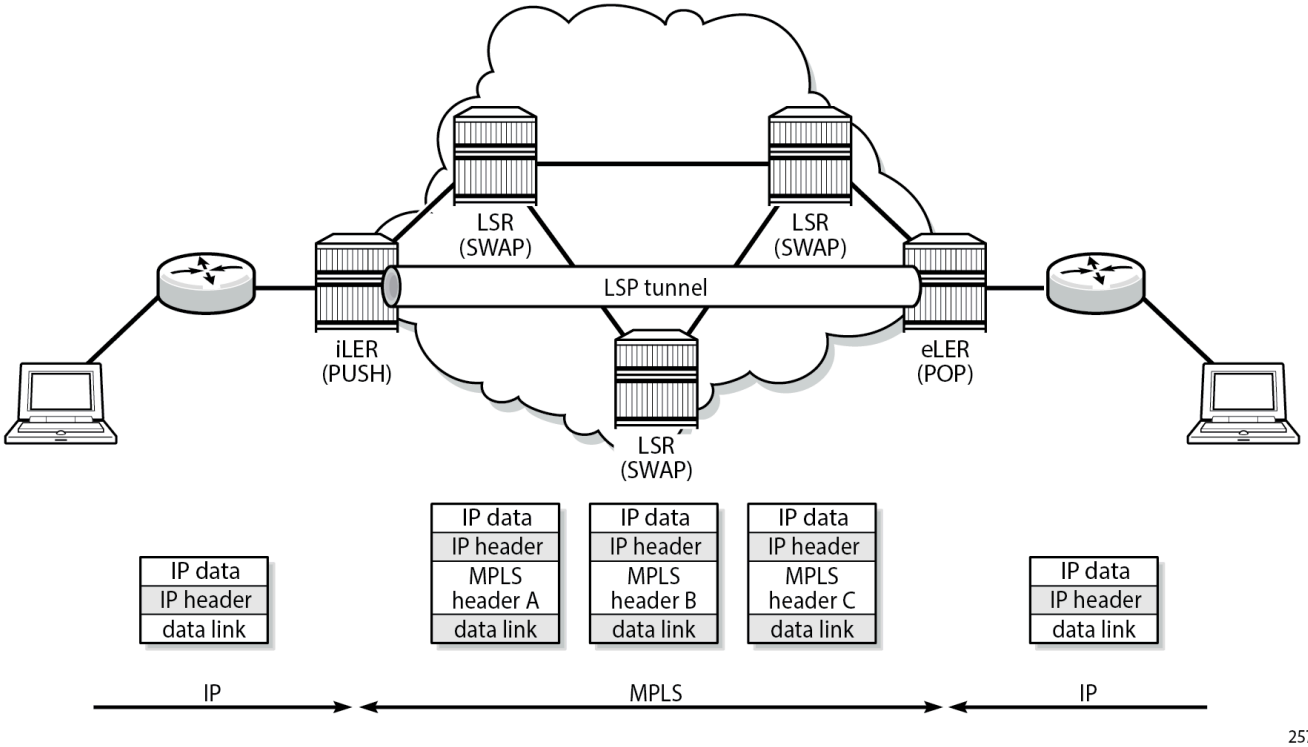


Figure 14: Generic MPLS network, MPLS label operations shows a general network topology clarifying the MPLS-related terms. A Label Edge Router (LER) is a device at the edge of an MPLS network, with at

least one interface outside the MPLS domain. A router is usually defined as an LER based on its position relative to a particular LSP:

- The MPLS router at the head-end of an LSP is called the ingress Label Edge Router (ILER)
- The MPLS router at the tail-end of an LSP is called the egress Label Edge Router (ELER)

The ILER receives unlabeled packets from outside the MPLS domain, applies MPLS egress labels to the packets, and forwards the labeled packets into the MPLS domain.

The ELER receives labeled packets from the MPLS domain, removes the ingress labels, and forwards unlabeled packets outside the MPLS domain. The ELER can signal an implicit-null label. This informs the previous hop to send MPLS packets without an outer egress label. This is known as Penultimate Hop Popping (PHP).

A Label Switching Router (LSR) is a device internal to an MPLS network, with all interfaces inside the MPLS domain. These devices switch labeled packets inside the MPLS domain. In the core of the network, LSRs ignore the packet IP header and simply forward the packet using the MPLS label swapping mechanism.

8.2.3 LSP establishment

The LSP must be established before any packets can be forwarded. To set up an LSP, labels need to be distributed for the path. Labels are usually distributed by a downstream router in the upstream direction (relative to the data flow). Label distribution can be static or via a protocol such as LDP. For static P2P LSPs, see Static MPLS LSPs.

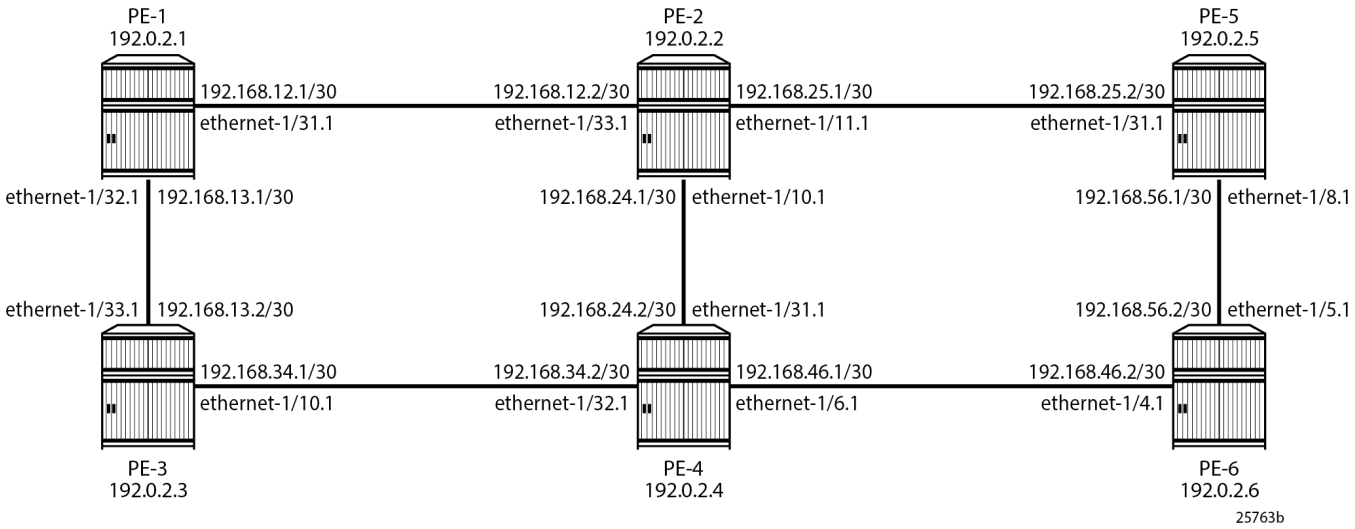
LDP (RFC 5036) can be considered as an extension to the network Interior Gateway Protocol (IGP). As routers become aware of new destination networks, they advertise labels in the upstream direction that allow upstream routers to reach the destination.

LDP loopfree alternate (LFA) allows for computing backup paths and advertising the backup labels before a failure takes place. In this way traffic can flow almost continuously, without waiting for routing protocol convergence; see MPLS LDP LFA using ISIS as IGP.

8.2.4 Example topology

Figure 15: MPLS example topology shows the example topology consisting of six SR Linux nodes located in a single autonomous system.

Figure 15: MPLS example topology



8.3 Configuration

The configuration of dynamic MPLS LSPs requires a correctly working Interior Gateway Protocol (IGP). Intermediate System to Intermediate System (IS-IS) or Open Shortest Path First (OSPF) can be used as IGP.

LDP is a simple Label Distribution Protocol with basic MPLS functionality (no traffic engineering). It supports LFA for fast rerouting; see MPLS LDP LFA using ISIS as IGP. LDP relies on the underlying routing information provided by an IGP to forward labeled packets. Each LDP configured LSR originates a label for its system address and a label for each FEC for which it has a next hop that is external to the MPLS domain, without the explicit need to manually configure the LSPs. When deviations from this default behavior are needed, import and export policies can be applied.

The configuration is as simple as enabling the LDP protocol instance and adding all network interfaces, for each node. The configuration for IPv4 on node PE-1 is as follows; similar configurations apply on the other nodes. Configuration for IPv6 is also supported, but not described in this chapter.

```
# on PE-1:
enter candidate
    system mpls label-ranges {
                dynamic dlb-ldp {
                    start-label 20000
                    end-label 29999
                }

enter candidate
    network-instance default protocols ldp {
                admin-state enable
                dynamic-label-block dlb-ldp
                fec-resolution {
                    longest-prefix true        # optional; default: exact match
                }
                discovery {
```

```
                    interfaces {
                        interface ethernet-1/31.1 {
                            ipv4 {
                                admin-state enable
                            }
                        }
                        interface ethernet-1/32.1 {
                            ipv4 {
                                admin-state enable
                            }
                        }
                    }
                }
```

The LDP label range must be explicitly configured on all nodes as **dynamic** in the **system mpls label-ranges context**. The FEC resolution is based on the longest prefix match, with **longest-prefix true** in the **network-instance default protocols ldp fec-resolution** context. By default, SR Linux supports /32 IPv4 and /128 IPv6 FEC resolution using IGP routes. When longest-prefix match is enabled for IPv4 and IPv6 FEC resolution, IPv4 and IPv6 prefix FECs can be resolved by less-specific routes in the route table, as long as the prefix bits of the route match the prefix bits of the FEC. The IP route with the longest prefix match is the route that is used to resolve the FEC.

On each node, the local network interfaces that are part of the MPLS network must be configured in the **network-instance default protocols ldp discovery interfaces** context.

The LDP configuration can be verified as follows:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default protocols ldp summary
=========================================================================================================
=========================================================
Net-Inst default LDP Summary
---------------------------------------------------------------------------------------------------------
---------------------------------------------------------
Admin State                     : enable
FEC Match Longest Prefix        : true
Dynamic Label Block             : dlb-ldp
Dynamic Label Block Status      : available
Graceful Restart Enabled        : false
GR Max Reconnect Time           : 120
GR Max Recovery Time            : 120
Max Multipaths                  : 1
IPv4 Oper State                 : up
IPv4 Last oper state change     : 2025-08-25T11:58:41.600Z
IPv4 LSR ID                     : 192.0.2.1    # different for each node
IPv6 Oper State                 : down         # this setup does not have IPv6 configuration
IPv6 Oper Down Reason           : no-system-ipv6-address
IPv6 Last oper state change     : 2025-08-25T11:58:39.900Z
IPv6 LSR ID                     : ::
Session Keepalive Holdtime      : 180
Session Keepalive Interval      : 60
---------------------------------------------------------------------------------------------------------
---------------------------------------------------------
=========================================================================================================
=========================================================
```

The LDP adjacencies can be verified as follows:

```
# On PE-1:
--{ running }--[  ]--
```

```
A:admin@PE-1# show / network-instance default protocols ldp neighbor
=============================================================================================================
=========================================================
Net-Inst default LDP neighbors
-------------------------------------------------------------------------------------------------------------
---------------------------------------------------------
+-----------------------------------------------------------------------------------------------------------
------------------------------+
| Interface              Peer LDP ID                Nbr Address       Local Address
 Proposed     Negotiated   Remaining  |
|
 Holdtime     Holdtime     Holdtime   |
+=============================================================================================================
==============================+
| ethernet-1/31.1        192.0.2.2:0                192.168.12.2      192.168.12.1      15
       15           12          |
| ethernet-1/32.1        192.0.2.3:0                192.168.13.2      192.168.13.1      15
       15           11          |
+-----------------------------------------------------------------------------------------------------------
------------------------------+
=============================================================================================================
=========================================================
```

The LDP tunnels that are automatically set up to the remote destinations can be verified as follows:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default tunnel-table all
-------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
IPv4 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
+---------------------+--------+---------------+----------+-----+----------+---------+-------
------------------+--------------+--------------+
|     IPv4 Prefix      | Encaps |  Tunnel Type   |  Tunnel  | FIB |  Metric  | Prefere |
 Last Update        |   Next-hop   |   Next-hop   |
|                      |  Type  |                |    ID    |     |          |   nce   |
|                    |   (Type)    |              |
+=====================+========+===============+==========+=====+==========+=========+=======
==================+==============+==============+
| 192.0.2.2/32         | mpls   | ldp            | 65537    | Y   | 10       | 9       | 2025-
08-25T11:59:08.272Z | 192.168.12.2 | ethernet-    |
|                      |        |                |          |     |          |         |
|                    | (mpls)       | 1/31.1       |
| 192.0.2.3/32         | mpls   | ldp            | 65538    | Y   | 10       | 9       | 2025-
08-25T11:59:27.962Z | 192.168.13.2 | ethernet-    |
|                      |        |                |          |     |          |         |
|                    | (mpls)       | 1/32.1       |
| 192.0.2.4/32         | mpls   | ldp            | 65539    | Y   | 20       | 9       | 2025-
08-25T11:59:55.797Z | 192.168.12.2 | ethernet-    |
|                      |        |                |          |     |          |         |
|                    | (mpls)       | 1/31.1       |
| 192.0.2.5/32         | mpls   | ldp            | 65540    | Y   | 20       | 9       | 2025-
08-25T12:00:14.802Z | 192.168.12.2 | ethernet-    |
|                      |        |                |          |     |          |         |
|                    | (mpls)       | 1/31.1       |
| 192.0.2.6/32         | mpls   | ldp            | 65541    | Y   | 30       | 9       | 2025-
08-25T12:00:32.542Z | 192.168.12.2 | ethernet-    |
|                      |        |                |          |     |          |         |
|                    | (mpls)       | 1/31.1       |
+---------------------+--------+---------------+----------+-----+----------+---------+-------
------------------+--------------+--------------+
```

```
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
5 LDP tunnels, 5 active, 0 inactive
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv6 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
<no_entries>
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
```

Five LDP tunnels start on each node, one to each remote node. A node does not have an LDP tunnel to itself. As a result of the SPF computation on PE-1, only the LDP tunnel from PE-1 to PE-3 (IPv4 prefix 192.0.2.3/32) starts at the ethernet-1/32.1 subinterface on PE-1 (to PE-3). The LDP tunnels from PE-1 to all other nodes start at the ethernet-1/31.1 subinterface on PE-1 (to PE-2). The SPF computation on the other nodes governs the LDP tunnels that start on them.

The LDP tunnel from PE-1 to PE-6 (tunnel ID 65541) uses egress label 20005 and passes through PE-2. This can be verified as follows:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default tunnel-table ipv4 tunnel
 * type * owner * id * |
 as table | filter fields encapsulation-type metric preference next-hop-group
+-------------+------------------+-------------------------+-------------+-----------+-------
-----------+-----------+-----------+--------------------+
|  Network-   |    Ipv4-prefix    |           Type           |    Owner    |    Id     |
 Encapsulation-  |  Metric   | Preferenc |   Next-hop-group   |
|  instance   |                   |                          |             |           |
 type       |           |     e     |                      |
+=============+==================+=========================+=============+===========+=======
===========+===========+===========+====================+
| default     | 192.0.2.2/32      | ldp                      | ldp_mgr     |     65537 | mpls
           |        10 |         9 |           28227483 |
| default     | 192.0.2.3/32      | ldp                      | ldp_mgr     |     65538 | mpls
           |        10 |         9 |           28227484 |
| default     | 192.0.2.4/32      | ldp                      | ldp_mgr     |     65539 | mpls
           |        20 |         9 |           28227485 |
| default     | 192.0.2.5/32      | ldp                      | ldp_mgr     |     65540 | mpls
           |        20 |         9 |           28227486 |
| default     | 192.0.2.6/32      | ldp                      | ldp_mgr     |     65541 | mpls
           |        30 |         9 |           28227487 |
+-------------+------------------+-------------------------+-------------+-----------+-------
-----------+-----------+-----------+--------------------+

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default tunnel-table
    network-instance default {
        tunnel-table {
            ---snip---
            ipv4 {
                ---snip---
                tunnel 192.0.2.6/32 type ldp owner ldp_mgr id 65541 {
                    encapsulation-type mpls
                    next-hop-group 28227487
                    metric 30
```

```
                    preference 9
                    last-app-update "2025-08-25T12:00:32.542Z (3 minutes ago)"
                    resource-allocation-failed false
                    fib-programming {
                        last-successful-operation-type add
                        last-successful-operation-timestamp "2025-08-25T12:00:32.543Z (3
 minutes ago)"
                        pending-operation-type none
                        last-failed-operation-type none
                    }
                }
                statistics {
                    active-tunnels 5
                    total-tunnels 5
                }
                tunnel-summary {
                    tunnel-type ldp {
                        active-tunnels 5
                    }
                }
            }

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop-
group *
    network-instance default {
        route-table {
            ---snip---
            next-hop-group 28227487 {
                backup-next-hop-group 0
                backup-active false
                fib-programming {
                    last-successful-operation-type add
                    last-successful-operation-timestamp "2025-08-25T12:00:32.543Z (7 minutes
 ago)"
                    pending-operation-type none
                    last-failed-operation-type none
                }
                next-hop 0 {
                    next-hop 28227474
                    resolved not-applicable
                    resource-allocation-failed false
                }
            }

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop * |
 as table | filter fields type ip-address subinterface mpls-encapsulation/pushed-mpls-label-
stack
+-------------------------+---------------------+--------------------+-----------------------
---+-------------------------+-------------------------+
|     Network-instance    |        Index        |        Type        |        Ip-address
   |       Subinterface      |    Mpls-encapsulation    |
|                         |                     |                    |
   |                         | pushed-mpls-label-stack  |
+=========================+=====================+====================+=======================
===+=========================+=========================+
| ---snip---    # non MPLS
                                                       |
| default                 |             28227470 | mpls               | 192.168.12.2
   | ethernet-1/31.1         | 20000                    |
| default                 |             28227471 | mpls               | 192.168.13.2
   | ethernet-1/32.1         | 20000                    |
```

```
| default                  |             28227472 | mpls              | 192.168.12.2
   | ethernet-1/31.1          | 20003                    |
| default                  |             28227473 | mpls              | 192.168.12.2
   | ethernet-1/31.1          | 20004                    |
| default                  |             28227474 | mpls              | 192.168.12.2
   | ethernet-1/31.1          | 20005                    |
+--------------------------+----------------------+--------------------+----------------------
---+--------------------------+--------------------------+

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop *
    network-instance default {
        route-table {
            ---snip---
            next-hop 28227474 {
                resource-allocation-failed false
                type mpls
                ip-address 192.168.12.2
                subinterface ethernet-1/31.1
                mpls-encapsulation {
                    entropy-label-transmit false
                    pushed-mpls-label-stack [
                        20005
                    ]
                }
            }
```

On PE-1, the LDP tunnel to PE-6 (tunnel ID 65541) has **next-hop-group 28227487**, which uses **next-hop 28227474** that specifies **pushed-mpls-label-stack [20005]** and **ip-address 192.168.12.2** via **subinterface ethernet-1/31.1**.

The MPLS ingress label processing on each node through which the LDP tunnel passes can be verified as follows:

```
# On PE-2:
--{ running }--[  ]--
A:admin@PE-2# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+===============
=======+==================+
| 20000   | POP       | ldp         | default         |                        |
       |                  |
| 20001   | SWAP      | ldp         | N/A             | 192.168.12.1 (mpls)    | ethernet-1/
33.1      | 20000            |
| 20002   | SWAP      | ldp         | N/A             | 192.168.12.1 (mpls)    | ethernet-1/
33.1      | 20002            |
| 20003   | SWAP      | ldp         | N/A             | 192.168.24.2 (mpls)    | ethernet-1/
10.1      | 20000            |
| 20004   | SWAP      | ldp         | N/A             | 192.168.25.2 (mpls)    | ethernet-1/
11.1      | 20000            |
| 20005   | SWAP      | ldp         | N/A             | 192.168.24.2 (mpls)    | ethernet-1/
10.1      | 20005            |
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+

--{ running }--[  ]--
A:admin@PE-2# info from state with-context / network-instance default route-table mpls label-
entry * |
```

```
 as table | filter fields operation entry-type next-hop-group
+-------------------------------------------------------------------------+-------------+-------
----+-----------------------------+----------------------+
|                          Network-instance                               | Label-value |
 Operation |         Entry-type          |    Next-hop-group    |
+=========================================================================+=============+=======
====+=============================+======================+
| default                                                                 |       20000 | pop
    | ldp                         |                      |
| default                                                                 |       20001 | swap
    | ldp                         |            28209398 |
| default                                                                 |       20002 | swap
    | ldp                         |            28209399 |
| default                                                                 |       20003 | swap
    | ldp                         |            28209400 |
| default                                                                 |       20004 | swap
    | ldp                         |            28209401 |
| default                                                                 |       20005 | swap
    | ldp                         |            28209402 |
+-------------------------------------------------------------------------+-------------+-------
----+-----------------------------+----------------------+
```

When PE-2 receives a packet labeled with (ingress) label 20000, PE-2 pops the label and processes the packet locally. When PE-2 receives a packet labeled with (ingress) label 20001, PE-2 swaps the label to the next-hop MPLS (egress) label 20000 and forwards the packet to PE-1 (next-hop IP 192.168.12.1) via next-hop subinterface ethernet-1/33.1. When PE-2 receives a packet labeled with (ingress) label 20003, PE-2 swaps the label to the next-hop MPLS (egress) label 20000 and forwards the packet to PE-4 (next-hop IP 192.168.24.2) via next-hop subinterface ethernet-1/10.1.

PE-2 receives a packet from PE-1, which is labeled with (ingress) label 20005. PE-2 swaps the label to the next-hop MPLS (egress) label 20005 and forwards the packet to PE-4 (next-hop IP 192.168.24.2) via next-hop subinterface ethernet-1/10.1.

```
# On PE-4:
--{ running }--[  ]--
A:admin@PE-4# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+===============
=======+==================+
| 20000   | POP       | ldp         | default         |                        |
       |                  |
| 20001   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20000            |
| 20002   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20001            |
| 20003   | SWAP      | ldp         | N/A             | 192.168.34.1 (mpls)    | ethernet-1/
32.1      | 20000            |
| 20004   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20004            |
| 20005   | SWAP      | ldp         | N/A             | 192.168.46.2 (mpls)    | ethernet-1/6.1
       | 20000            |
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
```

PE-4 receives the packet from PE-2, which is labeled with (ingress) label 20005. PE-4 swaps the label to the next-hop MPLS (egress) label 20000 and forwards the packet to PE-6 (next-hop IP 192.168.46.2) via next-hop subinterface ethernet-1/6.1.

```
# On PE-6:
--{ running }--[  ]--
A:admin@PE-6# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+===============
=======+==================+
| 20000   | POP       | ldp         | default         |                        |
       |                  |
| 20001   | SWAP      | ldp         | N/A             | 192.168.56.1 (mpls)    | ethernet-1/5.1
       | 20000            |
| 20002   | SWAP      | ldp         | N/A             | 192.168.46.1 (mpls)    | ethernet-1/4.1
       | 20002            |
| 20003   | SWAP      | ldp         | N/A             | 192.168.46.1 (mpls)    | ethernet-1/4.1
       | 20001            |
| 20004   | SWAP      | ldp         | N/A             | 192.168.46.1 (mpls)    | ethernet-1/4.1
       | 20003            |
| 20005   | SWAP      | ldp         | N/A             | 192.168.46.1 (mpls)    | ethernet-1/4.1
       | 20000            |
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
```

PE-6 receives the packet from PE-4, which is labeled with (ingress) label 20000. PE-6 pops the label and processes the packet locally.

The (egress) next hops can be verified as follows:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table next-hop
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
Next-hop route table of network instance default
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
---snip---    # non MPLS
Index             : 28227470
  Next-hop        : 192.168.12.2
  Type            : mpls
  MPLS label stack: [20000]
Index             : 28227471
  Next-hop        : 192.168.13.2
  Type            : mpls
  MPLS label stack: [20000]
Index             : 28227472
  Next-hop        : 192.168.12.2
  Type            : mpls
  MPLS label stack: [20003]
Index             : 28227473
  Next-hop        : 192.168.12.2
  Type            : mpls
  MPLS label stack: [20004]
Index             : 28227474
  Next-hop        : 192.168.12.2
```

```
  Type            : mpls
  MPLS label stack: [20005]

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop * |
 as table | filter fields type ip-address subinterface mpls-encapsulation/pushed-mpls-label-
stack
+--------------------------+---------------------+--------------------+-----------------------
---+--------------------------+--------------------------+
|     Network-instance     |        Index        |        Type        |        Ip-address
   |       Subinterface       |    Mpls-encapsulation    |
|                          |                     |                    |
   |                          | pushed-mpls-label-stack  |
+==========================+=====================+====================+=======================
===+==========================+==========================+
| ---snip---    # non MPLS
                                                        |
| default                  |            28227470 | mpls               | 192.168.12.2
   | ethernet-1/31.1          | 20000                    |
| default                  |            28227471 | mpls               | 192.168.13.2
   | ethernet-1/32.1          | 20000                    |
| default                  |            28227472 | mpls               | 192.168.12.2
   | ethernet-1/31.1          | 20003                    |
| default                  |            28227473 | mpls               | 192.168.12.2
   | ethernet-1/31.1          | 20004                    |
| default                  |            28227474 | mpls               | 192.168.12.2
   | ethernet-1/31.1          | 20005                    |
+--------------------------+---------------------+--------------------+-----------------------
---+--------------------------+--------------------------+
```

In the preceding output, the (egress) next hops that relate with LDP tunnels are those with **MPLS label stack: [<LDP label>]**. PE-1 learns the (egress) labels that it must use to reach a destination, from the FEC prefixes that its LDP peers (**interfaces** on PE-2 and PE-3) advertise. This information can be obtained as follows:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-address
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        received-address {
                            peer 192.0.2.2 label-space-id 0 {
                                ip-address [
                                    192.0.2.2
                                    192.168.12.2
                                    192.168.24.1
                                    192.168.25.1
                                ]
                            }
                            peer 192.0.2.3 label-space-id 0 {
                                ip-address [
                                    192.0.2.3
                                    192.168.13.2
                                    192.168.34.1
                                ]
                            }

--{ running }--[  ]--
```

```
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        received-prefix-fec {
                            prefix-fec 192.0.2.2/32 lsr-id 192.0.2.2 label-space-id 0 {
                                label 20000
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding true
                                next-hop 1 {
                                    next-hop 192.168.12.2
                                    next-hop-type primary
                                    interface ethernet-1/31.1
                                }
                            }
                            prefix-fec 192.0.2.2/32 lsr-id 192.0.2.3 label-space-id 0 {
                                label 20002
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                            }
                            prefix-fec 192.0.2.3/32 lsr-id 192.0.2.2 label-space-id 0 {
                                label 20002
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                            }
                            prefix-fec 192.0.2.3/32 lsr-id 192.0.2.3 label-space-id 0 {
                                label 20000
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding true
                                next-hop 1 {
                                    next-hop 192.168.13.2
                                    next-hop-type primary
                                    interface ethernet-1/32.1
                                }
                            }
                            prefix-fec 192.0.2.4/32 lsr-id 192.0.2.2 label-space-id 0 {
                                label 20003
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding true
                                next-hop 1 {
                                    next-hop 192.168.12.2
                                    next-hop-type primary
                                    interface ethernet-1/31.1
                                }
                            }
                            prefix-fec 192.0.2.4/32 lsr-id 192.0.2.3 label-space-id 0 {
                                label 20003
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                            }
                            prefix-fec 192.0.2.5/32 lsr-id 192.0.2.2 label-space-id 0 {
                                label 20004
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding true
```

```
                                next-hop 1 {
                                    next-hop 192.168.12.2
                                    next-hop-type primary
                                    interface ethernet-1/31.1
                                }
                            }
                            prefix-fec 192.0.2.5/32 lsr-id 192.0.2.3 label-space-id 0 {
                                label 20004
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                            }
                            prefix-fec 192.0.2.6/32 lsr-id 192.0.2.2 label-space-id 0 {
                                label 20005
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding true
                                next-hop 1 {
                                    next-hop 192.168.12.2
                                    next-hop-type primary
                                    interface ethernet-1/31.1
                                }
                            }
                            prefix-fec 192.0.2.6/32 lsr-id 192.0.2.3 label-space-id 0 {
                                label 20005
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                            }

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 |
 as table | filter fields *
+---------------+---------------+---------------+---------------+---------------+--------------
-+---------------+---------------+---------------+
|   Network-    |      Fec      |    Lsr-id     | Label-space-  |     Label     |   Entropy-
 | Ingress-lsr-  |   Used-in-    |   Not-used-   |
|   instance    |               |               |      id       |               |    label-
 |      fec      |  forwarding   |    reason     |
|               |               |               |               |               |   transmit
 |               |               |               |
+===============+===============+===============+===============+===============+==============
=+===============+===============+===============+
| default       | 192.0.2.2/32  | 192.0.2.2     |             0 | 20000         | false
 | true          | true          |               |
| default       | 192.0.2.2/32  | 192.0.2.3     |             0 | 20002         | false
 | true          | false         |               |
| default       | 192.0.2.3/32  | 192.0.2.2     |             0 | 20002         | false
 | true          | false         |               |
| default       | 192.0.2.3/32  | 192.0.2.3     |             0 | 20000         | false
 | true          | true          |               |
| default       | 192.0.2.4/32  | 192.0.2.2     |             0 | 20003         | false
 | true          | true          |               |
| default       | 192.0.2.4/32  | 192.0.2.3     |             0 | 20003         | false
 | true          | false         |               |
| default       | 192.0.2.5/32  | 192.0.2.2     |             0 | 20004         | false
 | true          | true          |               |
| default       | 192.0.2.5/32  | 192.0.2.3     |             0 | 20004         | false
 | true          | false         |               |
| default       | 192.0.2.6/32  | 192.0.2.2     |             0 | 20005         | false
 | true          | true          |               |
| default       | 192.0.2.6/32  | 192.0.2.3     |             0 | 20005         | false
 | true          | false         |               |
```

```
+---------------+---------------+--------------+---------------+---------------+-------------
-+---------------+---------------+---------------+

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 next-hop * |
 as table | filter fields *
+-------------+-----------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
|  Network-   |  Prefix-fec fec  | Prefix-fec  |   Prefix-fec label-    |  Index   |  Next-hop
  |  Next-hop-  |       Interface       | Outer-label |
|  instance   |                  |   lsr-id    |        space-id        |          |
  |    type     |                  |             |
+=============+=================+=============+=======================+==========+===========
==+=============+======================+=============+
| default     | 192.0.2.2/32     | 192.0.2.2   |                     0 |        1
 | 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |             |
| default     | 192.0.2.3/32     | 192.0.2.3   |                     0 |        1
 | 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |             |
| default     | 192.0.2.4/32     | 192.0.2.2   |                     0 |        1
 | 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |             |
| default     | 192.0.2.5/32     | 192.0.2.2   |                     0 |        1
 | 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |             |
| default     | 192.0.2.6/32     | 192.0.2.2   |                     0 |        1
 | 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |             |
+-------------+-----------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
```

PE-1 receives IP addresses and FEC prefixes from its directly connected (PE-2 and PE-3) LDP peers (**peer** or **lsr-id**). PE-1 may receive the same FEC prefix with (typically) different MPLS labels from all (or some) of its LDP peers. For each FEC prefix, PE-1 uses only the one marked with **used-in-forwarding true**: it labels the IP packet with the corresponding (egress) label and sends the labeled packet to the corresponding **next hop 1**.

Each node receives five FEC prefixes (from each of its LDP peers), which correspond with the system addresses of the remote nodes .

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp peers
    network-instance default {
        protocols {
            ldp {
                peers {
                    session-keepalive-holdtime 180
                    session-keepalive-interval 60
                    peer 192.0.2.2 label-space-id 0 {
                        ---snip---
                        end-of-lib {
                            ipv4-prefix-fecs {
                                sent true
                                received true
                            }
```

```
                        ---snip---
                    }
                    statistics {
                        ---snip---
                        address-statistics {
                            ipv4 {
                                received-addresses 4      # own system IP + 3 peer
 interface IPs
                                advertised-addresses 3    # own system IP + 2 peer
 interface IPs
                            }
                            ---snip---
                        }
                        fec-statistics {
                            ipv4-prefix {
                                received-fecs 5           # From each remote PE (5): 1 FEC
 (system)
                                advertised-fecs 5         # To each remote PE (5): 1 FEC
 (system)
                            }
                            ---snip---
                        }
                    }
                }
                peer 192.0.2.3 label-space-id 0 {
                    ---snip---
                    end-of-lib {
                        ipv4-prefix-fecs {
                            sent true
                            received true
                        }
                        ---snip---
                    }
                    statistics {
                        ---snip---
                        address-statistics {
                            ipv4 {
                                received-addresses 3      # own system IP + 2 peer
 interface IPs
                                advertised-addresses 3    # own system IP + 2 peer
 interface IPs
                            }
                            ---snip---
                        }
                        fec-statistics {
                            ipv4-prefix {
                                received-fecs 5           # From each remote PE (5): 1 FEC
 (system)
                                advertised-fecs 5         # To each remote PE (5): 1 FEC
 (system)
                            }
                            ---snip---
                        }
                    }
                }

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp statistics
 ipv4
    network-instance default {
        protocols {
            ldp {
                statistics {
                    ipv4 {
```

```
                        total-discovery-interfaces 2
                        total-discovery-targets 0
                        total-interface-hello-adjacencies 2
                        total-targeted-hello-adjacencies 0
                        total-peers 2    # PE-2 and PE-3
                    }

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp statistics
 fec-statistics ipv4-prefix
    network-instance default {
        protocols {
            ldp {
                statistics {
                    fec-statistics {
                        ipv4-prefix {
                            received-fecs 10
                            advertised-fecs 10
                        }
```

8.3.1 Penultimate hop popping

To signal PHP with LDP, **null-label implicit** must be configured in the **network-instance default protocols ldp** context on the ELER, as follows:

```
# on PE-6:
enter candidate
    network-instance default protocols ldp {
                null-label implicit
```

Before the **null-label implicit** configuration on PE-6, PE-6 advertises label 20000 for FEC prefix 192.0.2.6/32 to all remote nodes that belong to the MPLS network. Only PE-4 and PE-5 use (egress) label 20000 for FEC prefix 192.0.2.6/32 toward PE-6.

```
# On PE-6:
--{ running }--[  ]--
A:admin@PE-6# info from state with-context / network-instance default protocols ldp ipv4
 bindings advertised-prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        advertised-prefix-fec {
                            ---snip---
                            prefix-fec 192.0.2.6/32 lsr-id 192.0.2.4 label-space-id 0 {
                                egress-lsr-fec true
                                label 20000
                                label-type pop
                            }
                            prefix-fec 192.0.2.6/32 lsr-id 192.0.2.5 label-space-id 0 {
                                egress-lsr-fec true
                                label 20000
                                label-type pop
                            }
```

```
# On PE-4:    # similar on PE-5 with other next-hop 1
--{ running }--[  ]--
```

```
A:admin@PE-4# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        received-prefix-fec {
                            ---snip---
                            prefix-fec 192.0.2.6/32 lsr-id 192.0.2.6 label-space-id 0 {
                                label 20000
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding true
                                next-hop 1 {
                                    next-hop 192.168.46.2
                                    next-hop-type primary
                                    interface ethernet-1/6.1
                                }
                            }
```

```
# On PE-4:    # similar on PE-5 for other next-hop
--{ running }--[  ]--
A:admin@PE-4# show / network-instance default route-table next-hop
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Next-hop route table of network instance default
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
---snip---
Index             : 28330675
  Next-hop        : 192.168.46.2
  Type            : mpls
  MPLS label stack: [20000]
```

```
# On PE-4:    # similar on PE-5 with other next-hop
--{ running }--[  ]--
A:admin@PE-4# info from state with-context / network-instance default route-table next-hop *
    network-instance default {
        route-table {
            ---snip---
            next-hop 28330675 {
                resource-allocation-failed false
                type mpls
                ip-address 192.168.46.2
                subinterface ethernet-1/6.1
                mpls-encapsulation {
                    entropy-label-transmit false
                    pushed-mpls-label-stack [
                        20000
                    ]
                }
            }
```

```
# On PE-4:    # similar on PE-5 with other Next-hop IP and other Next-hop Subinterface
--{ running }--[  ]--
A:admin@PE-4# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
```

```
|         |           |             |                 |                         | Subinterface
       | labels           |
+=========+===========+=============+=================+=========================+==============
=======+==================+
| 20000   | POP       | ldp         | default         |                         |
       |                  |
| 20001   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)     | ethernet-1/
31.1      | 20000            |
| 20002   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)     | ethernet-1/
31.1      | 20001            |
| 20003   | SWAP      | ldp         | N/A             | 192.168.34.1 (mpls)     | ethernet-1/
32.1      | 20000            |
| 20004   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)     | ethernet-1/
31.1      | 20004            |
| 20005   | SWAP      | ldp         | N/A             | 192.168.46.2 (mpls)     | ethernet-1/6.1
       | 20000            |
+---------+-----------+-------------+-----------------+-------------------------+--------------
-------+------------------+
```

After the **null-label implicit** configuration on PE-6, PE-6 advertises label **IMPLICIT_NULL** for FEC prefix 192.0.2.6/32 to all remote nodes that belong to the MPLS network. Only PE-4 and PE-5 use (egress) label **IMPLICIT_NULL** for FEC prefix 192.0.2.6/32 toward PE-6.

All related labels are withdrawn and re-advertised immediately with label value **IMPLICIT_NULL**. The new label shows up on PE-4 and PE-5 as a swap from the ingress label to an egress label **IMPLICIT_NULL**, although label **IMPLICIT_NULL** is not pushed on to the frame.

```
# On PE-6:
--{ running }--[  ]--
A:admin@PE-6# info from state with-context / network-instance default protocols ldp ipv4
 bindings advertised-prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        advertised-prefix-fec {
                            ---snip---
                            prefix-fec 192.0.2.6/32 lsr-id 192.0.2.4 label-space-id 0 {
                                egress-lsr-fec true
                                label IMPLICIT_NULL
                                label-type pop
                            }
                            prefix-fec 192.0.2.6/32 lsr-id 192.0.2.5 label-space-id 0 {
                                egress-lsr-fec true
                                label IMPLICIT_NULL
                                label-type pop
                            }
```

```
# On PE-4:    # similar on PE-5 with other next-hop 1
--{ running }--[  ]--
A:admin@PE-4# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        received-prefix-fec {
                            ---snip---
                            prefix-fec 192.0.2.6/32 lsr-id 192.0.2.6 label-space-id 0 {
                                label IMPLICIT_NULL
```

```
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding true
                                next-hop 1 {
                                    next-hop 192.168.46.2
                                    next-hop-type primary
                                    interface ethernet-1/6.1
                                }
                            }
```

```
# On PE-4:    # similar on PE-5 for other next-hop
--{ running }--[  ]--
A:admin@PE-4# show / network-instance default route-table next-hop
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Next-hop route table of network instance default
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
---snip---
Index             : 28330676
  Next-hop        : 192.168.46.2
  Type            : mpls
  MPLS label stack: ['IMPLICIT_NULL']
```

```
# On PE-4:    # similar on PE-5 for other next-hop
--{ running }--[  ]--
A:admin@PE-4# info from state with-context / network-instance default route-table next-hop *
    network-instance default {
        route-table {
            ---snip---
            next-hop 28330676 {
                resource-allocation-failed false
                type mpls
                ip-address 192.168.46.2
                subinterface ethernet-1/6.1
                mpls-encapsulation {
                    entropy-label-transmit false
                    pushed-mpls-label-stack [
                        IMPLICIT_NULL
                    ]
                }
            }
```

```
# On PE-4:    # similar on PE-5 with other Next-hop IP and other Next-hop Subinterface
--{ running }--[  ]--
A:admin@PE-4# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+===============
=======+==================+
| 20000   | POP       | ldp         | default         |                        |
       |                  |
| 20001   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20000            |
| 20002   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20001            |
| 20003   | SWAP      | ldp         | N/A             | 192.168.34.1 (mpls)    | ethernet-1/
32.1      | 20000            |
```

```
| 20004   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20004           |
| 20005   | SWAP      | ldp         | N/A             | 192.168.46.2 (mpls)    | ethernet-1/6.1
       | IMPLICIT_NULL    |
+---------+-----------+-------------+-----------------+------------------------+--------------
-------+------------------+
```

8.3.2 Import and export policies

In each node, the default label handling behavior is to originate label bindings for the system address and to propagate all received FECs. If this is not the desired behavior, import or export policies can be applied. An LDP import policy impacts inbound filtering; an LDP export policy impacts outbound filtering. An export policy may be configured to control the set of LDP label bindings advertised by the LER (sending to LDP peers). As such, export policies are used to include additional FECs rather than filtering FECs from those advertised. An import policy can be used to control for which FECs a router generates labels (accepting from LDP peers). This functionality is not unique to LDP; it can be used for IS-IS and OSPF as well as others.

The policy can be global or LDP peer FEC prefix filtering, both for import and export. LDP peer FEC prefix filtering uses a similar policy context as the LDP global policies and works in addition to these global policies.

```
# On any LDP configured node:
enter candidate
    network-instance default protocols ldp {
        tree flat | grep prefix-

network-instance protocols ldp export-prefix-policy
network-instance protocols ldp import-prefix-policy
network-instance protocols ldp peers peer export-prefix-policy
network-instance protocols ldp peers peer import-prefix-policy
```

8.3.2.1 Export policy

By default, a node does not generate labels for its directly connected (local) interfaces. To change this behavior, an export policy is created and applied to the LDP instance or to the **peers peer** context of the LDP instance (applicable per peer). There is no configuration difference in defining an import and export policy.

A policy contains a list of statements. A statement typically contains matching criteria (however, it is not required in cases where everything matches) and a corresponding action. Statements without an action are considered incomplete and are rendered inactive. When processing the policy, the router executes the specified action on the first matching statement; it does not process any further matches. For this reason, statements must be sequenced correctly from most to least specific.

As an example, the local interface 192.168.24.0/30 is exported. The configuration of the LDP export policy to include local interface 192.168.24.0/30 is as follows.

```
# on all nodes:
enter candidate
    routing-policy {
        prefix-set export-prefix-set-test {
            prefix 192.168.24.0/30 mask-length-range exact { }
        }
```

```
        policy export-fec-test {
            default-action {
                policy-result reject    # local prefixes are not avertised, system addresses
 are still advertised
            }
            statement export-statement-test {
                match {
                    prefix {
                        prefix-set export-prefix-set-test
                    }
                }
                action {
                    policy-result accept
                }
            }
        }
```

The LDP export policy is applied to the LDP instance on the nodes, with the **export-prefix-policy** command in the **network-instance default protocols ldp** context.

```
# on all nodes:
enter candidate
    network-instance default {
        protocols {
            ldp {
                export-prefix-policy export-fec-test
```

The interface 192.168.24.0/30 is only local to PE-2 and PE-4, so only PE-2 and PE-4 advertise it. A node only advertises to its directly connected LDP peers (and to the LDP peers with which it has an LDP target binding). So, PE-2 advertises local interface 192.168.24.0/30 to PE-1, PE-4, and PE-5; PE-4 advertises local interface 192.168.24.0/30 to PE-2, PE-3, and PE-6. Each node propagates the received local interface 192.168.24.0/30 to its LDP peers.

```
# On PE-2:    # similar for PE-4 with other LDP peers
--{ running }--[  ]--
A:admin@PE-2# info from state with-context / network-instance default protocols ldp ipv4
 bindings advertised-prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        advertised-prefix-fec {
                            ---snip---    # FEC prefixes for system addresses
                            prefix-fec 192.168.24.0/30 lsr-id 192.0.2.1 label-space-id 0 {
                                egress-lsr-fec true
                                label 20006
                                label-type pop
                            }
                            prefix-fec 192.168.24.0/30 lsr-id 192.0.2.4 label-space-id 0 {
                                egress-lsr-fec true
                                label 20006
                                label-type pop
                            }
                            prefix-fec 192.168.24.0/30 lsr-id 192.0.2.5 label-space-id 0 {
                                egress-lsr-fec true
                                label 20006
                                label-type pop
                            }
```

When the export policy is applied, the active LDP binding table contains additional entries: the local interfaces of PE-2 or PE-4. In the following output, the entries for the system prefixes are snipped; only the additional prefix is shown:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        received-prefix-fec {
                            ---snip---    # FEC prefixes for system addresses
                            prefix-fec 192.168.24.0/30 lsr-id 192.0.2.2 label-space-id 0 {
                                label 20006
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                                not-used-reason rejected-on-rx
                            }

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 |
 as table | filter fields *
+---------------+---------------+---------------+---------------+---------------+--------------
-+---------------+---------------+---------------+
|   Network-    |      Fec      |    Lsr-id     | Label-space-  |     Label     |   Entropy-
 | Ingress-lsr-  |   Used-in-    |   Not-used-   |
|   instance    |               |               |      id       |               |    label-
 |      fec      |  forwarding   |    reason     |
|               |               |               |               |               |   transmit
 |               |               |               |
+===============+===============+===============+===============+===============+==============
=+===============+===============+===============+
| default       | 192.0.2.2/32  | 192.0.2.2     |             0 | 20000         | false
 | true          | true          |               |
| default       | 192.0.2.2/32  | 192.0.2.3     |             0 | 20002         | false
 | true          | false         |               |
| default       | 192.0.2.3/32  | 192.0.2.2     |             0 | 20002         | false
 | true          | false         |               |
| default       | 192.0.2.3/32  | 192.0.2.3     |             0 | 20000         | false
 | true          | true          |               |
| default       | 192.0.2.4/32  | 192.0.2.2     |             0 | 20003         | false
 | true          | true          |               |
| default       | 192.0.2.4/32  | 192.0.2.3     |             0 | 20003         | false
 | true          | false         |               |
| default       | 192.0.2.5/32  | 192.0.2.2     |             0 | 20004         | false
 | true          | true          |               |
| default       | 192.0.2.5/32  | 192.0.2.3     |             0 | 20004         | false
 | true          | false         |               |
| default       | 192.0.2.6/32  | 192.0.2.2     |             0 | 20005         | false
 | true          | true          |               |
| default       | 192.0.2.6/32  | 192.0.2.3     |             0 | 20005         | false
 | true          | false         |               |
| default       | 192.168.24.0/ | 192.0.2.2     |             0 | 20006         | false
 | true          | false         | rejected-on-  |
|               | 30            |               |               |               |
 |               |               | rx            |
+---------------+---------------+---------------+---------------+---------------+--------------
-+---------------+---------------+---------------+
```

PE-2 and PE-4 add an MPLS label for the local prefix.

```
# On PE-4:    # similar on PE-2
--{ running }--[  ]--
A:admin@PE-4# network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+--------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+==============
=======+==================+
| 20000   | POP       | ldp         | default         |                        |
       |                  |
| 20001   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20000            |
| 20002   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20001            |
| 20003   | SWAP      | ldp         | N/A             | 192.168.34.1 (mpls)    | ethernet-1/
32.1      | 20000            |
| 20004   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20004            |
| 20005   | SWAP      | ldp         | N/A             | 192.168.46.2 (mpls)    | ethernet-1/6.1
       | IMPLICIT_NULL    |
| 20006   | POP       | ldp         | default         |                        |
       |                  |
+---------+-----------+-------------+-----------------+------------------------+--------------
-------+------------------+
```

8.3.2.2 Import policy

By default, a node propagates all received FECs. To change this behavior, an import policy is created and applied to the LDP instance or to the **peers peer** context of the LDP instance (applicable per peer). There is no configuration difference in defining an import and export policy.

As an example, the system interface 192.0.2.3/32 is not propagated. The configuration of the LDP import policy to exclude system or local interfaces is as follows:

```
# On all nodes:
enter candidate
    routing-policy {
        prefix-set import-prefix-set-test {
            prefix 192.0.2.3/32 mask-length-range exact { }
        }
        policy import-fec-test {
            default-action {
                policy-result accept   # received local prefixes and system addresses are
 propagated
            }
            statement import-statement-test {
                match {
                    prefix {
                        prefix-set import-prefix-set-test
                    }
                }
                action {
                    policy-result reject
                }
            }
```

```
        }
```

The LDP import policy is applied to the LDP instance on the nodes, with the **import-prefix-policy** command in the **network-instance default protocols ldp** context.

```
# on all nodes:
enter candidate
    network-instance default {
        protocols {
            ldp {
                import-prefix-policy import-fec-test
```

Only PE-3 originates a label binding for this system interface, so only PE-3 advertises it. A node only advertises to its directly connected LDP peers (and to the LDP peers with which it has an LDP target binding). So, only PE-3 advertises system interface 192.0.2.3/32 to PE-1 and PE-4. Each node does not propagate the received system interface 192.0.2.3/32 to its LDP peers. So, only PE-1 and PE-4 receive it.

```
# On PE-3:
--{ running }--[  ]--
A:admin@PE-3# info from state with-context / network-instance default protocols ldp ipv4
 bindings advertised-prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        advertised-prefix-fec {
                            ---snip---
                            prefix-fec 192.0.2.3/32 lsr-id 192.0.2.1 label-space-id 0 {
                                egress-lsr-fec true
                                label 20000
                                label-type pop
                            }
                            prefix-fec 192.0.2.3/32 lsr-id 192.0.2.4 label-space-id 0 {
                                egress-lsr-fec true
                                label 20000
                                label-type pop
                            }
```

When the import policy is applied, the active LDP binding table contains less entries: the system interface of PE-3. Before the import policy is applied, the LDP binding table for PE-1 contains the following entries:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        received-prefix-fec {
                            ---snip---    # FEC prefixes for other system addresses
                            prefix-fec 192.0.2.3/32 lsr-id 192.0.2.2 label-space-id 0 {
                                label 20002
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                            }
                            prefix-fec 192.0.2.3/32 lsr-id 192.0.2.3 label-space-id 0 {
                                label 20000
```

```
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding true
                                next-hop 1 {
                                    next-hop 192.168.13.2
                                    next-hop-type primary
                                    interface ethernet-1/32.1
                                }
                            }
                            prefix-fec 192.168.24.0/30 lsr-id 192.0.2.2 label-space-id 0 {
                                label 20006
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                                not-used-reason rejected-on-rx
                            }

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 |
 as table | filter fields *
+---------------+---------------+---------------+---------------+---------------+-------------
-+---------------+---------------+---------------+
|   Network-    |      Fec      |    Lsr-id     | Label-space-  |     Label     |   Entropy-
 | Ingress-lsr-  |   Used-in-    |   Not-used-   |
|   instance    |               |               |      id       |               |    label-
 |      fec      |  forwarding   |    reason     |
|               |               |               |               |               |   transmit
 |               |               |               |
+===============+===============+===============+===============+===============+=============
=+===============+===============+===============+
| default       | 192.0.2.2/32  | 192.0.2.2     |             0 | 20000         | false
 | true          | true          |               |
| default       | 192.0.2.2/32  | 192.0.2.3     |             0 | 20002         | false
 | true          | false         |               |
| default       | 192.0.2.3/32  | 192.0.2.2     |             0 | 20002         | false
 | true          | false         |               |
| default       | 192.0.2.3/32  | 192.0.2.3     |             0 | 20000         | false
 | true          | true          |               |
| default       | 192.0.2.4/32  | 192.0.2.2     |             0 | 20003         | false
 | true          | true          |               |
| default       | 192.0.2.4/32  | 192.0.2.3     |             0 | 20003         | false
 | true          | false         |               |
| default       | 192.0.2.5/32  | 192.0.2.2     |             0 | 20004         | false
 | true          | true          |               |
| default       | 192.0.2.5/32  | 192.0.2.3     |             0 | 20004         | false
 | true          | false         |               |
| default       | 192.0.2.6/32  | 192.0.2.2     |             0 | 20005         | false
 | true          | true          |               |
| default       | 192.0.2.6/32  | 192.0.2.3     |             0 | 20005         | false
 | true          | false         |               |
| default       | 192.168.24.0/ | 192.0.2.2     |             0 | 20006         | false
 | true          | false         | rejected-on-  |
|               | 30            |               |               |               |
 |               |               | rx            |
+---------------+---------------+---------------+---------------+---------------+-------------
-+---------------+---------------+---------------+
```

When the import policy is applied, the LDP binding table for PE-1 contains the following entries:

```
# On PE-1:
--{ running }--[  ]--
```

```
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec
    network-instance default {
        protocols {
            ldp {
                ipv4 {
                    bindings {
                        received-prefix-fec {
                            ---snip---    # FEC prefixes for other system addresses
                            prefix-fec 192.0.2.3/32 lsr-id 192.0.2.3 label-space-id 0 {
                                label 20000
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                                not-used-reason rejected-on-rx
                            }
                            prefix-fec 192.168.24.0/30 lsr-id 192.0.2.2 label-space-id 0 {
                                label 20006
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                                next-hop 1 {
                                    next-hop 192.168.12.2
                                    next-hop-type primary
                                    interface ethernet-1/31.1
                                }
                            }
                            prefix-fec 192.168.24.0/30 lsr-id 192.0.2.3 label-space-id 0 {
                                label 20006
                                entropy-label-transmit false
                                ingress-lsr-fec true
                                used-in-forwarding false
                            }

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 |
 as table | filter fields *
+--------------+--------------+--------------+--------------+--------------+--------------
-+--------------+--------------+--------------+
|   Network-   |      Fec     |    Lsr-id    | Label-space- |    Label     |   Entropy-
 | Ingress-lsr- |   Used-in-   |   Not-used-  |
|   instance   |              |              |      id      |              |    label-
 |      fec     |  forwarding  |    reason    |
|              |              |              |              |              |   transmit
 |              |              |              |
+==============+==============+==============+==============+==============+==============
=+==============+==============+==============+
| default      | 192.0.2.2/32 | 192.0.2.2    |            0 | 20000        | false
 | true         | true         |              |
| default      | 192.0.2.2/32 | 192.0.2.3    |            0 | 20002        | false
 | true         | false        |              |
| default      | 192.0.2.3/32 | 192.0.2.3    |            0 | 20000        | false
 | true         | false        | rejected-on- |
|              |              |              |              |              |
 |              |              | rx           |
| default      | 192.0.2.4/32 | 192.0.2.2    |            0 | 20003        | false
 | true         | true         |              |
| default      | 192.0.2.4/32 | 192.0.2.3    |            0 | 20003        | false
 | true         | false        |              |
| default      | 192.0.2.5/32 | 192.0.2.2    |            0 | 20004        | false
 | true         | true         |              |
| default      | 192.0.2.5/32 | 192.0.2.3    |            0 | 20004        | false
 | true         | false        |              |
```

```
| default       | 192.0.2.6/32  | 192.0.2.2     |             0 | 20005         | false
 | true          | true          |               |
| default       | 192.0.2.6/32  | 192.0.2.3     |             0 | 20005         | false
 | true          | false         |               |
| default       | 192.168.24.0/ | 192.0.2.2     |             0 | 20006         | false
 | true          | false         |               |
|               | 30            |               |               |               |
 |               |               |               |
| default       | 192.168.24.0/ | 192.0.2.3     |             0 | 20006         | false
 | true          | false         |               |
|               | 30            |               |               |               |
 |               |               |               |
+---------------+---------------+---------------+---------------+---------------+-------------
-+---------------+---------------+---------------+
```

PE-4 and PE-1 lose the MPLS label (20003) for the 192.0.2.3/32 system address.

```
# On PE-4:    # similar on PE-1
--{ running }--[  ]--
A:admin@PE-4# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+--------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+==============
=======+==================+
| 20000   | POP       | ldp         | default         |                        |
       |                  |
| 20001   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20000            |
| 20002   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20001            |
| 20004   | SWAP      | ldp         | N/A             | 192.168.24.1 (mpls)    | ethernet-1/
31.1      | 20004            |
| 20005   | SWAP      | ldp         | N/A             | 192.168.46.2 (mpls)    | ethernet-1/6.1
       | IMPLICIT_NULL    |
| 20006   | POP       | ldp         | default         |                        |
       |                  |
+---------+-----------+-------------+-----------------+------------------------+--------------
-------+------------------+
```

8.3.3 OAM

The following operations, administration, and maintenance operations can be launched on an LDP LSP:

- oam lsp-ping
- oam lsp-trace

As an example, an LSP ping is sent from PE-1 to PE-6:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# tools oam lsp-ping ldp fec 192.0.2.6/32

/oam/lsp-ping/ldp/fec[prefix=192.0.2.6/32]:
    Initiated LSP Ping to prefix 192.0.2.6/32 with session id 49152
```

The result is not directly visible from the response, but can be verified as follows:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / oam lsp-ping ldp fec 192.0.2.6/32
    oam {
        lsp-ping {
            ldp {
                fec 192.0.2.6/32 {
                    session-id 49152 {
                        test-active false
                        statistics {
                            round-trip-time {
                                minimum 4520
                                maximum 4520
                                average 4520
                                standard-deviation 0
                            }
                        }
                        path-destination {
                            ip-address 127.0.0.1
                        }
                        sequence 1 {
                            probe-size 48
                            request-sent true
                            out-interface ethernet-1/31.1
                            reply {
                                received true
                                reply-sender 192.0.2.6
                                udp-data-length 40
                                mpls-ttl 255
                                round-trip-time 4520
                                return-code replying-router-is-egress-for-fec-at-stack-depth-n
                                return-subcode 1
                            }
                        }
```

The ELER (PE-6) returns a reply. The reply includes the sender of the reply, the MPLS TTL (255), the round trip time (in microseconds), and a return-code.

LSP ping results remain present in the state. They can be cleared with:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# tools oam lsp-ping ldp clear

/oam/lsp-ping:
    LDP Ping data has been cleared
```

As an example, an LSP trace is sent from PE-1 to PE-6:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# tools oam lsp-trace ldp fec 192.0.2.6/32

/oam/lsp-trace/ldp/fec[prefix=192.0.2.6/32]:
    Initiated LSP Trace to prefix 192.0.2.6/32 with session id 49153
```

The result can be verified as follows:

```
# On PE-1:
```

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / oam lsp-trace ldp fec 192.0.2.6/32
    oam {
        lsp-trace {
            ldp {
                fec 192.0.2.6/32 {
                    session-id 49153 {
                        test-active false
                        path-destination {
                            ip-address 127.0.0.1
                        }
                        hop 1 {
                            probe 1 {
                                probe-size 76
                                probes-sent 1
                                reply {
                                    received true
                                    reply-sender 192.0.2.2
                                    udp-data-length 60
                                    mpls-ttl 1
                                    round-trip-time 4348
                                    return-code label-switched-at-stack-depth-n
                                    return-subcode 1
                                }
                                downstream-detailed-mapping 1 {
                                    mtu 1500
                                    address-type ipv4-numbered
                                    downstream-router-address 192.168.24.2
                                    downstream-interface-address 192.168.24.2
                                    mpls-label 1 {
                                        label 20005
                                        protocol ldp
                                    }
                                }
                            }
                        }
                        hop 2 {
                            probe 1 {
                                probe-size 76
                                probes-sent 1
                                reply {
                                    received true
                                    reply-sender 192.0.2.4
                                    udp-data-length 60
                                    mpls-ttl 2
                                    round-trip-time 4829
                                    return-code label-switched-at-stack-depth-n
                                    return-subcode 1
                                }
                                downstream-detailed-mapping 1 {
                                    mtu 1500
                                    address-type ipv4-numbered
                                    downstream-router-address 192.168.46.2
                                    downstream-interface-address 192.168.46.2
                                    mpls-label 1 {
                                        label 20000
                                        protocol ldp
                                    }
                                }
                            }
                        }
                        hop 3 {
                            probe 1 {
                                probe-size 76
```

```
                                probes-sent 1
                                reply {
                                    received true
                                    reply-sender 192.0.2.6
                                    udp-data-length 32
                                    mpls-ttl 3
                                    round-trip-time 5102
                                    return-code replying-router-is-egress-for-fec-at-stack-
depth-n
                                    return-subcode 1
                                }
                            }
                        }

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / oam lsp-trace ldp fec * session-id * hop * probe *
 | as table
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
|     Fec      |  Session-id  |     Hop      | Probe-index  | Probes-sent  | Last-probe-  |
 Reply reply- | Reply round- |    Reply     |    Reply     |
|              |              |              |              |              |    send-     |
 sender    |  trip-time   | return-code  |   return-    |
|              |              |              |              |              |   failure-   |
          |              |              |   subcode    |
|              |              |              |              |              |    reason    |
          |              |              |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 192.0.2.6/32 |        49153 |            1 |            1 |            1 |
 | 192.0.2.2    |         4348 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.6/32 |        49153 |            2 |            1 |            1 |
 | 192.0.2.4    |         4829 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.6/32 |        49153 |            3 |            1 |            1 |
 | 192.0.2.6    |         5102 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
```

The LSP trace has three hops: PE-6 is reached from PE-1 via PE-2 and PE-4.

The ELER (PE-6) and the LSRs (PE-2 and PE-4) return a reply. The reply includes the sender of the reply, the MPLS TTL (a sequence number that increases with 1 on each hop along the LSP trace), the round trip time (in microseconds), and a return-code. The ELER has another return-code than the LSRs.

The LSRs have additional downstream (toward the destination) detailed mapping information. The downstream detailed mapping information includes the maximum transfer unit (MTU), the type of IP address, the downstream router address and router interface address, and the label and protocol that is used to reach the next hop.

LSP trace results remain present in the state. They can be cleared with:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# tools oam lsp-trace ldp clear

/oam/lsp-trace:
    LDP Trace data has been cleared
```

8.3.4 LDP statistics

LDP related statistics on each node can be verified as follows:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default protocols ldp statistics
===============================================================================================================
=========================================================
Net-Inst default LDP statistics
---------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
IPv4 Total Discovery Interfaces           : 2    # PE-2 and PE-3
IPv6 Total Discovery Interfaces           : 0
IPv4 Total Discovery Targets              : 0
IPv6 Total Discovery Targets              : 0
IPv4 Total Interface Hello Adjacencies    : 2
IPv6 Total Interface Hello Adjacencies    : 0
IPv4 Total Targeted Hello Adjacencies     : 0
IPv6 Total Targeted Hello Adjacencies     : 0
IPv4 Total Peers                          : 2
IPv6 Total Peers                          : 0
IPv4 Received Prefix FECs                 : 11   # From PE-2: 4 FECs (system) + 1 FEC (non-
system); From PE-3: 5 FECs (system) + 1 FEC (non-system)
IPv4 Advertised Prefix FECs               : 11   # To   PE-2: 4 FECs (system) + 1 FEC (non-
system); To   PE-3: 5 FECs (system) + 1 FEC (non-system)
IPv6 Received Prefix FECs                 : 0
IPv6 Advertised Prefix FECs               : 0
Bad Ldp Identifier                        : 0
Bad Protocol Version                      : 0
Bad Pdu Length                            : 0
Bad Message Length                        : 0
Unknown Tlv                               : 0
Bad Tlv Length                            : 0
Malformed Tlv Value                       : 0
Session Rejected No Hello                 : 0
Session Rejected Parameters Adv Mode      : 0
Session Rejected Parameters Max Pdu Length: 0
Session Rejected Parameters Label Range   : 0
---------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
```

```
===============================================================================================
=========================================================
```

```
# on PE-1:
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp statistics
    network-instance default {
        protocols {
            ldp {
                statistics {
                    ipv4 {
                        total-discovery-interfaces 2        # PE-2 and PE-3
                        total-discovery-targets 0
                        total-interface-hello-adjacencies 2
                        total-targeted-hello-adjacencies 0
                        total-peers 2
                    }
                    ipv6 {
                        total-discovery-interfaces 0
                        total-discovery-targets 0
                        total-interface-hello-adjacencies 0
                        total-targeted-hello-adjacencies 0
                        total-peers 0
                    }
                    fec-statistics {
                        ipv4-prefix {
                            received-fecs 11               # From PE-2: 4 FECs (system) + 1
 FEC (non-system); From PE-3: 5 FECs (system) + 1 FEC (non-system)
                            advertised-fecs 11             # To   PE-2: 4 FECs (system) + 1
 FEC (non-system); To   PE-3: 5 FECs (system) + 1 FEC (non-system)
                        }
                        ipv6-prefix {
                            received-fecs 0
                            advertised-fecs 0
                        }
                    }
                    protocol-errors {
                        bad-ldp-identifier 0
                        bad-protocol-version 0
                        bad-pdu-length 0
                        bad-message-length 0
                        unknown-tlv 0
                        bad-tlv-length 0
                        malformed-tlv-value 0
                        session-rejected-no-hello 0
                        session-rejected-parameters-adv-mode 0
                        session-rejected-parameters-max-pdu-length 0
                        session-rejected-parameters-label-range 0
                    }
```

Parts can be filtered out with the following commands:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp statistics
 ipv4
A:admin@PE-1# info from state with-context / network-instance default protocols ldp statistics
 ipv6
A:admin@PE-1# info from state with-context / network-instance default protocols ldp statistics
 fec-statistics
A:admin@PE-1# info from state with-context / network-instance default protocols ldp statistics
 fec-statistics ipv4-prefix
```

```
A:admin@PE-1# info from state with-context / network-instance default protocols ldp statistics
 fec-statistics ipv6-prefix
```

Each node has additional LDP peer statistics. They can be verified as follows:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp peers
    network-instance default {
        protocols {
            ldp {
                peers {
                    session-keepalive-holdtime 180
                    session-keepalive-interval 60
                    peer 192.0.2.2 label-space-id 0 {
                        fec-limit 0
                        adjacency-type link
                        session-state operational
                        last-oper-state-change "2025-08-25T11:59:07.856Z (20 minutes ago)"
                        ---snip---
                        session-holdtime {
                            peer-proposed 180
                            negotiated 180
                            remaining 142
                        }
                        statistics {
                            received-messages {
                                total-messages 35
                                address 1
                                address-withdraw 0
                                initialization 1
                                keepalive 19
                                label-abort-request 0
                                label-mapping 7   # after applying export policy
                                label-release 2   # after applying export and import policy
                                label-request 0
                                label-withdraw 2  # after applying export and import policy
                                notification 3
                                capability 0
                            }
                            sent-messages {
                                total-messages 35
                                address 1
                                address-withdraw 0
                                initialization 1
                                keepalive 19
                                label-abort-request 0
                                label-mapping 7   # after applying export and import policy
                                label-release 2   # after applying export and import policy
                                label-request 0
                                label-withdraw 2  # after applying export and import policy
                                notification 3
                                capability 0
                            }
                            address-statistics {
                                ipv4 {
                                    received-addresses 4
                                    advertised-addresses 3
                                }
                                ipv6 {
                                    received-addresses 0
                                    advertised-addresses 0
                                }
```

```
                        }
                        fec-statistics {
                            ipv4-prefix {
                                received-fecs 5
                                advertised-fecs 5
                            }
                            ipv6-prefix {
                                received-fecs 0
                                advertised-fecs 0
                            }
                        }
                    }
                }
                peer 192.0.2.3 label-space-id 0 {
                    ---snip---
                }
```

On each node, LDP peer statistics can be filtered out for a single peer with the following command:

```
# On PE-1:
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp peers peer
 <LSR IS> label-space-id 0
```

8.3.5 Debug

Debug logging can be configured for IS-IS and LDP as follows:

```
# On all nodes:
enter candidate
    system logging {
            file isis-log-messages {
                directory /var/log/srlinux/file    # default
                format RSYSLOG_FileFormat          # default
                rotate 4                           # default
                size 10M                           # default
                subsystem isis {
                    priority {
                        match-above debug
                        match-exact [ debug ]
                    }
                }
            }
            file ldp-log-messages {
                directory /var/log/srlinux/file    # default
                format RSYSLOG_FileFormat          # default
                rotate 4                           # default
                size 10M                           # default
                subsystem ldp {
                    priority {
                        match-above debug
                        match-exact [ debug ]
                    }
                }
            }
```

The log file can be verified as follows:

```
# On all nodes:
```

```
--{ running }--[  ]--
A:admin@PE-x# show / system logging file isis-log-messages
###############################################################################################################
# /var/log/srlinux/file/*isis-log-messages*        # presented with option: -c2
###############################################################################################################
2025-08-25T13:47:29.949 sr_isis_mgr: isis|47200|W: In network-instance default, the level-1 IS-
IS adjacency with system 0100.0000.0002, using interface ethernet-1/31.1, moved to state INIT.
2025-08-25T13:47:29.953 sr_isis_mgr: isis|47200|W: In network-instance default, the level-1 IS-
IS adjacency with system 0100.0000.0002, using interface ethernet-1/31.1, moved to state UP.
2025-08-25T13:47:49.394 sr_isis_mgr: isis|47200|W: In network-instance default, the level-1 IS-
IS adjacency with system 0100.0000.0003, using interface ethernet-1/32.1, moved to state INIT.
2025-08-25T13:47:49.399 sr_isis_mgr: isis|47200|W: In network-instance default, the level-1 IS-
IS adjacency with system 0100.0000.0003, using interface ethernet-1/32.1, moved to state UP.
###############################################################################################################

--{ running }--[  ]--
A:admin@PE-x# show / system logging file ldp-log-messages
###############################################################################################################
# /var/log/srlinux/file/*ldp-log-messages*        # presented with option: -c2
###############################################################################################################
2025-08-25T13:58:41.626 sr_ldp_mgr: ldp|61030|I: In network-instance default, LDP is now up and
 functional on the following IPv4 interface ethernet-1/31.1.
2025-08-25T13:58:41.626 sr_ldp_mgr: ldp|61030|I: In network-instance default, LDP is now up and
 functional on the following IPv4 interface ethernet-1/32.1.
2025-08-25T13:58:41.626 sr_ldp_mgr: ldp|61030|I: In network-instance default, LDP-IPv4 is now
 up and functional.
2025-08-25T13:59:07.856 sr_ldp_mgr: ldp|61030|I: In network-instance default, an LDP session is
 now up and operational with peer 192.0.2.2:0.
2025-08-25T13:59:27.572 sr_ldp_mgr: ldp|61030|I: In network-instance default, an LDP session is
 now up and operational with peer 192.0.2.3:0.
###############################################################################################################

--{ running }--[  ]--
A:admin@PE-1#     bash
    cd /var/log/srlinux/file
    ls -lr
        /var/log/srlinux/file
        total 272
        -rw-rw-rw-+ 1 syslog adm 266888 Aug 25 13:58 messages
        -rw-rw-r--+ 1 syslog adm    839 Aug 25 13:59 ldp-log-messages
        -rw-rw-r--+ 1 syslog adm    860 Aug 25 13:47 isis-log-messages

    cat ldp-log-messages
        2025-08-25T13:47:29.949527+02:00 PE-1 sr_isis_mgr: isis|47200|47231|00000|W: In
 network-instance default, the level-1 IS-IS adjacency with system 0100.0000.0002, using
 interface ethernet-1/31.1, moved to state INIT.
        2025-08-25T13:47:29.953380+02:00 PE-1 sr_isis_mgr: isis|47200|47231|00001|W: In
 network-instance default, the level-1 IS-IS adjacency with system 0100.0000.0002, using
 interface ethernet-1/31.1, moved to state UP.
        2025-08-25T13:47:49.394323+02:00 PE-1 sr_isis_mgr: isis|47200|47231|00002|W: In
 network-instance default, the level-1 IS-IS adjacency with system 0100.0000.0003, using
 interface ethernet-1/32.1, moved to state INIT.
        2025-08-25T13:47:49.399233+02:00 PE-1 sr_isis_mgr: isis|47200|47231|00003|W: In
 network-instance default, the level-1 IS-IS adjacency with system 0100.0000.0003, using
 interface ethernet-1/32.1, moved to state UP.
        2025-08-25T13:58:41.626722+02:00 PE-1 sr_ldp_mgr: ldp|61030|61062|00001|I: In network-
instance default, LDP is now up and functional on the following IPv4 interface ethernet-1/31.1.
        2025-08-25T13:58:41.626738+02:00 PE-1 sr_ldp_mgr: ldp|61030|61062|00002|I: In network-
instance default, LDP is now up and functional on the following IPv4 interface ethernet-1/32.1.
        2025-08-25T13:58:41.626746+02:00 PE-1 sr_ldp_mgr: ldp|61030|61062|00003|I: In network-
instance default, LDP-IPv4 is now up and functional.
        2025-08-25T13:59:07.856267+02:00 PE-1 sr_ldp_mgr: ldp|61030|61062|00004|I: In network-
instance default, an LDP session is now up and operational with peer 192.0.2.2:0.
```

```
        2025-08-25T13:59:27.572245+02:00 PE-1 sr_ldp_mgr: ldp|61030|61062|00005|I: In network-
instance default, an LDP session is now up and operational with peer 192.0.2.3:0.
```

8.4 Conclusion

MPLS provides the capability to establish connection-oriented paths over a connectionless network. LDP point-to-point LSPs are dynamically signaled and LDP LFA is supported. This can greatly improve network resiliency. In this chapter, the configuration of several LDP point-to-point LSP features is given together with the associated show output which can be used to verify and troubleshoot.

9 MAC-VRF network-instances for server aggregation

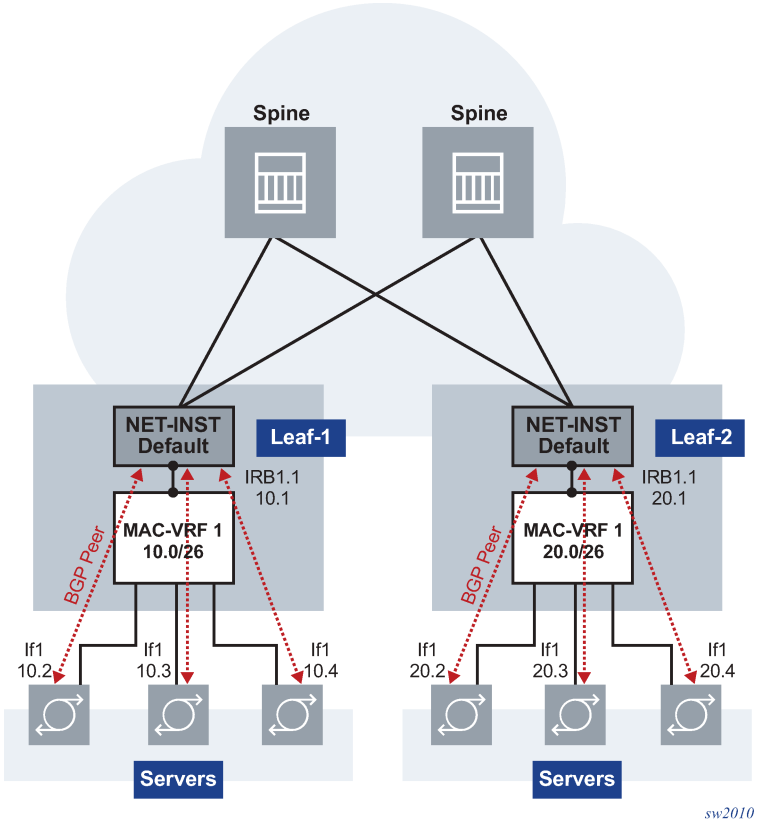
MAC-VRF network-instances can provide aggregation for a group of servers into the same subnet. This chapter defines concepts and procedures for configuring MAC-VRF network-instances and Integrated Routing and Bridging (IRB) subinterfaces.

9.1 Overview

Data Center (DC) servers or hosts are connected to TOR routers so that they can be reached from other TOR routers in the same IP fabric. The TOR nodes use BGP to learn and propagate subnet reachability in the underlaying routing infrastructure. The servers or hosts connected to these TOR BGP routers use routed subinterfaces on the TOR, and static routes or a PE-CE BGP session, to learn or advertise reachability to the rest of the DC.

Each server requires a separate routed subinterface and subnet on the TOR, and the number of subinterfaces and local routes in the route-table grows linearly as the number of servers increases. The use of a MAC-VRF network-instance provides aggregation for a group of servers into the same subnet. This saves routes and subinterfaces in the TOR. A MAC-VRF is attached to the default network-instance by a single IRB interface and subnet, instead of a separate subinterface and route per server. The following figure shows an example of MAC-VRF network-instances for server aggregation.

Figure 16: MAC-VRF network-instances for server aggregation

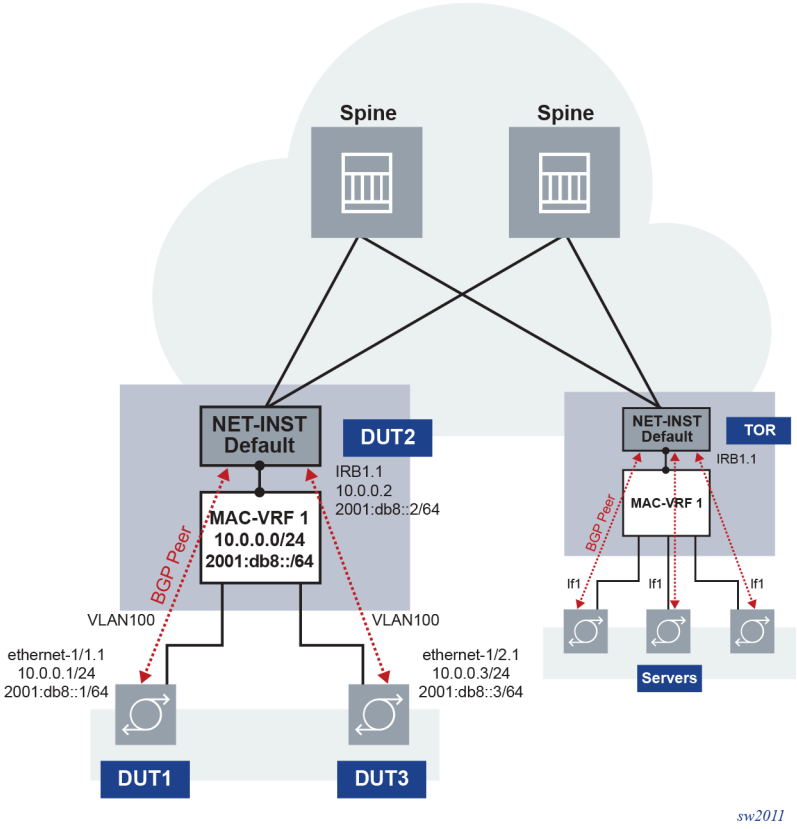


In this example, Leaf-1 and Leaf-2 are configured with MAC-VRF instances that aggregate a group of servers. These servers are assigned IP addresses on the same subnet and are connected to the leaf default network-instance by a single IRB subinterface. The servers use a PE-CE BGP session with the IRB IP address to exchange reachability. The use of the MAC-VRF with an IRB subinterface saves routed subinterfaces on the default network-instance; only one routed subinterface is needed instead of one per server.

9.2 Configuration of MAC-VRF network-instances and IRB subinterfaces

The following figure shows an example of how to configure MAC-VRF network-instances and their IRB subinterfaces to the default network-instance, and how EBGP sessions are configured with the servers. In this example, DUT2 is the TOR being configured. DUT1 and DUT3 are servers that are running BGP against the DUT2 IRB subinterface.

Figure 17: MAC-VRF and IRB example in DUT2



9.2.1 Example: Configure DUT2 with MAC-VRF, IRB, and static BGP on IRB

Prerequisites

This example assumes DUT2 is pre-configured with a default network-instance that runs BGP sessions to the spine routers, as defined in the section: BGP for underlay routing.

About this task

This example shows how to configure the DUT2 with a MAC-VRF, bridged subinterfaces to DUT1 and DUT3, and an IRB subinterface (see Figure 17: MAC-VRF and IRB example in DUT2).

Procedure

Step 1. In candidate mode, create the interfaces and bridged subinterfaces to connect to DUT1 and DUT3.

In this example:

- Connect ethernet-1/1 and ethernet-1/2 to DUT1 and DUT3, respectively. Although these interfaces could be defined untagged, this example configures them as tagged (vlan-tagging true).

- Create a subinterface with index 1 under each interface. The subinterface must be configured as type bridged. Bridged subinterfaces can be associated with MAC-VRF instances so that MAC learning and layer-2 forwarding can be enabled on them.
- The subinterfaces use vlan-id 100 because this is the VLAN ID used by the servers (DUT1 and DUT2) to send and receive frames.

Example

```
--{ candidate shared default }--[ interface * ]--
A:dut2# info
    interface ethernet-1/1 {
        description dut2-dut1
        vlan-tagging true
        subinterface 1 {
            type bridged
            vlan {
                encap {
                    single-tagged {
                        vlan-id 100
                    }
                }
            }
        }
    }
    interface ethernet-1/2 {
        description dut2-dut3
        vlan-tagging true
        subinterface 1 {
            type bridged
            vlan {
                encap {
                    single-tagged {
                        vlan-id 100
                    }
                }
            }
        }
    }
```

Step 2. Configure an IRB interface and subinterface to connect the MAC-VRF to the existing default network-instance.

The IRB is configured in a similar way to a loopback interface and subinterfaces. The IRB subinterface must be type routed, but does not need to be explicitly configured as routed.

Example

```
--{ candidate shared default }--[ interface irb* ]--
A:dut2# info
    interface irb1 {
        subinterface 1 {
            ipv4 {
                admin-state enable
                address 10.0.0.2/24 {
                }
            }
            ipv6 {
                admin-state enable
                address 2001:db8::2/64 {
                }
            }
```

```
        }
    }
```

Step 3. Configure the network-instance type mac-vrf and associate it with the bridged and IRB interfaces.

Example

```
--{ candidate shared default }--[ network-instance MAC-VRF-1 ]--
A:dut2# info
    type mac-vrf
    admin-state enable
    interface ethernet-1/1.1 {
    }
    interface ethernet-1/2.1 {
    }
    interface irb1.1 {
    }
```

Step 4. Associate the same IRB interface with the network-instance default and configure the BGP IPv4 and IPv6 neighbors to DUT1 and DUT3.

See BGP for underlay routing for more information about configuring BGP sessions.

Example

```
--{ candidate shared default }--[ network-instance default ]--
A:dut2# info
    type default
    admin-state enable
    router-id 2.2.2.2
    interface irb1.1 {
    }
    interface lo0.1 {
    }
    protocols {
        bgp {
            admin-state enable
            afi-safi ipv4-unicast {
                admin-state enable
            }
            autonomous-system 64502
            router-id 10.0.0.2
            ebgp-default-policy {
                import-reject-all false
            }
            failure-detection {
                enable-bfd true
                fast-failover true
            }
            group tor {
                admin-state enable
                export-policy pass-all
                afi-safi ipv4-unicast {
                    admin-state enable
                }
                afi-safi ipv6-unicast {
                    admin-state enable
               }
               local-as as-number 64502 {
               }
               timers {
                   minimum-advertisement-interval 1
               }
               trace-options {
```

```
                    flag update {
                    }
                    flag graceful-restart {
                    }
                    flag events {
                    }
                    flag keepalive {
                    }
                    flag notification {
                    }
                    flag open {
                    }
                    flag packets {
                    }
                    flag route {
                    }
                    flag socket {
                    }
                    flag timers {
                    }
                }
            }
            afi-safi ipv4-unicast {
                admin-state enable
            }
            afi-safi ipv6-unicast {
                admin-state enable
            }
            neighbor 10.0.0.1 {
               peer-as 64501
               peer-group tor
               transport {
                   local-address 10.0.0.2
               }
             }
            neighbor 10.0.0.3 {
                peer-as 64503
                peer-group tor
                transport {
                    local-address 10.0.0.2
                }
            }
            neighbor 2001:db8::1 {
                peer-as 64501
                peer-group tor
                transport {
                    local-address 2001:db8::2
                }
            }
            neighbor 2001:db8::3 {
                peer-as 64503
                peer-group tor
                transport {
                    local-address 2001:db8::2
                }
            }
        }
    }
```

Step 5. Review all the changes and commit if correct.

Example

```
--{ candidate shared default }--[  ]--
```

```
A:dut2# commit stay
```

Step 6. Check the state of the MAC-VRF and the connectivity to DUT1 and DUT3 using the following commands:

- **show network-instance MAC-VRF-1 interfaces**
- **show network-instance default interfaces**
- **show network-instance MAC-VRF-1 bridge-table mac-table all**
- **show arpnd arp-entries interface irb1**
- **show arpnd neighbors interface irb1**
- **show network-instance default protocols bgp neighbor**

Example

```
A:dut2# show network-instance MAC-VRF-1 interfaces
===========================================================================
Net instance    : MAC-VRF-1
Interface       : ethernet-1/1.1
Type            : bridged
Oper state      : up
===========================================================================
Net instance    : MAC-VRF-1
Interface       : ethernet-1/2.1
Type            : bridged
Oper state      : up
===========================================================================
Net instance    : MAC-VRF-1
Interface       : irb1.1
Oper state      : up
Ip mtu          : 1500
                  Prefix                      Origin        Status
  ===========================================================================
  10.0.0.2/24                                 static
  2001:db8::2/64                              static       preferred
  fe80::201:2ff:feff:41/64                    link-layer   preferred
===========================================================================
```

```
A:dut2# show network-instance default interfaces
===========================================================================
Net instance    : default
Interface       : irb1.1
Oper state      : up
Ip mtu          : 1500
                  Prefix                      Origin        Status
  ===========================================================================
  10.0.0.2/24                                 static
  2001:db8::2/64                              static       preferred
  fe80::201:2ff:feff:41/64                    link-layer   preferred
===========================================================================
Net instance    : default
Interface       : lo0.1
Oper state      : up
                  Prefix                      Origin        Status
  ===========================================================================
  2.2.2.2/32                                  static
  2001:db8:1::2/128                           static       preferred
```

```
===============================================================
```

```
A:dut2# show network-instance MAC-VRF-1 bridge-table mac-table all
-------------------------------------------------------------------------------------------------
Mac-table of network instance MAC-VRF-1
-------------------------------------------------------------------------------------------------
+-------------------+----------------+-------+-----------+--------+-------+--------------------------+
|        address    |   Destination  | Dest  |   Type    | Active | Aging |  Last Update             |
|                   |                | Index |           |        |       |                          |
+===================+================+=======+===========+========+=======+==========================+
| 00:01:01:FF:00:00 | ethernet-1/1.1 | 16    | learnt    | true   | 287   | 2020-06-03T13:40:25.000Z |
| 00:01:02:FF:00:41 | irb-interface  | 0     | irb-      | true   | N/A   | 2020-06-02T13:53:50.000Z |
|                   |                |       | interface |        |       |                          |
| 00:01:03:FF:00:00 | ethernet-1/2.1 | 17    | learnt    | true   | 287   | 2020-06-03T13:40:25.000Z |
+-------------------+----------------+-------+-----------+--------+-------+--------------------------+
Total Irb Macs            :    1 Total    1 Active
Total Static Macs         :    0 Total    0 Active
Total Duplicate Macs      :    0 Total    0 Active
Total Learnt Macs         :    2 Total    2 Active
Total Macs                :    3 Total    3 Active
-------------------------------------------------------------------------------------------------
```

```
A:dut2# show arpnd arp-entries interface irb1
+-----------+-------------+----------+---------+----------------------+--------------------+
| Interface | Subinterface | Neighbor | Origin  |  Link layer address  |    Expiry          |
+===========+=============+==========+=========+======================+====================+
| irb1      |      1       | 10.0.0.1 | dynamic | 00:01:01:FF:00:00    | 3 hours from now   |
| irb1      |      1       | 10.0.0.3 | dynamic | 00:01:03:FF:00:00    | 3 hours from now   |
+-----------+-------------+----------+---------+----------------------+--------------------+
-------------------------------------------------------------------------------------------
  Total entries : 2 (0 static, 2 dynamic)
-------------------------------------------------------------------------------------------
```

```
A:dut2# show arpnd neighbors interface irb1
+-----------+-----------+---------------+---------+--------------------+---------+-----------+------+
| Interface |   Sub     | Neighbor      | Origin  | Link layer address | Current | Next state| Is   |
|           | interface |               |         |                    |  state  |  change   |Router|
+===========+===========+===============+=========+====================+=========+===========+======+
| irb1      |    1      | 2001:db8::1   | dynamic | 00:01:01:FF:00:00  | stale   | 2 hours   | true |
|           |           |               |         |                    |         | from now  |      |
| irb1      |    1      | 2001:db8::3   | dynamic | 00:01:03:FF:00:00  | stale   | 2 hours   | true |
|           |           |               |         |                    |         | from now  |      |
| irb1      |    1      | fe80::201:1ff:| dynamic | 00:01:01:FF:00:00  | stale   | 2 hours   | true |
|           |           |  feff:0       |         |                    |         | from now  |      |
| irb1      |    1      | fe80::201:3ff:| dynamic | 00:01:03:FF:00:00  | stale   | 2 hours   | true |
|           |           | feff:0        |         |                    |         | from now  |      |
+-----------+-----------+---------------+---------+--------------------+---------+-----------+------+
-----------------------------------------------------------------------------------------------
  Total entries : 4 (0 static, 4 dynamic)
-----------------------------------------------------------------------------------------------
```

```
A:dut2# show network-instance default protocols bgp neighbor
-------------------------------------------------------------------------------------------------
BGP neighbor summary for network-instance "default"
Flags: S static, D dynamic, L discovered by LLDP, B BFD enabled, - disabled, * slow
-------------------------------------------------------------------------------------------------
+----------+-------------+-----+----+-------+-------------+---------------+------------+------------+
| Net-Inst |   Peer      |Group|Flag| Peer  |    State    |    Uptime     |  AFI/SAFI  | [Rx/Active |
|          |             |     |    |  -AS  |             |               |            |    /Tx]    |
+==========+=============+=====+====+=======+=============+===============+============+============+
| default  | 10.0.0.1    | tor | SB | 64501 | established | 0d:3h:12m:33s | ipv4-unicast | [3/2/4]  |
```

```
|           |              |     |    |       |             |                | ipv6-unicast | [3/2/4]  |
| default   | 10.0.0.3     | tor | SB | 64503 | established | 0d:3h:10m:55s | ipv4-unicast | [3/2/4]  |
|           |              |     |    |       |             |                | ipv6-unicast | [3/2/4]  |
| default   | 2001:db8::1  | tor | SB | 64501 | established | 0d:3h:12m:31s | ipv4-unicast | [0/0/0]  |
|           |              |     |    |       |             |                | ipv6-unicast | [6/0/6]  |
| default   | 2001:db8::3  | tor | SB | 64503 | established | 0d:3h:10m:52s | ipv4-unicast | [0/0/0]  |
|           |              |     |    |       |             |                | ipv6-unicast | [6/0/6]  |
+-----------+--------------+-----+----+-------+-------------+----------------+--------------+----------+
-------------------------------------------------------------------------------------------------------
Summary:
4 configured neighbors, 4 configured sessions are established,0 disabled peers
0 dynamic peers
```

9.3 Advanced configuration: bridge-table settings

A MAC-VRF network-instance uses a bridge-table to forward frames between its subinterfaces. Some bridge-table properties can be configured. For example:

Example:

```
--{ * candidate shared default }--[ network-instance MAC-VRF-1 bridge-table ]
A:dut2# tree detail
bridge-table!    net_inst_mgr
+-- discard-unknown-dest-mac?    net_inst_mgr
+-- mac-learning    net_inst_mgr
|   +-- admin-state?    net_inst_mgr
|   +-- aging    net_inst_mgr
|       +-- admin-state?    net_inst_mgr
|       +-- age-time?    net_inst_mgr
+-- mac-duplication    net_inst_mgr
|   +-- admin-state?    net_inst_mgr
|   +-- monitoring-window?    net_inst_mgr
|   +-- num-moves?    net_inst_mgr
|   +-- hold-down-time?    net_inst_mgr
|   +-- action?    net_inst_mgr
+-- mac-limit    net_inst_mgr
|   +-- maximum-entries?    net_inst_mgr
|   +-- warning-threshold-pct?    net_inst_mgr
+-- static-mac    l2_static_mac_mgr
    +-- mac* [address]    l2_static_mac_mgr
        +-- address    l2_static_mac_mgr
        +-- destination?M    l2_static_mac_mgr
```

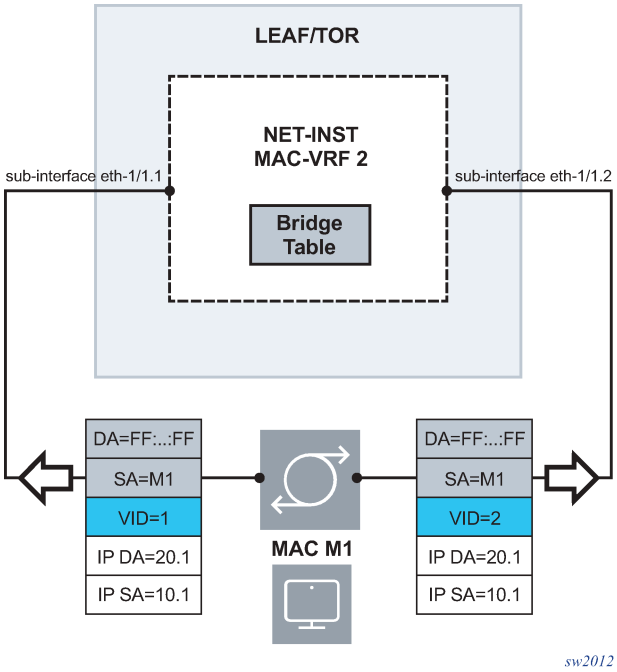
Where:

- The “mac-learning” container provides control over how MACs are dynamically learned on the subinterfaces, including whether learning is enabled (admin-state) or controlled by the aging timer for the mac-table.
- The “mac-duplication” container controls how the system behaves when duplicate MACs are detected.
- The “mac-limit” container provides parameters for limiting the maximum number of MACs installed for a specific mac-vrf.
- The “static-macs” provides control to configure and associate to either a subinterface destination or with a blackhole. Incoming frames with the source or destination MAC matching a configured "blackholed mac" are discarded by the system.

9.4 Advanced configuration: MAC-duplication for loop protection

SR Linux supports MAC-duplication detection and associated procedures to protect the system against network loops. The following figure shows a simple loop and describes the associated configuration.

Figure 18: MAC-Duplication for loop protection



In this example, MAC-VRF 2 is connected using two bridged subinterfaces to a layer 2 switch. When a host with MAC M1 sends a broadcast frame, a loop is created. MAC-duplication is, by default, enabled in mac-vrf network-instances with the following parameters:

```
--{ * candidate shared default }--[ network-instance MAC-VRF-1 bridge-table mac-
duplication ]--
A:dut2# info detail
    admin-state enable
    monitoring-window 3
    num-moves 5
    hold-down-time 10
    action stop-learning
```

The loops shown in this example are resolved in the following sequence:

1. MAC-duplication detection.
   - A MAC M1 is declared as "duplicate" when the number of moves across two or more subinterfaces exceeds the configured num-moves in the configured monitoring-window.
   - When M1 is "duplicate", it is kept in a duplicate-entries list and stays associated with the last subinterface where the MAC was learned before the number of moves exceed the num-moves value.
2. MAC-duplication action.

- When the MAC M1 is declared "duplicate" in a subinterface, an action is taken in that subinterface. The action is configurable per network-instance and can be overridden on a per-subinterface basis.
- Possible actions on the subinterface are oper-down, blackhole, and stop-learning.
  - oper-down - Brings down the subinterface, breaks the loop, and discards all the frames arriving on the subinterface.
  - blackhole - Discards frames with a source or destination MAC that matches the duplicate MAC. but allows the remaining frames to forward normally on the subinterface.
  - stop-learning - Does not discard any frame on the subinterface and keeps the existing MACs learned against it. No new MACs are learned on the subinterface until the action is cleared.

```
--{ * candidate shared default }--[ network-instance MAC-VRF-1 bridge-table mac-duplication ]--
A:dut2# action <value>
usage: action <blackhole|oper-down|stop-learning>
Action to take on the subinterface whose action is use-net-instance-action,
 upon detecting one or more mac addresses as duplicate
In particular:
- Oper-down: if configured, upon detecting a duplicate mac on the subinterface, the subinterface
  will be brought oper-down.
- Blackhole: upon detecting a duplicate mac on the subinterface, the mac will be blackholed. Any
  frame received on this or any other subinterface with MAC SA matching a blackhole mac is discarded.
- Stop-learning: this is the default action, compliant with RFC7432. Upon detecting a duplicate mac
 on the subinterface, the mac will not be relearned anymore on this or any subinterface.
Positional arguments: value
```

3. MAC-duplication hold-down-time and process restart.
   - When the configured hold-down-time expires, the duplicate MAC is flushed from the mac-table and the entire process restarts for the MAC.
   - The duplicate action on a subinterface clears when there are no longer duplicate MAC addresses in the subinterface.

As a loop protection mechanism, MAC-duplication is self-contained and does not require a control plane protocol that runs network-wide among network devices.

9.4.1 Example: Configure MAC-duplication and troubleshoot loops in DUT2

About this task

Use this example to assist in configuring MAC-duplication. This example assumes MAC-VRF 1 is connected to a layer 2 switch (not shown) using two bridge subinterfaces (ethernet-1/1.2 and ethernet-1/1.3). This creates a loop.

Configure DUT2 with the following MAC-duplication settings to troubleshoot the loop:

Procedure

Step 1. Use the **mac-duplication** command to configure MAC-duplication settings, as shown in the following example:

Example

```
--{ candidate shared default }--[ network-instance MAC-VRF-1 ]--
A:dut2# info
    type mac-vrf
    admin-state enable
```

```
    interface ethernet-1/1.1 {
    }
    interface ethernet-1/1.2 {
    }
    interface ethernet-1/1.3 {
    }
    interface ethernet-1/2.1 {
    }
    interface irb1.1 {
    }
    bridge-table {
        mac-duplication {
            num-moves 3
            hold-down-time 300
            action stop-learning
        }
    }
```

Step 2. Configure the subinterfaces with the following **mac-duplication** actions:

In this example, the MAC-duplication action configured under the network-instance is overridden by the more specific action under the subinterfaces 2 and 3. When traffic is generated by the remote layer 2 switch, the same MAC address moves between ethernet-1/1.2 and ethernet-1/1.3. After the third move, the MAC is declared a duplicate and appears in the duplicate-entries list:

Example

```
--{ * candidate shared default }--[ interface * subinterface * bridge-table mac-
duplication ]--
A:dut2# info
    interface ethernet-1/1 {
        subinterface 1 {
            bridge-table {
                mac-duplication {
                }
            }
        }
        subinterface 2 {
            bridge-table {
                mac-duplication {
                    action oper-down
                }
            }
        }
        subinterface 3 {
            bridge-table {
                mac-duplication {
                    action oper-down
                }
            }
```

Step 3. Use the **show network-instance bridge-table mac-table** command to display the duplicate MAC entries.

Example

```
A:dut2# show network-instance MAC-VRF-1 bridge-table mac-table all
------------------------------------------------------------------------------------------------
Mac-table of network instance MAC-VRF-1
------------------------------------------------------------------------------------------------
+------------------+----------------+-------+-----------+--------+-------+--------------------------+
| address          |  Destination   | Dest  |   Type    | Active | Aging |  Last Update             |
|                  |                | Index |           |        |       |                          |
```

```
+===================+================+=======+===========+========+=======+=========================+
| 00:01:01:FF:00:00 | ethernet-1/1.1 | 16    | learnt    | true   | 287   | 2020-06-03T13:40:25.000Z |
| 00:01:01:FF:00:41 | ethernet-1/1.3 | 20    | duplicate | true   | N/A   | 2020-06-05T20:07:24.000Z |
| 00:01:02:FF:00:41 | irb-interface  | 0     | irb-      | true   | N/A   | 2020-06-02T13:53:50.000Z |
|                   |                |       | interface |        |       |                          |
| 00:01:03:FF:00:00 | ethernet-1/2.1 | 17    | learnt    | true   | 287   | 2020-06-03T13:40:25.000Z |
+-------------------+----------------+-------+-----------+--------+-------+--------------------------+
Total Irb Macs            :    1 Total    1 Active
Total Static Macs         :    0 Total    0 Active
Total Duplicate Macs      :    1 Total    1 Active
Total Learnt Macs         :    2 Total    2 Active
Total Macs                :    4 Total    4 Active
-------------------------------------------------------------------------------------------------


A:dut2# show network-instance MAC-VRF-1 bridge-table mac-duplication duplicate-entries
-------------------------------------------------------------------------------------------------
Mac-Duplication in network instance MAC-VRF-1
-------------------------------------------------------------------------------------------------
Admin state            : enable
Monitoring window      : 3
Number of moves allowed: 3
Hold down time         : 300
Action                 : stop-learning
-------------------------------------------------------------------------------------------------
+-------------------+----------------+------------+--------------------------+--------------------+
| Duplicate MAC     | Destination    | Dest Index |      Detect Time         | Hold Time Remaining |
+===================+================+============+==========================+====================+
| 00:01:01:FF:00:41 | ethernet-1/1.3 | 20         | 2020-06-05T20:07:24.000Z | 270                |
+-------------------+----------------+------------+--------------------------+--------------------+
Total Duplicate Macs      :    1 Total    0 Active
-------------------------------------------------------------------------------------------------
```

9.4.2 Using logs to detect duplicate MACs

Procedure

You can use a log event to help troubleshoot when MACs are detected as duplicate, or when they are deleted after the hold-down-timer. For example:

Example

```
[root@dut2 srlinux]# tail -f /var/log/srlinux/debug/sr_l2_mac_mgr.log
2020-06-06T06:22:48.679070+00:00 dut2 local6|NOTI sr_l2_mac_mgr: bridgetable|2608|2608|00035|N:
    A duplicate MAC address 00:01:01:FF:00:00 was detected on MAC-VRF-1.
2020-06-06T06:27:48.933312+00:00 dut2 local6|NOTI sr_l2_mac_mgr: bridgetable|2608|2608|00036|N:
    A duplicate MAC address 00:01:01:FF:00:00 detected on MAC-VRF-1 is now deleted.
```

The network-instance manager logs also show when the subinterfaces go down as a result of MAC-duplication. For example:

Example

```
[root@dut2 srlinux]# tail -f /var/log/srlinux/debug/sr_net_inst_mgr.log
2020-06-06T06:22:48.680609+00:00 dut2 local6|WARN sr_net_inst_mgr: netinst|2663|2663|00080|W:
    The interface ethernet-1/1.3 in network-instance MAC-VRF-1 is now down for reason:
    A duplicate MAC address has been detected
```

10 MPLS LDP LFA using ISIS as IGP

This chapter describes Multi- Protocol Label Switching (MPLS) Label Distribution Protocol (LDP) Loop Free Alternate (LFA) using Intermediate System to Intermediate System (IS-IS) as the Interior Gateway Protocol (IGP).

Topics in this chapter include:

10.1 Applicability

The configuration in this chapter corresponds to SR Linux Release 25.7.R1. There are no prerequisites for this configuration.

10.2 Overview

LDP LFA improves convergence in case of a single link or single node failure in the network. Convergence times are in the order of tens of milliseconds. This is important to some application services, such as voice over IP (VoIP), which are sensitive to traffic loss when running over the MPLS network.

Without LFA, link or node failures inside an MPLS LDP network result in traffic loss in the order of hundreds of milliseconds. The reason for that is that LDP depends on the convergence of the underlying IGP (IS-IS sending link state PDUs (LSPs) in this case). After IGP convergence, LDP itself needs to compute new primary Next Hop Label Forwarding Entries (NHLFEs) for all affected Forwarding Equivalence Classes (FECs). Finally, the different Label Forwarding Information Bases (LFIBs) are updated.

When LFA is configured on a node, the node computes primary NHLFEs for all FECs and, in addition, the node computes backup NHLFEs for all FECs. The backup NHLFE corresponds to the label received for the same FEC from a Loop-Free Alternate (LFA) next hop, see RFC 5286.

The SR Linux software has implemented inequality 1 (link criterion) and inequality 3 (node criterion) of RFC 5286. The LFA next hop computation is based on the IGP metric, similar to the Shortest Path Tree (SPT) computation that is part of standard link-state routing functionality, .

The underlying LFA formulas appear in the following format:

Inequality 1:

```
SP(backup NHR, D) < SP(backup NHR, S) + SP(S, D)
```

Inequality 3:

```
SP(backup NHR, D) < SP(backup NHR, PN) + SP(PN, D)
```

In these inequalities:

- SP is shortest IGP metric path
- NHR is next hop router
- D is destination
- S is source node or upstream node doing the actual LFA next-hop computation
- PN is protected node

The inequality 3 rule is stricter than the inequality 1 rule. See Additional topics for a practical example on these inequalities.

10.3 Configuration

This section includes the following:

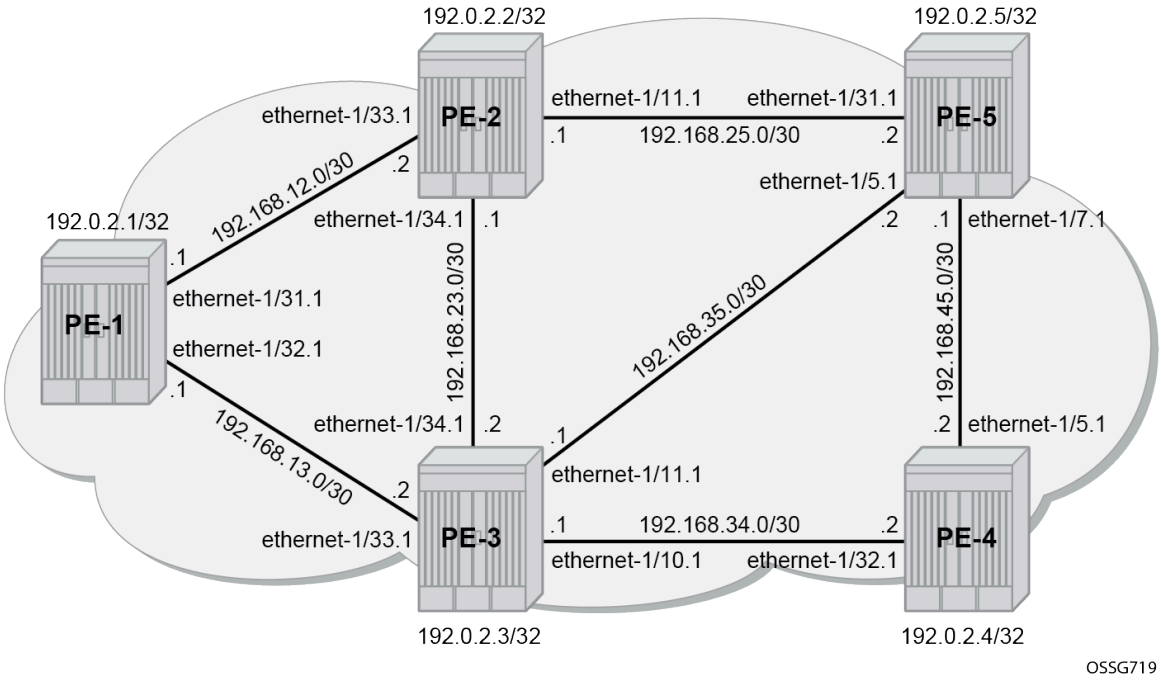
- Configure the IP/MPLS network
- Enable LDP LFA and verify
- Enable synchronization timer
- Verify data path

The subsection Additional topics includes:

- Metric change
- IS-IS overload

Figure 19: Initial example topology shows the example topology with five PEs in the same autonomous system.

Figure 19: Initial example topology



10.3.1 Configure the IP/MPLS network

The system addresses and IP interface addresses are configured according to Figure 19: Initial example topology. An interior gateway protocol (IGP) is needed to distribute routing information on all PEs. In this case, the IGP is IS-IS where each PE is acting as a level 2 router. On PE-1, the IS-IS configuration is as follows. The configuration is similar on the other PEs.

```
# On PE-1:
enter candidate
    network-instance default protocols isis {
                instance 0 {
                    admin-state enable
                    level-capability L2
                    level 2 {
                        metric-style wide    # default
                    }
                    net [ 49.0000.0100.0000.0001.00 ]
                    interface ethernet-1/31.1 {
                        admin-state enable
                        circuit-type point-to-point
                    }
                    interface ethernet-1/32.1 {
                        admin-state enable
                        circuit-type point-to-point
                    }
                    interface system0.0 { }
```

IS-IS interfaces are set up as type point-to-point to improve convergence because no Designated Router/ Backup Designated Router (DR/BDR) election process is done. The **show / network-instance default protocols isis adjacency** command on PE-1 verifies that the IS-IS adjacencies are up:

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default protocols isis adjacency
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Network Instance: default
Instance        : 0
Instance Id     : 0
+-----------------+--------------------+-----------------+--------------+--------------+-------
+-------------------------+--------------------+
| Interface Name  | Neighbor System Id | Adjacency Level |  Ip Address  | Ipv6 Address | State
 |     Last transition      | Remaining holdtime |
+=================+====================+=================+==============+==============+=======
+=========================+====================+
| ethernet-1/31.1 | 0100.0000.0002     | L2              | 192.168.12.2 | ::           | up
 | 2025-08-29T09:35:15.200Z | 27                 |
| ethernet-1/32.1 | 0100.0000.0003     | L2              | 192.168.13.2 | ::           | up
 | 2025-08-29T09:35:34.000Z | 27                 |
+-----------------+--------------------+-----------------+--------------+--------------+-------
+-------------------------+--------------------+
Adjacency Count: 2
-------------------------------------------------------------------------------------------------
-------------------------------------------------------

--{ running }--[  ]--
A:admin@PE-1# show / network-instance default protocols isis adjacency detail
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Network Instance: default
Instance        : 0
Instance Id     : 0
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Neighbor System Id         : 0100.0000.0002
Adjacency Level            : L2
Operational Adjacency Level: L2
Interface Name             : ethernet-1/31.1
State                      : up
Hello Interval             : 9 Max hold:27, Remaining hold:21
Ip Address                 : V4:192.168.12.2  V6:::
Hostname                   : PE-2
SNPA                       : 00:01:02:FF:00:20
Priority                   : 0
Adjacency Up Time          : 2025-08-29T09:35:15.200Z
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Neighbor System Id         : 0100.0000.0003
Adjacency Level            : L2
Operational Adjacency Level: L2
Interface Name             : ethernet-1/32.1
State                      : up
Hello Interval             : 9 Max hold:27, Remaining hold:22
Ip Address                 : V4:192.168.13.2  V6:::
Hostname                   : PE-3
SNPA                       : 00:01:03:FF:00:20
Priority                   : 0
Adjacency Up Time          : 2025-08-29T09:35:34.000Z
```

```
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
```

The **show / network-instance default route-table all** command on PE-1 verifies which IP interface addresses or subnets are known on the PE:

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table all
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
|     Prefix      |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
    | Next-hop  | Next-hop  |  Backup   |  Backup   |
|                 |      |   Type    |                    |         | Network |        |
    |  (Type)   | Interface | Next-hop  | Next-hop  |
|                 |      |           |                    |         | Instanc |        |
    |           |           |  (Type)   | Interface |
|                 |      |           |                    |         |    e    |        |
    |           |           |           |                    |
+=================+======+===========+====================+=========+=========+========+=======
====+===========+===========+===========+===========+
| 192.0.2.1/32    | 15   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.0.2.2/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.0.2.3/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.0.2.4/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.0.2.5/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.12.0/30 | 13   | local     | net_inst_mgr       | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.1       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.12.1/32 | 13   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
```

```
| 192.168.12.3/32 | 13   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.0/30 | 14   | local     | net_inst_mgr       | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.1       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.13.1/32 | 14   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.3/32 | 14   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.23.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.25.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.34.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.35.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.45.0/30 | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 routes total                    : 16
IPv4 prefixes with active routes     : 16
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------------
-------------------------------------------------------

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default route-table ipv4-unicast
 route * id * route-type * route-owner * origin-network-instance * |
 as table | filter fields active metric preference next-hop-group next-hop-group-network-
instance
+------------+------------+------------+------------+------------+------------+------------+---
---------+------------+------------+------------+
|  Network-  |   Ipv4-    |     Id     | Route-type |   Route-   |  Origin-   |   Active   |
 Metric   | Preference | Next-hop-  | Next-hop-  |
|  instance  |   prefix   |            |            |   owner    |  network-  |            |
         |            |   group    |   group-   |
```

```
|            |            |            |            |            |  instance  |            |
        |           |           |  network-  |
|            |            |            |            |            |            |            |
        |           |           |  instance  |
+============+============+============+============+============+============+============+===
=========+============+============+============+
| default    | 192.0.2.1/ |         15 | host       | net_inst_m | default    | true       |
      0 |          0 |   23775975 | default    |
|            | 32         |            |            | gr         |            |            |
        |           |           |            |
| default    | 192.0.2.2/ |          0 | isis       | isis_mgr   | default    | true       |
     10 |         18 |   23775981 | default    |
|            | 32         |            |            |            |            |            |
        |           |           |            |
| default    | 192.0.2.3/ |          0 | isis       | isis_mgr   | default    | true       |
     10 |         18 |   23775982 | default    |
|            | 32         |            |            |            |            |            |
        |           |           |            |
| default    | 192.0.2.4/ |          0 | isis       | isis_mgr   | default    | true       |
     20 |         18 |   23775982 | default    |
|            | 32         |            |            |            |            |            |
        |           |           |            |
| default    | 192.0.2.5/ |          0 | isis       | isis_mgr   | default    | true       |
     20 |         18 |   23775981 | default    |
|            | 32         |            |            |            |            |            |
        |           |           |            |
| default    | 192.168.12 |         13 | local      | net_inst_m | default    | true       |
      0 |          0 |   23775976 | default    |
|            | .0/30      |            |            | gr         |            |            |
        |           |           |            |
| default    | 192.168.12 |         13 | host       | net_inst_m | default    | true       |
      0 |          0 |   23775977 | default    |
|            | .1/32      |            |            | gr         |            |            |
        |           |           |            |
| default    | 192.168.12 |         13 | host       | net_inst_m | default    | true       |
      0 |          0 |   23775978 | default    |
|            | .3/32      |            |            | gr         |            |            |
        |           |           |            |
| default    | 192.168.13 |         14 | local      | net_inst_m | default    | true       |
      0 |          0 |   23775979 | default    |
|            | .0/30      |            |            | gr         |            |            |
        |           |           |            |
| default    | 192.168.13 |         14 | host       | net_inst_m | default    | true       |
      0 |          0 |   23775980 | default    |
|            | .1/32      |            |            | gr         |            |            |
        |           |           |            |
| default    | 192.168.13 |         14 | host       | net_inst_m | default    | true       |
      0 |          0 |   23775978 | default    |
|            | .3/32      |            |            | gr         |            |            |
        |           |           |            |
| default    | 192.168.23 |          0 | isis       | isis_mgr   | default    | true       |
     20 |         18 |   23775981 | default    |
|            | .0/30      |            |            |            |            |            |
        |           |           |            |
| default    | 192.168.25 |          0 | isis       | isis_mgr   | default    | true       |
     20 |         18 |   23775981 | default    |
|            | .0/30      |            |            |            |            |            |
        |           |           |            |
| default    | 192.168.34 |          0 | isis       | isis_mgr   | default    | true       |
     20 |         18 |   23775982 | default    |
|            | .0/30      |            |            |            |            |            |
        |           |           |            |
| default    | 192.168.35 |          0 | isis       | isis_mgr   | default    | true       |
     20 |         18 |   23775982 | default    |
```

```
|           | .0/30      |           |           |           |           |           |
        |           |          |           |
| default   | 192.168.45 |         0 | isis      | isis_mgr  | default   | true      |
      30 |         18 |   23775981 | default   |
|           | .0/30      |           |           |           |           |           |
        |           |          |           |
+-----------+-----------+-----------+-----------+-----------+-----------+-----------+---
---------+-----------+-----------+-----------+
```

As an example, detail for one node (PE-5) and one link (the link between PE-2 and PE-5) for which LFA protection is verified further on, is shown as follows:

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table ipv4-unicast prefix detail
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
---snip---
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Destination            : 192.0.2.5/32
ID                     : 0
Route Type             : isis
Route Owner            : isis_mgr
Origin Network Instance: default
Metric                 : 20
Preference             : 18
Active                 : true
Last change            : 2025-08-29T09:36:15.658Z
Resilient hash         : false
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Next hops: 1 entries
192.168.12.2 (direct) via [ethernet-1/31.1]
Backup Next hops: 0 entries

-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Route Programming Status
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Suppressed                       : false
Last successful FIB operation    : add
Last successful FIB operation time: 2025-08-29T09:36:15.658Z
Current FIB operation pending    : none
Last failed FIB operation        : none
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Primary NHG
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Backup NHG
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
---snip---
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
```

```
Destination            : 192.168.25.0/30
ID                     : 0
Route Type             : isis
Route Owner            : isis_mgr
Origin Network Instance: default
Metric                 : 20
Preference             : 18
Active                 : true
Last change            : 2025-08-29T09:35:16.175Z
Resilient hash         : false
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Next hops: 1 entries
192.168.12.2 (direct) via [ethernet-1/31.1]
Backup Next hops: 0 entries

-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Route Programming Status
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Suppressed                       : false
Last successful FIB operation    : add
Last successful FIB operation time: 2025-08-29T09:35:16.175Z
Current FIB operation pending    : none
Last failed FIB operation        : none
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Primary NHG
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Backup NHG
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
---snip---
```

The next hops for the routes are verfied as follows:

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table next-hop
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Next-hop route table of network instance default
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Index             : 3
  Type            : broadcast
  Subinterface    : N/A
  Resolving Route : None (None)
Index             : 23775963
  Type            : extract
  Subinterface    : N/A
  Resolving Route : None (None)
Index             : 23775964
  Next-hop        : 192.168.12.1
  Type            : direct
  Subinterface    : ethernet-1/31.1
Index             : 23775965
  Type            : extract
```

```
  Subinterface    : N/A
  Resolving Route : None (None)
Index             : 23775966
  Next-hop        : 192.168.13.1
  Type            : direct
  Subinterface    : ethernet-1/32.1
Index             : 23775967
  Type            : extract
  Subinterface    : N/A
  Resolving Route : None (None)
Index             : 23775968
  Next-hop        : 192.168.12.2
  Type            : direct
  Subinterface    : ethernet-1/31.1
Index             : 23775969
  Next-hop        : 192.168.13.2
  Type            : direct
  Subinterface    : ethernet-1/32.1
```

The **info from state with-context / network-instance default route-table next-hop-group *** command on PE-1 shows the content of the forwarding information base (FIB):

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop-
group * |
 as table | filter fields *
+----------+----------+----------+----------+----------+----------+----------+----------
-+----------+----------+----------+----------+
| Network-  |   Index   |  Group-   | Programme |  Backup-  |  Backup-  | Fib-progr | Fib-progr
 | Fib-progr | Fib-progr | Fib-progr | Fib-progr |
| instance  |           |   name-   |  d-index  | next-hop- |  active   | amming su |  amming
 |  amming   |  amming   |  amming   |  amming   |
|           |           |   alias   |           |   group   |           | ppressed  | last-succ
 | last-succ | pending-o |   last-   |   last-   |
|           |           |           |           |           |           |           | essful-op
 | essful-op | peration- | failed-op |  failed-  |
|           |           |           |           |           |           |           | eration-
 | eration-  |   type    | eration-  | locations |
|           |           |           |           |           |           |           |   type
 | timestamp |           |   type    |           |
+==========+==========+==========+==========+==========+==========+==========+==========
=+==========+==========+==========+==========+
| default   |  23775975 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:14: |           |           |           |
|           |           |           |           |           |           |           |
 | 29.461Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (23       |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775976 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:14: |           |           |           |
|           |           |           |           |           |           |           |
 | 34.246Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (23       |           |           |           |
```

```
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775977 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:14: |           |           |           |
|           |           |           |           |           |           |           |
 | 34.246Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (23       |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775978 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:14: |           |           |           |
|           |           |           |           |           |           |           |
 | 34.246Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (23       |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775979 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:14: |           |           |           |
|           |           |           |           |           |           |           |
 | 34.853Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (23       |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775980 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:14: |           |           |           |
|           |           |           |           |           |           |           |
 | 34.853Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (23       |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775981 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:35: |           |           |           |
|           |           |           |           |           |           |           |
 | 16.175Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (2        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
```

```
| default   |  23775982 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:35: |           |           |           |
|           |           |           |           |           |           |           |
 | 35.063Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (2        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
+-----------+-----------+-----------+-----------+-----------+-----------+-----------+----------
-+-----------+-----------+-----------+-----------+
```

Initially, the following default IS-IS Level 2 metric applies to all interfaces.

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols isis instance 0
 interface * level 2 |
 as table | filter fields disable metric priority passive
+-----------------------------+-----------------------------+-----------------------------+-
------------+---------+----------+----------+---------+
|       Network-instance      |           Instance          |          Interface          |
 Level-number | Disable |  Metric  | Priority | Passive |
+=============================+=============================+=============================+=
============+=========+==========+==========+=========+
| default                     | 0                           | ethernet-1/31.1             |
           2 | false   |       10 |       64 | false   |
| default                     | 0                           | ethernet-1/32.1             |
           2 | false   |       10 |       64 | false   |
| default                     | 0                           | system0.0                   |
           2 | false   |        0 |       64 | false   |
+-----------------------------+-----------------------------+-----------------------------+-
------------+---------+----------+----------+---------+
```

The next step in the process of setting up the IP/MPLS network is setting up interface-LDP sessions on all interfaces. The LDP configuration on PE-1 is as follows:

```
# On PE-1:
# Configure LDP dynamic label block - on all nodes
enter candidate
    system mpls label-ranges dynamic dlb-ldp {
                    start-label 20000
                    end-label 29999

# Configure LDP sessions - per node
enter candidate
    network-instance default protocols ldp {
                admin-state enable
                dynamic-label-block dlb-ldp
                fec-resolution { }
                discovery {
                    interfaces {
                        interface ethernet-1/31.1 {
                            ipv4 {
                                admin-state enable
                            }
                        }
                        interface ethernet-1/32.1 {
                            ipv4 {
                                admin-state enable
```

```
                            }
                        }
                    }
                }
```

The routes in the IPv4 route table remain the same. There is now a full mesh of LDP label switched paths (LSPs) set up between all system interfaces of the PEs. The LSPs are visible in the MPLS route table.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+===============
=======+==================+
| 20000   | POP       | ldp         | default         |                        |
       |                  |
| 20001   | SWAP      | ldp         | N/A             | 192.168.12.2 (mpls)    | ethernet-1/
31.1      | 20000            |
| 20002   | SWAP      | ldp         | N/A             | 192.168.13.2 (mpls)    | ethernet-1/
32.1      | 20000            |
| 20003   | SWAP      | ldp         | N/A             | 192.168.13.2 (mpls)    | ethernet-1/
32.1      | 20003            |
| 20004   | SWAP      | ldp         | N/A             | 192.168.12.2 (mpls)    | ethernet-1/
31.1      | 20004            |
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
```

There are additional next hops, corresponding with the LSPs.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table next-hop
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
Next-hop route table of network instance default
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
---snip---
Index             : 23775970
  Next-hop        : 192.168.12.2
  Type            : mpls
  MPLS label stack: [20000]
Index             : 23775971
  Next-hop        : 192.168.13.2
  Type            : mpls
  MPLS label stack: [20000]
Index             : 23775972
  Next-hop        : 192.168.13.2
  Type            : mpls
  MPLS label stack: [20003]
Index             : 23775973
  Next-hop        : 192.168.12.2
  Type            : mpls
  MPLS label stack: [20004]
```

The tunnel table on PE-1 looks as follows:

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default tunnel-table all
```

```
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
+----------------------+--------+----------------+----------+-----+----------+---------+-------
------------------+--------------+--------------+
|     IPv4 Prefix      | Encaps |  Tunnel Type   |  Tunnel  | FIB |  Metric  | Prefere |
 Last Update        |   Next-hop   |   Next-hop   |
|                      |  Type  |                |    ID    |     |          |   nce   |
                   |    (Type)    |              |
+======================+========+================+==========+=====+==========+=========+=======
==================+==============+==============+
| 192.0.2.2/32         | mpls   | ldp            | 65537    | Y   | 10       | 9       | 2025-
08-29T09:40:58.208Z | 192.168.12.2 | ethernet-    |
|                      |        |                |          |     |          |         |
                   | (mpls)       | 1/31.1       |
| 192.0.2.3/32         | mpls   | ldp            | 65538    | Y   | 10       | 9       | 2025-
08-29T09:41:21.350Z | 192.168.13.2 | ethernet-    |
|                      |        |                |          |     |          |         |
                   | (mpls)       | 1/32.1       |
| 192.0.2.4/32         | mpls   | ldp            | 65539    | Y   | 20       | 9       | 2025-
08-29T09:41:32.609Z | 192.168.13.2 | ethernet-    |
|                      |        |                |          |     |          |         |
                   | (mpls)       | 1/32.1       |
| 192.0.2.5/32         | mpls   | ldp            | 65540    | Y   | 20       | 9       | 2025-
08-29T09:42:08.856Z | 192.168.12.2 | ethernet-    |
|                      |        |                |          |     |          |         |
                   | (mpls)       | 1/31.1       |
+----------------------+--------+----------------+----------+-----+----------+---------+-------
------------------+--------------+--------------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
4 LDP tunnels, 4 active, 0 inactive
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv6 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
<no_entries>
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
```

Corresponding entries are added to the forwarding information base (FIB):

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop-
group * |
 as table | filter fields *
+-----------+-----------+-----------+-----------+-----------+-----------+-----------+----------
-+-----------+-----------+-----------+-----------+
| Network-  |   Index   |  Group-   | Programme |  Backup-  |  Backup-  | Fib-progr | Fib-progr
 | Fib-progr | Fib-progr | Fib-progr | Fib-progr |
| instance  |           |   name-   |  d-index  | next-hop- |  active   | amming su |  amming
 |  amming   |  amming   |  amming   |  amming   |
|           |           |   alias   |           |   group   |           | ppressed  | last-succ
 | last-succ | pending-o |   last-   |   last-   |
|           |           |           |           |           |           |           | essful-op
 | essful-op | peration- | failed-op |  failed-  |
```

```
|           |           |           |           |           |           |           | eration-
 | eration-  |   type    | eration-  | locations |
|           |           |           |           |           |           |           |   type
 | timestamp |           |   type    |           |
+===========+===========+===========+===========+===========+===========+===========+==========
=+===========+===========+===========+===========+
| ---snip---
                                                |
| default   |  23775983 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:40: |           |           |           |
|           |           |           |           |           |           |           |
 | 58.209Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (3        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775984 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:41: |           |           |           |
|           |           |           |           |           |           |           |
 | 21.351Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (2        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775985 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:41: |           |           |           |
|           |           |           |           |           |           |           |
 | 32.610Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (2        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775986 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:42: |           |           |           |
|           |           |           |           |           |           |           |
 | 08.857Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (a minute |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
+-----------+-----------+-----------+-----------+-----------+-----------+-----------+----------
-+-----------+-----------+-----------+-----------+
```

The LDP LSP metric follows the IGP cost. Optionally, LSP metrics can be applied but that is beyond the scope for this chapter.

Without LFA, only an FEC that is learned from the LDP peer with the shortest path to that FEC (primary next hop) can be used in forwarding.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default protocols ldp ipv4 fec
=============================================================================================================
=========================================================
Net-Inst default LDP IPv4: All FEC prefixes table
=============================================================================================================
=========================================================
Received FEC prefixes
-------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
+-------------------------------------------------------------------------------------------+
| FEC prefix          Peer LDP ID               Label               Ingress   Used in     |
|                                                                   LSR       Forwarding  |
+===========================================================================================+
| 192.0.2.2/32        192.0.2.2:0               20000               true      true        |
| 192.0.2.2/32        192.0.2.3:0               20002               true      false       |
| 192.0.2.3/32        192.0.2.2:0               20002               true      false       |
| 192.0.2.3/32        192.0.2.3:0               20000               true      true        |
| 192.0.2.4/32        192.0.2.2:0               20003               true      false       |
| 192.0.2.4/32        192.0.2.3:0               20003               true      true        |
| 192.0.2.5/32        192.0.2.2:0               20004               true      true        |
| 192.0.2.5/32        192.0.2.3:0               20004               true      false       |
+-------------------------------------------------------------------------------------------+
-------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
Advertised FEC prefixes
-------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
+-------------------------------------------------------------------------------------------+
| FEC prefix          Peer LDP ID               Label               Label       Egress    |
|                                                                   Status      LSR       |
+===========================================================================================+
| 192.0.2.1/32        192.0.2.2:0               20000                           true      |
| 192.0.2.1/32        192.0.2.3:0               20000                           true      |
| 192.0.2.2/32        192.0.2.3:0               20001                           false     |
| 192.0.2.3/32        192.0.2.2:0               20002                           false     |
| 192.0.2.4/32        192.0.2.2:0               20003                           false     |
| 192.0.2.4/32        192.0.2.3:0               20003                           false     |
| 192.0.2.5/32        192.0.2.2:0               20004                           false     |
| 192.0.2.5/32        192.0.2.3:0               20004                           false     |
+-------------------------------------------------------------------------------------------+
-------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
Total received FEC prefixes  : 8 (4 used in forwarding)
Total advertised FEC prefixes: 8
=============================================================================================================
=========================================================

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 next-hop * |
 as table | filter fields *
+-------------+-----------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
|  Network-   |  Prefix-fec fec  | Prefix-fec  |   Prefix-fec label-    |  Index   |  Next-hop
  |  Next-hop-  |       Interface       | Outer-label |
|  instance   |                  |   lsr-id    |       space-id        |          |
  |    type     |                      |             |
+=============+=================+=============+=======================+==========+===========
==+=============+======================+=============+
```

```
| default     | 192.0.2.2/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |           |                  |             |             |
| default     | 192.0.2.3/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |           |                  |             |             |
| default     | 192.0.2.4/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |           |                  |             |             |
| default     | 192.0.2.5/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |           |                  |             |             |
+-------------+------------------+-------------+------------------------+----------+-----------
--+-------------+----------------------+-------------+
```

10.3.2 Enable LDP LFA and verify

Because LDP LFA is using LFA next-hop computation by the IGP, as described in RFC 5286, LFA must be enabled in the IGP context, as follows:

```
# On PE-1:
enter candidate
    network-instance default protocols isis instance 0 loopfree-alternate {
                    admin-state enable
                    augment-route-table true
```

The **info from state with-context / network-instance default protocols isis instance 0 loopfree-alternate** command on PE-1 verifies that LFA is enabled in IS-IS:

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols isis instance 0
 loopfree-alternate |
 as table | filter fields *
+---------+---------+---------+---------+---------+---------+---------+---------+---------+----
-----+---------+---------+---------+---------+
| Network | Instanc | Admin-  | Augment | Exclude | Multi-  | Multi-  | Remote- | Remote- |
 Remote- | Remote- | Ti-lfa  | Ti-lfa  | Ti-lfa  |
| -instan |    e    |  state  | -route- | prefix- | homed-  | homed-  |   lfa   |   lfa   |
 lfa   |   lfa   | admin-  | max-sr- |  node-  |
|   ce    |         |         |  table  | policy  | prefix  | prefix  | admin-  | max-pq- |
 node-  |  node-  |  state  | policy- | protect |
|         |         |         |         |         | admin-  | prefere |  state  |  cost   |
 protect | protect |         |  lfa-   | admin-  |
|         |         |         |         |         |  state  |   nce   |         |         |
 admin-  | max-pq- |         | labels  |  state  |
|         |         |         |         |         |         |         |         |         |
 state  |  nodes  |         |         |         |
+=========+=========+=========+=========+=========+=========+=========+=========+=========+====
=====+=========+=========+=========+=========+
| default | 0       | enable  | true    |         | disable | none    | disable |       0 |
 disable |       0 | disable |       0 | disable |
+---------+---------+---------+---------+---------+---------+---------+---------+---------+----
-----+---------+---------+---------+---------+
```

Remote LFA (RLFA) and Topology-independent LFA (TI-LFA) are disabled (by default), because they are beyond the scope of this chapter.

After enabling LFA inside the IGP context, LFA needs to be enabled within the LDP context, as follows:

```
# On PE-1:
enter candidate
    network-instance default protocols ldp loopfree-alternate {
                admin-state enable
```

This chapter describes LFA for unicast LDP.

After these two CLI commands, the software computes for each LDP FEC in the network both a primary and a backup NHLFE. The primary NHLFE corresponds to the label of the FEC received from the primary next-hop as per standard LDP resolution of the FEC prefix in the Routing Table Manager (RTM). The backup NHLFE corresponds to the label received for the same FEC from an LFA next hop.

For point-to-point interfaces, when multiple LFA next hops are found for a primary next hop, the following selection criteria are used:

1. SPF selects the node-protect type in favor of the link-protect type.
2. If there is more than one LFA next hop within the selected type, then SPF selects an LFA next hop with the lowest cost.
3. If there is more than one LFA next hop with the same cost, then SPF selects the first one. This is not a deterministic selection and it varies following each SPF computation.

Several **show** commands are possible to display LFA information:

The **info from state with-context / network-instance default protocols isis instance 0 statistics** command shows the number of LFA runs on a specific node.

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols isis instance 0
 statistics |
 as table | filter fields *
+-------------+-------------+-----------+-----------------------------------------+--------
--------+-----------------------------------------------+
|  Network-   |  Instance   | Spf-runs  |                 Last-spf                  |
 Partial-spf-  |             Last-partial-spf              |
|  instance   |             |           |                                           |
 runs      |                                           |
+=============+=============+===========+===========================================+========
========+===============================================+
| default     | 0           |         7 | 2025-08-29T09:50:44.500Z (5 minutes ago)  |
      0 |                                           |
+-------------+-------------+-----------+-----------------------------------------+--------
--------+-----------------------------------------------+
```

In the example topology (see Figure 19: Initial example topology), all IS-IS links have a default level 2 metric of 10. This results in all four nodes and all IS-IS routes learned by PE-1 being LFA protected: the LFA node coverage on PE-1 is 4/4=100%; the LFA link coverage on PE-1 is 9/9=100%. The next hop groups change for the recomputed SPF paths.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table all
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 unicast route table of network instance default
```

```
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+----------+-----------+-----------+
|     Prefix      |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
    | Next-hop  | Next-hop  |  Backup   |  Backup   |
|                 |      |   Type    |                    |         | Network |        |
    |  (Type)   | Interface | Next-hop  | Next-hop  |
|                 |      |           |                    |         | Instanc |        |
    |           |           |  (Type)   | Interface |
|                 |      |           |                    |         |    e    |        |
    |           |           |           |           |
+=================+======+===========+====================+=========+=========+========+=======
====+===========+===========+===========+===========+
| 192.0.2.1/32    | 15   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.0.2.2/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.0.2.3/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.0.2.4/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.0.2.5/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.12.0/30 | 13   | local     | net_inst_mgr       | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.1       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.12.1/32 | 13   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.12.3/32 | 13   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.0/30 | 14   | local     | net_inst_mgr       | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.1       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.13.1/32 | 14   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.3/32 | 14   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.23.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
```

```
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.25.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.34.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.35.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.45.0/30 | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 routes total                    : 16
IPv4 prefixes with active routes     : 16
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------------
-------------------------------------------------------

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default route-table ipv4-unicast
 route * id * route-type * route-owner * origin-network-instance * |
 as table | filter fields active metric preference next-hop-group next-hop-group-network-
instance
+------------+------------+------------+------------+------------+------------+------------+---
---------+------------+------------+------------+
|  Network-  |   Ipv4-    |     Id     | Route-type |   Route-   |  Origin-   |   Active   |
 Metric   | Preference | Next-hop-  | Next-hop-  |
|  instance  |   prefix   |            |            |   owner    |  network-  |            |
         |            |   group    |   group-   |
|            |            |            |            |            |  instance  |            |
         |            |            |  network-  |
|            |            |            |            |            |            |            |
         |            |            |  instance  |
+============+============+============+============+============+============+============+===
=========+============+============+============+
| default    | 192.0.2.1/ |         15 | host       | net_inst_m | default    | true       |
       0 |          0 |   23775975 | default    |
|            | 32         |            |            | gr         |            |            |
         |            |            |            |
| default    | 192.0.2.2/ |          0 | isis       | isis_mgr   | default    | true       |
      10 |         18 |   23775987 | default    |
|            | 32         |            |            |            |            |            |
         |            |            |            |
| default    | 192.0.2.3/ |          0 | isis       | isis_mgr   | default    | true       |
      10 |         18 |   23775988 | default    |
```

```
|            | 32          |             |            |             |             |             |
          |             |           |
| default    | 192.0.2.4/  |           0 | isis       | isis_mgr    | default     | true        |
      20 |          18 |    23775988 | default    |
|            | 32          |             |            |             |             |             |
          |             |           |
| default    | 192.0.2.5/  |           0 | isis       | isis_mgr    | default     | true        |
      20 |          18 |    23775987 | default    |
|            | 32          |             |            |             |             |             |
          |             |           |
| default    | 192.168.12  |          13 | local      | net_inst_m  | default     | true        |
       0 |           0 |    23775976 | default    |
|            | .0/30       |             |            | gr          |             |             |
          |             |           |
| default    | 192.168.12  |          13 | host       | net_inst_m  | default     | true        |
       0 |           0 |    23775977 | default    |
|            | .1/32       |             |            | gr          |             |             |
          |             |           |
| default    | 192.168.12  |          13 | host       | net_inst_m  | default     | true        |
       0 |           0 |    23775978 | default    |
|            | .3/32       |             |            | gr          |             |             |
          |             |           |
| default    | 192.168.13  |          14 | local      | net_inst_m  | default     | true        |
       0 |           0 |    23775979 | default    |
|            | .0/30       |             |            | gr          |             |             |
          |             |           |
| default    | 192.168.13  |          14 | host       | net_inst_m  | default     | true        |
       0 |           0 |    23775980 | default    |
|            | .1/32       |             |            | gr          |             |             |
          |             |           |
| default    | 192.168.13  |          14 | host       | net_inst_m  | default     | true        |
       0 |           0 |    23775978 | default    |
|            | .3/32       |             |            | gr          |             |             |
          |             |           |
| default    | 192.168.23  |           0 | isis       | isis_mgr    | default     | true        |
      20 |          18 |    23775987 | default    |
|            | .0/30       |             |            |             |             |             |
          |             |           |
| default    | 192.168.25  |           0 | isis       | isis_mgr    | default     | true        |
      20 |          18 |    23775987 | default    |
|            | .0/30       |             |            |             |             |             |
          |             |           |
| default    | 192.168.34  |           0 | isis       | isis_mgr    | default     | true        |
      20 |          18 |    23775988 | default    |
|            | .0/30       |             |            |             |             |             |
          |             |           |
| default    | 192.168.35  |           0 | isis       | isis_mgr    | default     | true        |
      20 |          18 |    23775988 | default    |
|            | .0/30       |             |            |             |             |             |
          |             |           |
| default    | 192.168.45  |           0 | isis       | isis_mgr    | default     | true        |
      30 |          18 |    23775987 | default    |
|            | .0/30       |             |            |             |             |             |
          |             |           |
+------------+-------------+-------------+------------+-------------+-------------+-------------+---
---------+------------+------------+------------+
```

As an example, detail for one node (PE-5) and one link (the link between PE-2 and PE-5) for which LFA protection is is in place, is shown as follows:

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table ipv4-unicast prefix detail
```

```
-------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------
-------------------------------------------------------
---snip---
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Destination            : 192.0.2.5/32
ID                     : 0
Route Type             : isis
Route Owner            : isis_mgr
Origin Network Instance: default
Metric                 : 20
Preference             : 18
Active                 : true
Last change            : 2025-08-29T09:50:45.853Z
Resilient hash         : false
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Next hops: 1 entries
192.168.12.2 (direct) via [ethernet-1/31.1]
Backup Next hops: 1 entries
192.168.13.2 (direct) via [ethernet-1/32.1]
-------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Route Programming Status
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Suppressed                        : false
Last successful FIB operation     : modify
Last successful FIB operation time: 2025-08-29T09:50:45.853Z
Current FIB operation pending     : none
Last failed FIB operation         : none
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Primary NHG
-------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Backup NHG
-------------------------------------------------------------------------------------------
-------------------------------------------------------
---snip---
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Destination            : 192.168.25.0/30
ID                     : 0
Route Type             : isis
Route Owner            : isis_mgr
Origin Network Instance: default
Metric                 : 20
Preference             : 18
Active                 : true
Last change            : 2025-08-29T09:50:45.853Z
Resilient hash         : false
-------------------------------------------------------------------------------------------
-------------------------------------------------------
Next hops: 1 entries
192.168.12.2 (direct) via [ethernet-1/31.1]
Backup Next hops: 1 entries
```

```
192.168.13.2 (direct) via [ethernet-1/32.1]
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Route Programming Status
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Suppressed                       : false
Last successful FIB operation    : modify
Last successful FIB operation time: 2025-08-29T09:50:45.853Z
Current FIB operation pending    : none
Last failed FIB operation        : none
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Primary NHG
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Backup NHG
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
---snip---
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
```

The LSPs remain the same.

The next hops are recomputed:

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table next-hop
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
Next-hop route table of network instance default
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
---snip---
Index             : 23775974
  Next-hop        : 192.168.12.2
  Type            : direct
  Subinterface    : ethernet-1/31.1
Index             : 23775975
  Next-hop        : 192.168.13.2
  Type            : direct
  Subinterface    : ethernet-1/32.1
Index             : 23775976
  Next-hop        : 192.168.13.2
  Type            : mpls
  MPLS label stack: [20002]
Index             : 23775977
  Next-hop        : 192.168.12.2
  Type            : mpls
  MPLS label stack: [20000]
Index             : 23775978
  Next-hop        : 192.168.12.2
  Type            : mpls
  MPLS label stack: [20002]
Index             : 23775979
  Next-hop        : 192.168.13.2
  Type            : mpls
  MPLS label stack: [20000]
Index             : 23775980
```

```
  Next-hop        : 192.168.12.2
  Type            : mpls
  MPLS label stack: [20003]
Index             : 23775981
  Next-hop        : 192.168.13.2
  Type            : mpls
  MPLS label stack: [20003]
Index             : 23775982
  Next-hop        : 192.168.13.2
  Type            : mpls
  MPLS label stack: [20004]
Index             : 23775983
  Next-hop        : 192.168.12.2
  Type            : mpls
  MPLS label stack: [20004]
```

The MPLS tunnel table is updated:

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default tunnel-table all
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
IPv4 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
+----------------------+--------+----------------+----------+-----+----------+---------+-------
------------------+--------------+--------------+
|     IPv4 Prefix      | Encaps |  Tunnel Type   |  Tunnel  | FIB |  Metric  | Prefere |
 Last Update        |   Next-hop   |   Next-hop   |
|                      |  Type  |                |    ID    |     |          |   nce   |
                     |    (Type)    |              |
+======================+========+================+==========+=====+==========+=========+=======
==================+==============+==============+
| 192.0.2.2/32         | mpls   | ldp            | 65537    | Y   | 10       | 9       | 2025-
08-29T09:52:20.354Z | 192.168.12.2 | ethernet-    |
|                      |        |                |          |     |          |         |
                     | (mpls)       | 1/31.1       |
| 192.0.2.3/32         | mpls   | ldp            | 65538    | Y   | 10       | 9       | 2025-
08-29T09:52:20.354Z | 192.168.13.2 | ethernet-    |
|                      |        |                |          |     |          |         |
                     | (mpls)       | 1/32.1       |
| 192.0.2.4/32         | mpls   | ldp            | 65539    | Y   | 20       | 9       | 2025-
08-29T09:52:20.354Z | 192.168.13.2 | ethernet-    |
|                      |        |                |          |     |          |         |
                     | (mpls)       | 1/32.1       |
| 192.0.2.5/32         | mpls   | ldp            | 65540    | Y   | 20       | 9       | 2025-
08-29T09:52:20.354Z | 192.168.12.2 | ethernet-    |
|                      |        |                |          |     |          |         |
                     | (mpls)       | 1/31.1       |
+----------------------+--------+----------------+----------+-----+----------+---------+-------
------------------+--------------+--------------+
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
4 LDP tunnels, 4 active, 0 inactive
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
IPv6 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
<no_entries>
```

```
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
```

Corresponding entries are added to the forwarding information base (FIB):

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop-
group * |
 as table | filter fields *
+-----------+-----------+-----------+-----------+-----------+-----------+-----------+----------
-+-----------+-----------+-----------+-----------+
| Network-  |   Index   |  Group-   | Programme |  Backup-  |  Backup-  | Fib-progr | Fib-progr
 | Fib-progr | Fib-progr | Fib-progr | Fib-progr |
| instance  |           |   name-   |  d-index  | next-hop- |  active   | amming su |  amming
 |  amming   |  amming   |  amming   |  amming   |
|           |           |   alias   |           |   group   |           | ppressed  | last-succ
 | last-succ | pending-o |   last-   |   last-   |
|           |           |           |           |           |           |           | essful-op
 | essful-op | peration- | failed-op |  failed-  |
|           |           |           |           |           |           |           | eration-
 | eration-  |   type    | eration-  | locations |
|           |           |           |           |           |           |           |   type
 | timestamp |           |   type    |           |
+===========+===========+===========+===========+===========+===========+===========+==========
=+===========+===========+===========+===========+
| ---snip---
                                                |
| default   |  23775987 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:50: |           |           |           |
|           |           |           |           |           |           |           |
 | 45.853Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (4        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775988 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:50: |           |           |           |
|           |           |           |           |           |           |           |
 | 45.853Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (4        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775989 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:52: |           |           |           |
|           |           |           |           |           |           |           |
 | 20.355Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (2        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
```

```
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775990 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:52: |           |           |           |
|           |           |           |           |           |           |           |
 | 20.355Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (2        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775991 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:52: |           |           |           |
|           |           |           |           |           |           |           |
 | 20.355Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (2        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
| default   |  23775992 |           |           |         0 | false     |           | add
 | 2025-08-  | none      | none      |           |
|           |           |           |           |           |           |           |
 | 29T09:52: |           |           |           |
|           |           |           |           |           |           |           |
 | 20.355Z   |           |           |           |
|           |           |           |           |           |           |           |
 | (2        |           |           |           |
|           |           |           |           |           |           |           |
 | minutes   |           |           |           |
|           |           |           |           |           |           |           |
 | ago)      |           |           |           |
```

The **show / network-instance default protocols ldp ipv4 fec** command on PE-1 verifies that LFA is enabled in LDP: an FEC that is learned from another LDP peer (LFA next hop) than from the one with the shortest path to that FEC (primary next hop) can also be used in forwarding.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default protocols ldp ipv4 fec
===============================================================================================
=======================================================
Net-Inst default LDP IPv4: All FEC prefixes table
===============================================================================================
=======================================================
Received FEC prefixes
-----------------------------------------------------------------------------------------------
-------------------------------------------------------
+-----------------------------------------------------------------------------------------------+
| FEC prefix           Peer LDP ID                Label                Ingress   Used in    |
|                                                                      LSR       Forwarding |
+===============================================================================================+
| 192.0.2.2/32         192.0.2.2:0                20000                true      true       |
| 192.0.2.2/32         192.0.2.3:0                20002                true      true       |
| 192.0.2.3/32         192.0.2.2:0                20002                true      true       |
| 192.0.2.3/32         192.0.2.3:0                20000                true      true       |
| 192.0.2.4/32         192.0.2.2:0                20003                true      true       |
| 192.0.2.4/32         192.0.2.3:0                20003                true      true       |
```

```
| 192.0.2.5/32         192.0.2.2:0                20004               true      true       |
| 192.0.2.5/32         192.0.2.3:0                20004               true      true       |
+-------------------------------------------------------------------------------------------+
-------------------------------------------------------------------------------------------
-----------------------------------------------------------
Advertised FEC prefixes
-------------------------------------------------------------------------------------------
-----------------------------------------------------------
---snip---
-------------------------------------------------------------------------------------------
-----------------------------------------------------------
Total received FEC prefixes  : 8 (8 used in forwarding)
Total advertised FEC prefixes: 8
===========================================================================================
===========================================================

--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 next-hop * |
 as table | filter fields *
+-------------+-----------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
|  Network-   |  Prefix-fec fec  | Prefix-fec  |   Prefix-fec label-    |  Index   |  Next-hop
  |  Next-hop-  |       Interface       | Outer-label |
|  instance   |                  |   lsr-id    |        space-id        |          |
  |    type     |                  |             |                        |          |
+=============+=================+=============+========================+==========+===========
==+=============+======================+=============+
| default     | 192.0.2.2/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |             |
| default     | 192.0.2.2/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | alternate   | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |             |
| default     | 192.0.2.3/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | alternate   | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |             |
| default     | 192.0.2.3/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |             |
| default     | 192.0.2.4/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | alternate   | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |             |
| default     | 192.0.2.4/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |             |
| default     | 192.0.2.5/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |             |
| default     | 192.0.2.5/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | alternate   | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |             |
+-------------+-----------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
```

On PE-1, node PE-5 (192.0.2.5/32) has a primary SPF next-hop pointing toward PE-2 (192.168.12.2) and an LFA next-hop pointing toward PE-3 (192.168.13.2).

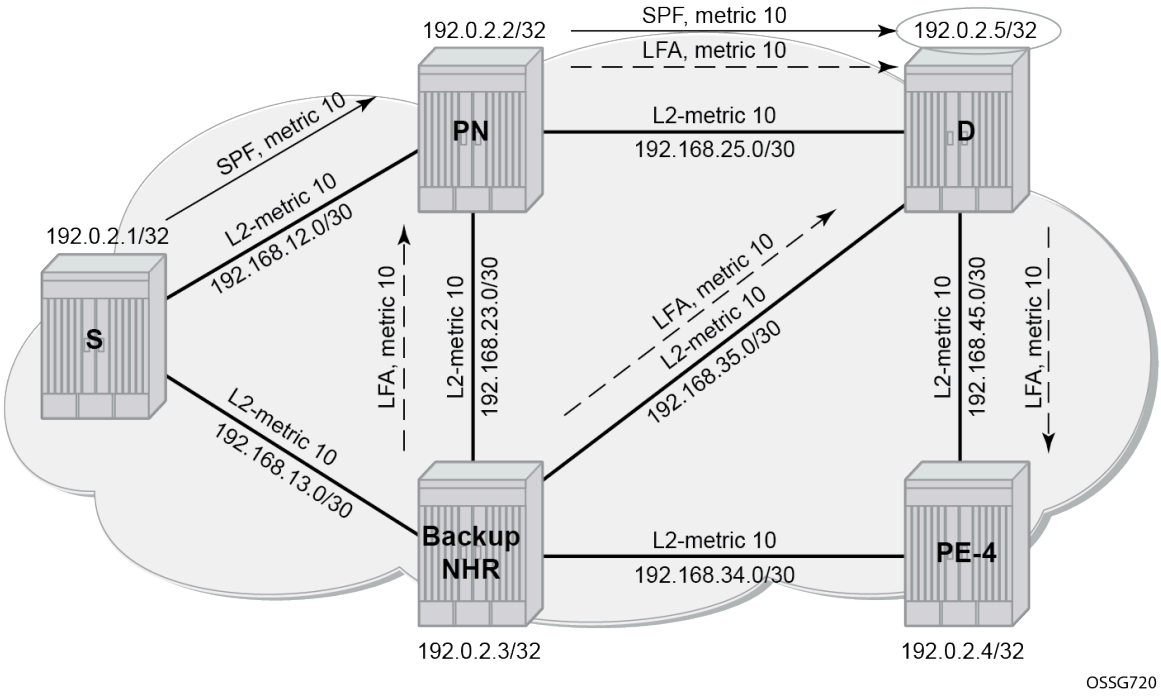
The inequality 3 formula on PE-1 for prefix 192.0.2.5/32 results in the following:

Inequality 3:

```
SP(backup NHR, D) < SP(backup NHR, PN) + SP(PN, D) or
   SP(PE-3, PE-5) <     SP(PE-3, PE-2) + SP(PE-2, PE-5) or
               10 <                  10 + 10 => OK
```

This means that inequality 3 is met. The calculated LFA next-hop for prefix 192.0.2.5/32 on PE-1 is protecting node PE-2, see Figure 20: LFA computation: inequality 3 for prefix PE-5 (D) on PE-1 (S) for a graphical representation.

Figure 20: LFA computation: inequality 3 for prefix PE-5 (D) on PE-1 (S)



On PE-1, the link between PE-2 and PE-5 has a primary SPF next-hop pointing toward PE-2 (192.168.12.2) and an LFA next-hop pointing toward PE-3 (192.168.13.2).

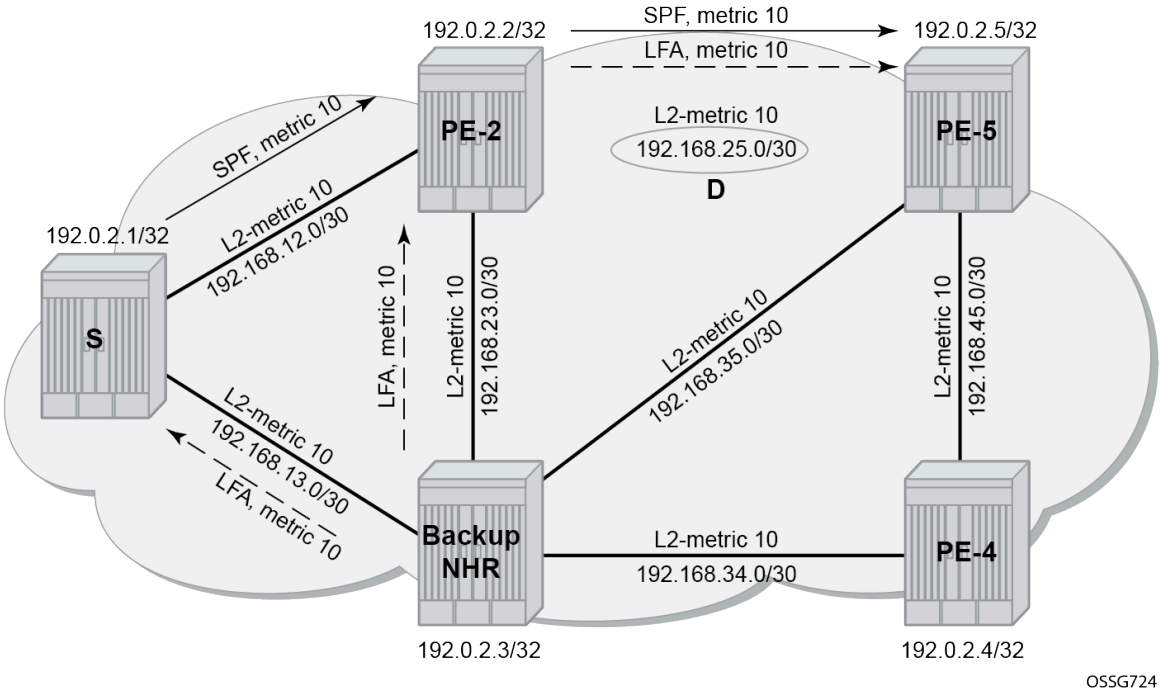
The inequality 1 formula on PE-1 for prefix 192.168.25.0/30 results in the following:

Inequality 1:

```
SP(backup NHR, D) < SP(backup NHR, S) + SP(S, D) or
      SP(PE-3, D) <    SP(PE-3, PE-1) + SP(PE-1, D) or
          10 + 10 <                 10 + (10 + 10) => OK
```

This means that inequality 1 is also met. The calculated LFA next-hop for prefix 192.168.25.0/30 on PE-1 is protecting the link between PE-2 and PE-5, see Figure 21: LFA computation: inequality 1 for prefix NW 192.168.25.0/30 (D) on PE-1 (S) for a graphical representation.

Figure 21: LFA computation: inequality 1 for prefix NW 192.168.25.0/30 (D) on PE-1 (S)



10.3.3 Enable synchronization timer

Within an MPLS network using LDP, it is common practice to enable a synchronization timer between LDP and the IGP. Also, when LDP LFA is enabled, a situation can occur in which a synchronization timer between IGP and LDP helps: the revert scenario. When the interface for the previous primary next hop is restored, IGP may re-converge before LDP completed the FEC exchange with its neighbor over that interface. This may cause LDP to remove the LFA next hop from the FEC and blackhole traffic.

To avoid traffic being blackholed, it is recommended to enable IGP-LDP synchronization on the interface. The time is expressed in seconds and can have a value between 1 and 1800 seconds. It is also possible to configure an end-of-LIB option to optimize the synchronization time. On PE-1, the following configures the LDP synchronization timer with a value of 10 seconds on the interfaces to PE-2 and PE-3:

```
# On PE-1:
enter candidate
    network-instance default protocols isis instance 0 {
                    interface ethernet-1/31.1 {
                        ldp-synchronization {
                            hold-down-timer 10
                            end-of-lib true
                        }
                    }
                    interface ethernet-1/32.1 {
                        ldp-synchronization {
                            hold-down-timer 10
                            end-of-lib true
                        }
```

```
                    }
```

The configuration on the other nodes is similar.

When this timer is enabled, the IGP advertises a link in the network with an infinite metric, when its interface is restored. When the **ldp-synchronization hold-down-timer** is started, LDP adjacencies are brought up together with a label exchange. When the **ldp-synchronization hold-down-timer** expires, the normal metric is advertised in the network again.

10.3.4 Verify data path

As an example, data path verification is performed using LSP traces.

```
# On PE-1:
enter running
tools oam lsp-trace ldp clear
tools oam lsp-trace ldp fec 192.0.2.1/32    # no LDP tunnel to self
tools oam lsp-trace ldp fec 192.0.2.2/32
tools oam lsp-trace ldp fec 192.0.2.3/32
tools oam lsp-trace ldp fec 192.0.2.4/32
tools oam lsp-trace ldp fec 192.0.2.5/32

/oam/lsp-trace:
    LDP Trace data has been cleared

/oam/lsp-trace/ldp/fec[prefix=192.0.2.1/32]:
    No valid SR ISIS / LDP Tunnel to 192.0.2.1/32 found

/oam/lsp-trace/ldp/fec[prefix=192.0.2.2/32]:
    Initiated LSP Trace to prefix 192.0.2.2/32 with session id 49156

/oam/lsp-trace/ldp/fec[prefix=192.0.2.3/32]:
    Initiated LSP Trace to prefix 192.0.2.3/32 with session id 49157

/oam/lsp-trace/ldp/fec[prefix=192.0.2.4/32]:
    Initiated LSP Trace to prefix 192.0.2.4/32 with session id 49158

/oam/lsp-trace/ldp/fec[prefix=192.0.2.5/32]:
    Initiated LSP Trace to prefix 192.0.2.5/32 with session id 49159
```

With the default IS-IS Level 2 metric values for all interfaces on all nodes and LFA enabled, the outcome of the LSP traces indicates that the data paths from PE-1 to PE-2 and to PE-5 go to or via PE-2, while the data paths from PE-1 to PE-3 and to PE-4 go to or via PE-3. Two hops are needed to reach PE-4 (via PE-3) or PE-5 (via PE-2).

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / oam lsp-trace ldp fec * session-id * hop * probe *
 | as table
+-------------+-------------+-------------+-------------+-------------+-------------+----
----------+-------------+-------------+-------------+
|     Fec     |  Session-id  |     Hop     | Probe-index  | Probes-sent  | Last-probe-  |
 Reply reply- | Reply round- |    Reply    |    Reply    |
|             |              |             |             |              |    send-    |
 sender    |  trip-time   | return-code  |   return-    |
|             |              |             |             |              |   failure-   |
          |             |             |   subcode    |
|             |              |             |             |              |    reason    |
          |             |             |             |
```

```
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 192.0.2.2/32 |        49156 |            1 |            1 |            1 |
 | 192.0.2.2    |         3559 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.3/32 |        49157 |            1 |            1 |            1 |
 | 192.0.2.3    |         2652 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.4/32 |        49158 |            1 |            1 |            1 |
 | 192.0.2.3    |         2478 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.4/32 |        49158 |            2 |            1 |            1 |              |
 192.0.2.4    |        3836 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.5/32 |        49159 |            1 |            1 |            1 |
 | 192.0.2.2    |         3572 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.5/32 |        49159 |            2 |            1 |            1 |              |
 192.0.2.5    |        3850 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
```

```
|              |              |              |              |              |              |
          |              | depth-n      |              |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
```

10.3.4.1 Link failure

Disable the interface between PE-1 and PE-2 to simulate a failure of the link.

```
# On PE-1:
enter candidate
    interface ethernet-1/31 admin-state disable
```

The outcome of the LSP traces now indicates that all destinations are reached from PE-1 via PE-3 only and that two hops are needed also to reach PE-2 (via PE-3).

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / oam lsp-trace ldp fec * session-id * hop * probe *
 | as table
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
|     Fec      |  Session-id  |     Hop      | Probe-index  | Probes-sent  | Last-probe-  |
 Reply reply- | Reply round- |    Reply     |    Reply     |
|              |              |              |              |              |    send-     |
 sender    |  trip-time   | return-code  |   return-    |
|              |              |              |              |              |   failure-   |
|              |              |              |   subcode    |
|              |              |              |              |              |    reason    |
|              |              |              |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 192.0.2.2/32 |        49160 |            1 |            1 |            1 |
 | 192.0.2.3    |         2750 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.2/32 |        49160 |            2 |            1 |            1 |              |
 192.0.2.2    |        3730 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.3/32 |        49161 |            1 |            1 |            1 |              |
 192.0.2.3    |        3208 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
```

```
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.4/32 |        49162 |            1 |            1 |            1 |
 | 192.0.2.3    |         3548 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.4/32 |        49162 |            2 |            1 |            1 |              |
 192.0.2.4    |        3827 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.5/32 |        49163 |            1 |            1 |            1 |
 | 192.0.2.3    |         2667 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.5/32 |        49163 |            2 |            1 |            1 |              |
 192.0.2.5    |        3854 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
```

There are no LFA paths any more from PE-1.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table all
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
|     Prefix      |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
    | Next-hop  | Next-hop  |  Backup   |  Backup   |
|                 |      |   Type    |                    |         | Network |        |
    |  (Type)   | Interface | Next-hop  | Next-hop  |
```

```
|                  |      |           |                     |         | Instanc |         |
    |           |          |  (Type)   | Interface |
|                  |      |           |                     |         |    e    |         |
    |           |          |           |                     |
+==================+======+===========+=====================+=========+=========+=========+=======
====+===========+===========+===========+===========+
| 192.0.2.1/32     | 15   | host      | net_inst_mgr        | True    | default | 0       | 0
    | None       | None      |           |           |
| 192.0.2.2/32     | 0    | isis      | isis_mgr            | True    | default | 20      | 18
    | 192.168.1  | ethernet- |           |           |
|                  |      |           |                     |         |         |         |
    | 3.2        | 1/32.1    |           |           |
|                  |      |           |                     |         |         |         |
    | (direct)   |           |           |           |
| 192.0.2.3/32     | 0    | isis      | isis_mgr            | True    | default | 10      | 18
    | 192.168.1  | ethernet- |           |           |
|                  |      |           |                     |         |         |         |
    | 3.2        | 1/32.1    |           |           |
|                  |      |           |                     |         |         |         |
    | (direct)   |           |           |           |
| 192.0.2.4/32     | 0    | isis      | isis_mgr            | True    | default | 20      | 18
    | 192.168.1  | ethernet- |           |           |
|                  |      |           |                     |         |         |         |
    | 3.2        | 1/32.1    |           |           |
|                  |      |           |                     |         |         |         |
    | (direct)   |           |           |           |
| 192.0.2.5/32     | 0    | isis      | isis_mgr            | True    | default | 20      | 18
    | 192.168.1  | ethernet- |           |           |
|                  |      |           |                     |         |         |         |
    | 3.2        | 1/32.1    |           |           |
|                  |      |           |                     |         |         |         |
    | (direct)   |           |           |           |
| 192.168.13.0/30  | 14   | local     | net_inst_mgr        | True    | default | 0       | 0
    | 192.168.1  | ethernet- |           |           |
|                  |      |           |                     |         |         |         |
    | 3.1        | 1/32.1    |           |           |
|                  |      |           |                     |         |         |         |
    | (direct)   |           |           |           |
| 192.168.13.1/32  | 14   | host      | net_inst_mgr        | True    | default | 0       | 0
    | None       | None      |           |           |
| 192.168.13.3/32  | 14   | host      | net_inst_mgr        | True    | default | 0       | 0
    | None       | None      |           |           |
| 192.168.23.0/30  | 0    | isis      | isis_mgr            | True    | default | 20      | 18
    | 192.168.1  | ethernet- |           |           |
|                  |      |           |                     |         |         |         |
    | 3.2        | 1/32.1    |           |           |
|                  |      |           |                     |         |         |         |
    | (direct)   |           |           |           |
| 192.168.25.0/30  | 0    | isis      | isis_mgr            | True    | default | 30      | 18
    | 192.168.1  | ethernet- |           |           |
|                  |      |           |                     |         |         |         |
    | 3.2        | 1/32.1    |           |           |
|                  |      |           |                     |         |         |         |
    | (direct)   |           |           |           |
| 192.168.34.0/30  | 0    | isis      | isis_mgr            | True    | default | 20      | 18
    | 192.168.1  | ethernet- |           |           |
|                  |      |           |                     |         |         |         |
    | 3.2        | 1/32.1    |           |           |
|                  |      |           |                     |         |         |         |
    | (direct)   |           |           |           |
| 192.168.35.0/30  | 0    | isis      | isis_mgr            | True    | default | 20      | 18
    | 192.168.1  | ethernet- |           |           |
|                  |      |           |                     |         |         |         |
    | 3.2        | 1/32.1    |           |           |
```

```
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.45.0/30 | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
IPv4 routes total                    : 13
IPv4 prefixes with active routes     : 13
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------------
-----------------------------------------------------------
```

The paths from PE-1 to all destinations are primary paths and they all go via PE-3.

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 next-hop * |
 as table | filter fields *
+-------------+-----------------+-------------+------------------------+----------+-----------
--+-------------+----------------------+-------------+
|  Network-   |  Prefix-fec fec  | Prefix-fec  |   Prefix-fec label-    |  Index   |  Next-hop
  |  Next-hop-  |       Interface       | Outer-label |
|  instance   |                  |   lsr-id    |        space-id        |          |
  |    type     |                  |             |
+=============+==================+=============+========================+==========+===========
==+=============+======================+=============+
| default     | 192.0.2.2/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |
| default     | 192.0.2.3/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |
| default     | 192.0.2.4/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |
| default     | 192.0.2.5/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |
+-------------+-----------------+-------------+------------------------+----------+-----------
--+-------------+----------------------+-------------+
```

Enable the interface between PE-1 and PE-2 again.

```
# On PE-1:
enter candidate
    interface ethernet-1/31 admin-state enable
```

10.3.4.2 Node failure

Disable node PE-3 to simulate a failure of the node.

```
# On PE-3:
enter candidate
    network-instance default admin-state disable
```

The outcome of the LSP traces now indicates that PE-4 is reached from PE-1 via PE-2 only, needing three hops (PE-2, PE-5, PE-4) and that two hops are needed also to reach PE-5 (via PE-2). Paths to PE-3 are not present, because PE-3 is out.

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / oam lsp-trace ldp fec * session-id * hop * probe *
 | as table
+--------------+--------------+--------------+--------------+--------------+--------------+----
---------+--------------+--------------+
|     Fec      |  Session-id  |     Hop      | Probe-index  | Probes-sent  | Last-probe-  |
 Reply reply- | Reply round- |    Reply     |    Reply     |
|              |              |              |              |              |    send-     |
 sender    |  trip-time   | return-code  |   return-    |
|              |              |              |              |              |   failure-   |
          |              |              |   subcode    |
|              |              |              |              |              |    reason    |
          |              |              |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 192.0.2.2/32 |        49168 |            1 |            1 |            1 |              |
 192.0.2.2    |        3423 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.4/32 |        49169 |            1 |            1 |            1 |
 | 192.0.2.2    |         3325 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.4/32 |        49169 |            2 |            1 |            1 |
 | 192.0.2.5    |         3841 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.4/32 |        49169 |            3 |            1 |            1 |
 | 192.0.2.4    |         3721 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
```

```
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.5/32 |        49170 |            1 |            1 |            1 |              |
 192.0.2.2    |        1840 | label-       |              1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.5/32 |        49170 |            2 |            1 |            1 |              |
 192.0.2.5    |        3683 | replying-    |              1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
```

There are no LFA paths any more from PE-1. The 192.168.23.0/30, 192.168.34.0/30, and 192.168.35.0/30 networks are still reachable from PE-1, via paths through PE-2 (metric 20), through PE-2, PE-5, and PE-4 (metric 40), and through PE-2 and PE-5 (metric 30) respectively.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table all
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
|     Prefix      |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
    | Next-hop  | Next-hop  |  Backup   |  Backup   |
|                 |      |   Type    |                    |         | Network |        |
    |  (Type)   | Interface | Next-hop  | Next-hop  |
|                 |      |           |                    |         | Instanc |        |
    |           |           |  (Type)   | Interface |
|                 |      |           |                    |         |    e    |        |
    |           |           |           |           |
+=================+======+===========+====================+=========+=========+========+=======
====+===========+===========+===========+===========+
| 192.0.2.1/32    | 15   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.0.2.2/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.0.2.4/32    | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168.1 | ethernet- |           |           |
```

```
|                  |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                  |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.0.2.5/32     | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                  |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.12.0/30 | 13   | local     | net_inst_mgr       | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                    |         |         |        |
    | 2.1       | 1/31.1    |           |           |
|                  |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.12.1/32 | 13   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.12.3/32 | 13   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.0/30 | 14   | local     | net_inst_mgr       | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                    |         |         |        |
    | 3.1       | 1/32.1    |           |           |
|                  |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.13.1/32 | 14   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.3/32 | 14   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.23.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                  |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.25.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                  |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.34.0/30 | 0    | isis      | isis_mgr           | True    | default | 40     | 18
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                  |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.35.0/30 | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                  |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.45.0/30 | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                  |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
+------------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
```

```
IPv4 routes total                    : 15
IPv4 prefixes with active routes     : 15
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
```

The paths from PE-1 to all destinations are primary paths and they all go via PE-2.

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 next-hop * |
 as table | filter fields *
+------------+-----------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
|  Network-   |  Prefix-fec fec  | Prefix-fec  |   Prefix-fec label-    |  Index   |  Next-hop
  |  Next-hop-  |       Interface       | Outer-label |
|  instance   |                  |   lsr-id    |        space-id        |          |
  |    type     |                  |             |                        |          |
+=============+==================+=============+========================+==========+===========
==+=============+======================+=============+
| default     | 192.0.2.2/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |                        |
| default     | 192.0.2.4/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |                        |
| default     | 192.0.2.5/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |                        |
+-------------+-----------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
```

Enable node PE-3 again.

```
# On PE-3:
enter candidate
    network-instance default admin-state enable
```

10.3.5 Additional topics

10.3.5.1 Metric change

Decrease the IS-IS Level 2 metric values on the interfaces between PE-4 and PE-5 to 5, as follows:

```
# On PE-4, PE-5:
enter candidate
    network-instance default protocols isis instance 0 {
                    interface ethernet-1/5.1 {    # ethernet-1/7.1 for PE-5
                        level 2 {
                            metric 5
```

The outcome of the LSP traces indicates that two hops are needed only to reach PE-4 (via PE-3) and PE-5 (via PE-2). This is verified as follows:

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / oam lsp-trace ldp fec * session-id * hop * probe *
 | as table
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
|     Fec      |  Session-id  |     Hop      | Probe-index  | Probes-sent  | Last-probe-  |
 Reply reply- | Reply round- |    Reply     |    Reply     |
|              |              |              |              |              |    send-     |
 sender    |  trip-time   | return-code  |   return-    |
|              |              |              |              |              |   failure-   |
|          |              |              |   subcode    |
|              |              |              |              |              |    reason    |
|          |              |              |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 192.0.2.2/32 |        49175 |            1 |            1 |            1 |              |
 192.0.2.2    |         3212 | replying-    |            1 |
|              |              |              |              |              |              |
|          |              | router-is-   |              |
|              |              |              |              |              |              |
|          |              | egress-for-  |              |
|              |              |              |              |              |              |
|          |              | fec-at-      |              |
|              |              |              |              |              |              |
|          |              | stack-       |              |
|              |              |              |              |              |              |
|          |              | depth-n      |              |
| 192.0.2.3/32 |        49176 |            1 |            1 |            1 |              |
 192.0.2.3    |         3244 | replying-    |            1 |
|              |              |              |              |              |              |
|          |              | router-is-   |              |
|              |              |              |              |              |              |
|          |              | egress-for-  |              |
|              |              |              |              |              |              |
|          |              | fec-at-      |              |
|              |              |              |              |              |              |
|          |              | stack-       |              |
|              |              |              |              |              |              |
|          |              | depth-n      |              |
| 192.0.2.4/32 |        49177 |            1 |            1 |            1 |
 | 192.0.2.3    |         2512 | label-       |            1 |
|              |              |              |              |              |              |
|          |              | switched-at- |              |
|              |              |              |              |              |              |
|          |              | stack-       |              |
|              |              |              |              |              |              |
|          |              | depth-n      |              |
| 192.0.2.4/32 |        49177 |            2 |            1 |            1 |              |
 192.0.2.4    |         3843 | replying-    |            1 |
|              |              |              |              |              |              |
|          |              | router-is-   |              |
|              |              |              |              |              |              |
|          |              | egress-for-  |              |
|              |              |              |              |              |              |
|          |              | fec-at-      |              |
|              |              |              |              |              |              |
|          |              | stack-       |              |
|              |              |              |              |              |              |
|          |              | depth-n      |              |
```

```
| 192.0.2.5/32 |        49178 |            1 |            1 |            1 |
 | 192.0.2.2    |         3693 | label-       |            1 |
|              |              |              |              |              |              |
          |              | switched-at- |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
| 192.0.2.5/32 |        49178 |            2 |            1 |            1 |              |
 192.0.2.5    |        3858 | replying-    |            1 |
|              |              |              |              |              |              |
          |              | router-is-   |              |
|              |              |              |              |              |              |
          |              | egress-for-  |              |
|              |              |              |              |              |              |
          |              | fec-at-      |              |
|              |              |              |              |              |              |
          |              | stack-       |              |
|              |              |              |              |              |              |
          |              | depth-n      |              |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
```

All four nodes and all IS-IS routes learned by PE-1 are LFA protected (link or node). The total path metric to reach the 192.168.45.0/30 network (via PE-2 and PE-5) has decrased from 30 (10 + 10 + 10) to 25 (10 + 10 + 5):

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table all
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
|     Prefix      |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
    | Next-hop  | Next-hop  |  Backup   |  Backup   |
|                 |      |   Type    |                    |         | Network |        |
    |  (Type)   | Interface | Next-hop  | Next-hop  |
|                 |      |           |                    |         | Instanc |        |
    |           |           |  (Type)   | Interface |
|                 |      |           |                    |         |    e    |        |
    |           |           |           |           |
+=================+======+===========+====================+=========+=========+========+=======
====+===========+===========+===========+===========+
| 192.0.2.1/32    | 15   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.0.2.2/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.0.2.3/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.0.2.4/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.0.2.5/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
```

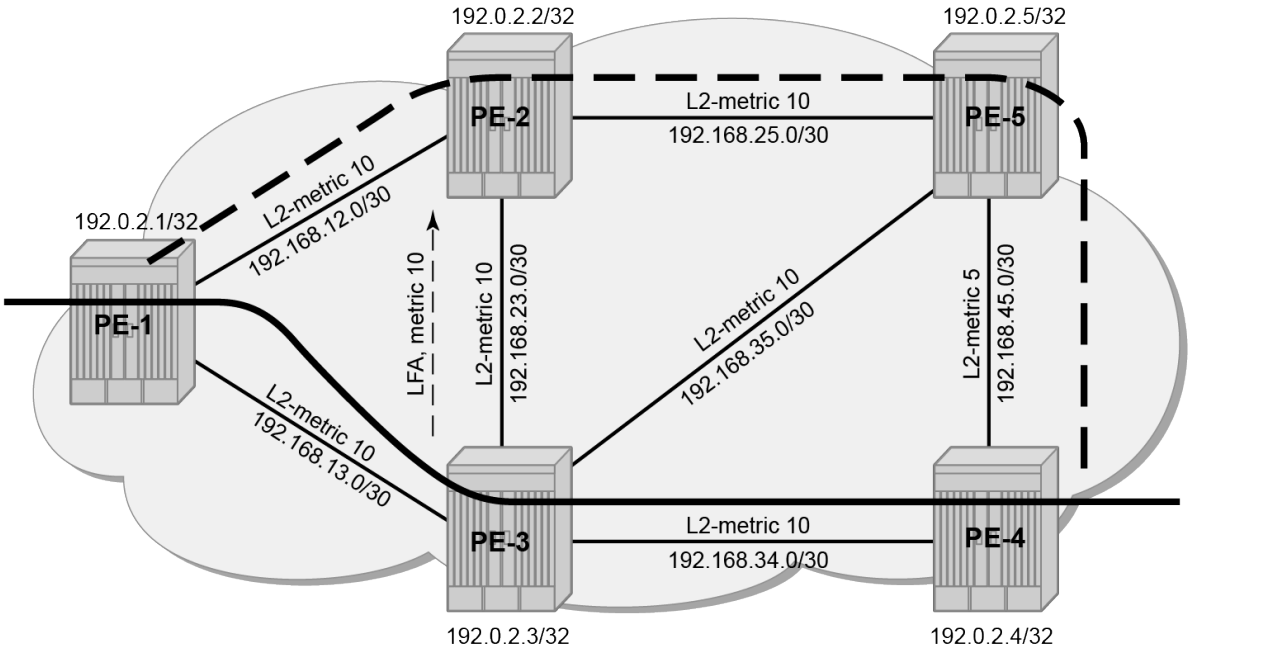
```
|                 |      |           |                     |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.12.0/30 | 13   | local     | net_inst_mgr        | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                     |         |         |        |
    | 2.1       | 1/31.1    |           |           |
|                 |      |           |                     |         |         |        |
    | (direct)  |           |           |           |
| 192.168.12.1/32 | 13   | host      | net_inst_mgr        | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.12.3/32 | 13   | host      | net_inst_mgr        | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.0/30 | 14   | local     | net_inst_mgr        | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                     |         |         |        |
    | 3.1       | 1/32.1    |           |           |
|                 |      |           |                     |         |         |        |
    | (direct)  |           |           |           |
| 192.168.13.1/32 | 14   | host      | net_inst_mgr        | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.3/32 | 14   | host      | net_inst_mgr        | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.23.0/30 | 0    | isis      | isis_mgr            | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                     |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.25.0/30 | 0    | isis      | isis_mgr            | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                     |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.34.0/30 | 0    | isis      | isis_mgr            | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                     |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                 |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.35.0/30 | 0    | isis      | isis_mgr            | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                     |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                 |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.45.0/30 | 0    | isis      | isis_mgr            | True    | default | 25     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                     |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
+-----------------+------+-----------+---------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv4 routes total                    : 16
IPv4 prefixes with active routes     : 16
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

Alternate data paths are back in place:

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 next-hop * |
 as table | filter fields *
+-------------+-----------------+------------+----------------------+----------+-----------
--+-------------+----------------------+------------+
|  Network-   |  Prefix-fec fec  | Prefix-fec  |   Prefix-fec label-    |  Index   |  Next-hop
  |  Next-hop-  |       Interface       | Outer-label |
|  instance   |                 |   lsr-id    |        space-id        |          |
  |    type     |                 |             |                        |
+=============+=================+============+=======================+==========+===========
==+=============+======================+=============+
| default     | 192.0.2.2/32    | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                 |             |                        |          | 2
  |             |                 |             |            |
| default     | 192.0.2.2/32    | 192.0.2.3   |                      0 |        1 |
 192.168.13. | alternate   | ethernet-1/32.1       |             |
|             |                 |             |                        |          | 2
  |             |                 |             |            |
| default     | 192.0.2.3/32    | 192.0.2.2   |                      0 |        1 |
 192.168.12. | alternate   | ethernet-1/31.1       |             |
|             |                 |             |                        |          | 2
  |             |                 |             |            |
| default     | 192.0.2.3/32    | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                 |             |                        |          | 2
  |             |                 |             |            |
| default     | 192.0.2.4/32    | 192.0.2.2   |                      0 |        1 |
 192.168.12. | alternate   | ethernet-1/31.1       |             |
|             |                 |             |                        |          | 2
  |             |                 |             |            |
| default     | 192.0.2.4/32    | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                 |             |                        |          | 2
  |             |                 |             |            |
| default     | 192.0.2.5/32    | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                 |             |                        |          | 2
  |             |                 |             |            |
| default     | 192.0.2.5/32    | 192.0.2.3   |                      0 |        1 |
 192.168.13. | alternate   | ethernet-1/32.1       |             |
|             |                 |             |                        |          | 2
  |             |                 |             |            |
+-------------+-----------------+------------+----------------------+----------+-----------
--+-------------+----------------------+------------+
```

Figure 22: Data verification in the direction from PE-1 to PE-4 shows the primary data path to PE-4 via PE-3 and the LFA alternate data path via PE-2 that is protecting node PE-3.

Figure 22: Data verification in the direction from PE-1 to PE-4



Restore the default IS-IS Level 2 metrics on PE-4 and PE-5.

```
# On PE-4, PE-5:
enter candidate
    network-instance default protocols isis instance 0 {
                    interface ethernet-1/5.1 {    # ethernet-1/7.1 for PE-5
                        level 2 {
                            delete metric
```

Increase the IS-IS Level 2 metric values on the interfaces between PE-2 and PE-3 to 30. LFA paths for some nodes and links are no longer possible.

```
# On PE-2, PE-3:
enter candidate
    network-instance default protocols isis instance 0 {
                    interface ethernet-1/34.1 {
                        level 2 {
                            metric 30
```

On PE-1, the inequality 3 formula finds LFA next-hop coverages for prefix PE-4 and PE-5. The inequality formula 1 finds LFA next-hop coverages for prefix PE-4, PE-5, and the subnet between PE-4 and PE-5. This can be derived from:

```
A:admin@PE-1# show / network-instance default route-table all | grep isis
| 192.0.2.2/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- |           |           |
| 192.0.2.3/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- |           |           |
```

```
| 192.0.2.4/32    | 0    | isis      | isis_mgr          | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
| 192.0.2.5/32    | 0    | isis      | isis_mgr          | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
| 192.168.23.0/30 | 0    | isis      | isis_mgr          | True    | default | 40     | 18
    | 192.168.1 | ethernet- |           |           |
| 192.168.25.0/30 | 0    | isis      | isis_mgr          | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
| 192.168.34.0/30 | 0    | isis      | isis_mgr          | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
| 192.168.35.0/30 | 0    | isis      | isis_mgr          | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
| 192.168.45.0/30 | 0    | isis      | isis_mgr          | True    | default | 30     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
```

Both inequality formulas are visualized in Figure 23: LFA computation: inequality 3 for prefix PE-4 (D) on PE-1 (S) and Figure 24: LFA computation: inequality 1 for prefix PE-4 (D) on PE-1 (S) for prefix 192.0.2.4/32 (= PE-4) on PE-1 which serves as the source node for LFA next-hop computation.

Figure 23: LFA computation: inequality 3 for prefix PE-4 (D) on PE-1 (S)

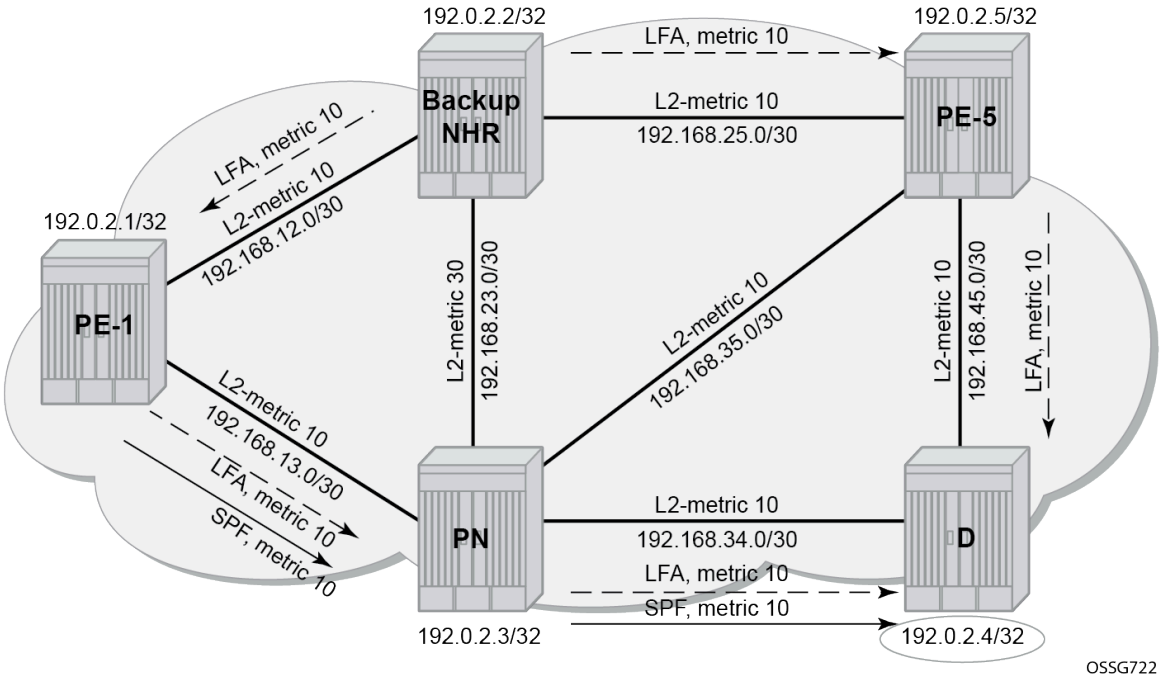
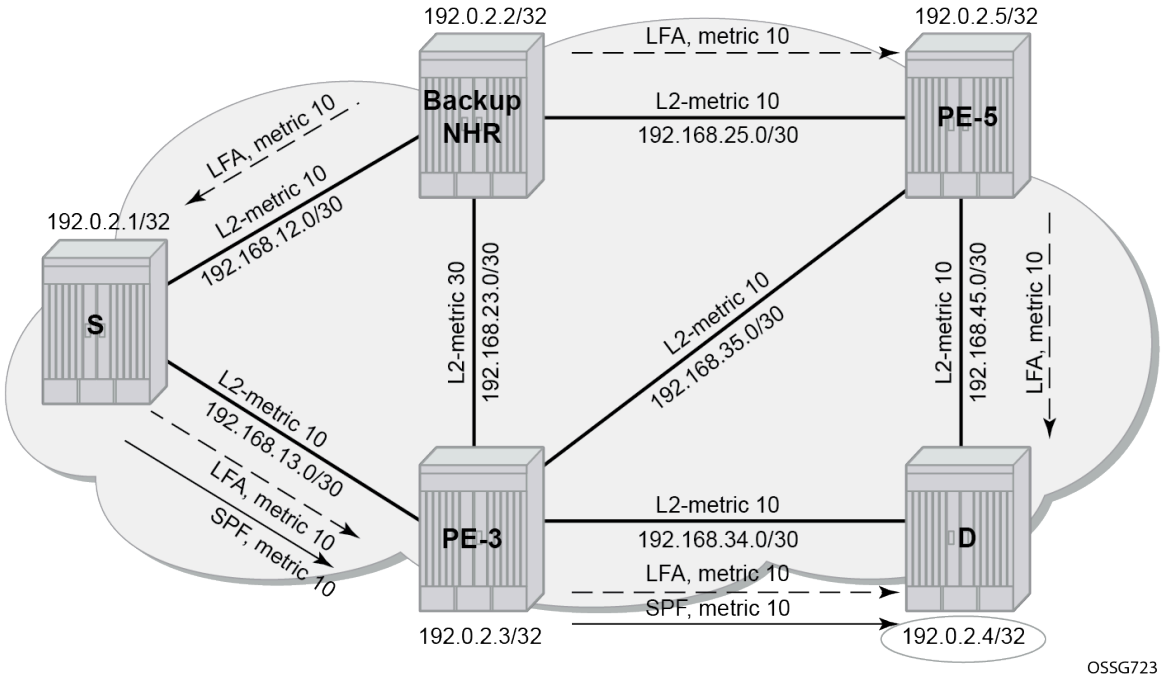


Figure 24: LFA computation: inequality 1 for prefix PE-4 (D) on PE-1 (S)



Inequality 3 formula:

```
SP(backup NHR, D) < SP(backup NHR, PN) + SP(PN, D)
```

For a node LFA next-hop computation of prefix 192.0.2.4/32 (D) on PE-1, this means that the shortest path from backup next-hop router PE-2 toward destination PE-4 must be smaller than the sum of the shortest path from backup next-hop router PE-2 toward protected node PE-3 and the shortest path from protected node PE-3 to destination PE-4.

The shortest path from backup next-hop router PE-2 toward destination PE-4 is going via PE-5, using IS-IS level 2 metric 10 for interface int-PE-2-PE-5 and IS-IS level 2 metric 10 for interface int-PE-5-PE-4. The shortest path from backup next-hop router PE-2 toward protected node PE-3 is going via PE-1, using IS-IS level 2 metric 10 for interface int-PE-2-PE-1 and IS-IS level 2 metric 10 for interface int-PE-1-PE-3. The shortest path from protected node PE-3 to destination PE-4 uses IS-IS level 2 metric 10 for interface int-PE-3-PE-4. The computation is as follows:

```
Prefix 192.0.2.4/32: SP(PE-2, PE-4) < SP(PE-2, PE-3) + SP(PE-3, PE-4)
                          10 + 10  <      (10 + 10) + 10            => OK
```

Inequality 1 formula:

```
SP(backup NHR, D) < SP(backup NHR, S) + SP(S, D)
```

For a link LFA next-hop computation of prefix 192.0.2.4/32 (D) on PE-1, this means that the shortest path from backup next-hop router PE-2 toward destination PE-4 must be smaller than the sum of the shortest

path from backup next-hop router PE-2 toward source PE-1 and the shortest path from source PE-1 to destination PE-4.

The shortest path from backup next-hop router PE-2 toward destination PE-4 is going over PE-5, using IS-IS level 2 metric 10 for interface int-PE-2-PE-5 and IS-IS level 2 metric 10 for interface int-PE-5-PE-4. The shortest path from backup next-hop router PE-2 toward source PE-1 uses IS-IS level 2 metric 10 for interface int-PE-2-PE-1. The shortest path from source PE-1 to destination PE-4 follows the normal SPF computation, going over PE-3, using IS-IS level 2 metric 10 for interface int-PE-1-PE-3, and IS-IS level 2 metric 10 for interface int-PE-3-PE-4.

The computation is as follows:

```
Prefix 192.0.2.4/32: SP(PE-2,PE-4) < SP(PE-2,PE-1) + SP(PE-1,PE-4)
                           10 + 10 <            10 + (10 + 10)      => OK
```

Considering all inequality 3 computations, only two out of four are valid (OK). So, the LFA node coverage on PE-1 is 2/4=50%.

Considering all inequality 1 computations, only three out of nine are valid (OK). So, the LFA IPv4 link coverage on PE-1 is 3/9=33%.

Restore the default IS-IS Level 2 metrics on PE-2 and PE-3.

10.3.5.2 IS-IS overload

As stated in RFC 3137, sometimes it is useful and desirable for a router not to be a transit node. For those cases, it is also desirable not to have that router used as transit node during the LFA next-hop computation. Within the IS-IS protocol, this is achieved by configuring IS-IS overload. When other routers detect that IS-IS overload is configured, they only use this router for packets destined to the overloaded router's directly connected networks and IP prefixes.

As an example, configure IS-IS overload on PE-2, as follows:

```
# On PE-2:
enter candidate
    network-instance default protocols isis instance 0 {
                    overload {
                        immediate {
                            set-bit true
                            max-metric false
```

The overload flag is advertised in the IS-IS link state database for LSP 0100.0000.0002.00-00 that corresponds with PE-2. This indicates to the other PEs that PE-2 is not available as a transit node and also not as a backup next hop node.

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols isis instance 0
 level 2
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    level 2 {
                        metric-style wide
                        loopfree-alternate-exclude false
                        ---snip---
                        link-state-database {
                            lsp 0100.0000.0001.00-00 {
```

```
                        ---snip---
                    }
                    lsp 0100.0000.0002.00-00 {
                        pdu-type level-2
                        is-type 3
                        ---snip---
                        flags [
                            overload
                        ]
                        tlvs {
                            ---snip---
                        }
                    }
                    lsp 0100.0000.0003.00-00 {
                        ---snip---
                    }
                    lsp 0100.0000.0004.00-00 {
                        ---snip---
                    }
                    lsp 0100.0000.0005.00-00 {
                        ---snip---
                    }
```

The primary path from PE-1 to PE-5 goes via PE-3 instead of via PE-2. This is also the case for the primary path from PE-1 to 192.168.45.0/30. There is no alternate path for the primary paths that go via PE-3. PE-3 still acts as the backup node for the primary paths that go via PE-2.

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 next-hop * |
 as table | filter fields *
+-------------+------------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
|  Network-   |  Prefix-fec fec  | Prefix-fec  |   Prefix-fec label-    |  Index   |  Next-hop
  |  Next-hop-  |       Interface       | Outer-label |
|  instance   |                  |   lsr-id    |        space-id        |          |
  |    type     |                      |             |
+=============+==================+=============+=======================+==========+===========
==+=============+======================+=============+
| default     | 192.0.2.2/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |            |
| default     | 192.0.2.2/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | alternate   | ethernet-1/32.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |            |
| default     | 192.0.2.3/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |            |
| default     | 192.0.2.4/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |            |
| default     | 192.0.2.5/32     | 192.0.2.3   |                      0 |        1
 | 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                       |          | 2
  |             |                  |             |            |
+-------------+------------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
```

Only three paths from PE-1 are LFA protected.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table all
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------------
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
|     Prefix      |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
    | Next-hop  | Next-hop  |  Backup   |  Backup   |
|                 |      |   Type    |                    |         | Network |        |
    |  (Type)   | Interface | Next-hop  | Next-hop  |
|                 |      |           |                    |         | Instanc |        |
    |           |           |  (Type)   | Interface |
|                 |      |           |                    |         |    e    |        |
    |           |           |           |           |
+=================+======+===========+====================+=========+=========+========+=======
====+===========+===========+===========+===========+
| 192.0.2.1/32    | 15   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.0.2.2/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.0.2.3/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.0.2.4/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.0.2.5/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.12.0/30 | 13   | local     | net_inst_mgr       | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.1       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.12.1/32 | 13   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.12.3/32 | 13   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.0/30 | 14   | local     | net_inst_mgr       | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.1       | 1/32.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (direct)  |           |           |           |
```

```
| 192.168.13.1/32 | 14   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.3/32 | 14   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.23.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |           |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |           |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.25.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |           |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |           |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.34.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |           |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |           |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.35.0/30 | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |           |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |           |           |                    |         |         |        |
    | (direct)  |           |           |           |
| 192.168.45.0/30 | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |           |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                 |           |           |                    |         |         |        |
    | (direct)  |           |           |           |
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv4 routes total                    : 16
IPv4 prefixes with active routes     : 16
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

With IS-IS **set-bit true** on PE-2 configured and **max-metric false**, the LFA coverage on PE-1 changes as follows.

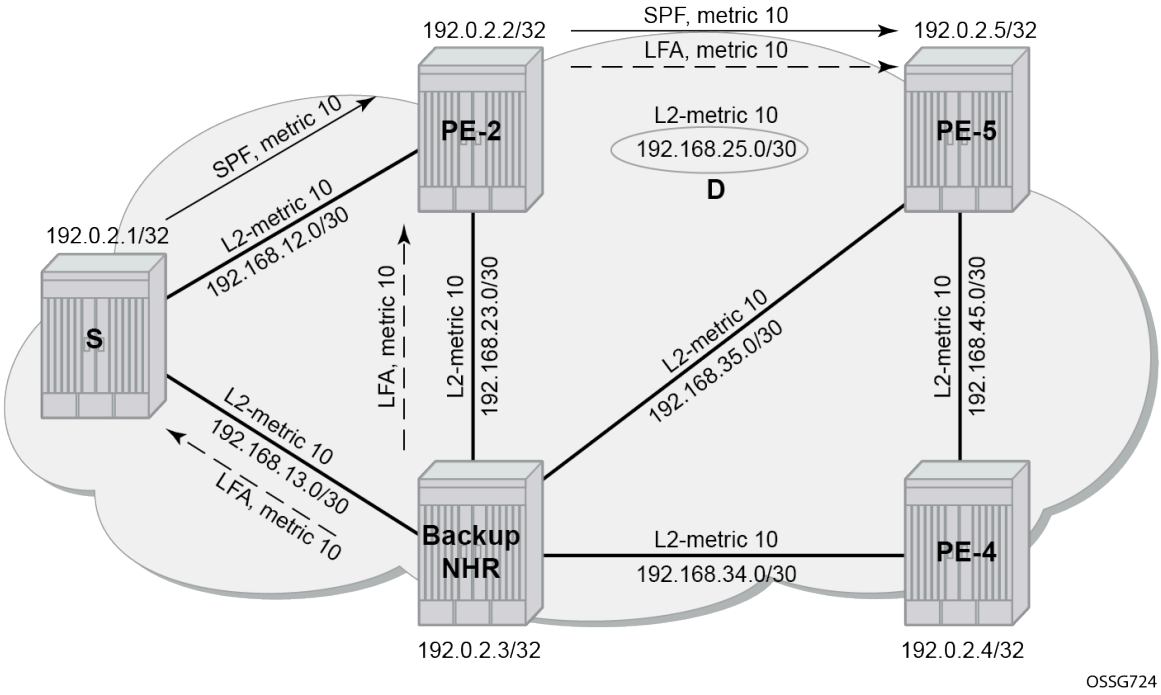
Considering all inequality 3 computations, only one out of four is valid (OK). So, the LFA node coverage on PE-1 is 1/4=25%.

Considering all inequality 1 computations, only three out of nine are valid (OK). So, the LFA IPv4 link coverage on PE-1 is 3/9=33%.

On PE-1, only three inequality 1 computations are possible, as seen in the previous **show** commands. The inequality 1 computation on PE-1 for destination 192.168.25.0/30 is as follows:

```
SP(backup NHR,D) < SP(backup NHR,S) + SP(S,D)
      SP(PE-3,D) <    SP(PE-3,PE-1) + SP(PE-1,D)
         10 + 10 <         10 + (10 + 10) => OK
```

Figure 25: IS-IS overload on PE-2, inequality 1 for 192.168.25.0/30 (D) on PE-1 (S)



It is also possible to configure a node as overloaded by advertising the node's transit links with maximum metric (16777214). As an example, configure IS-IS overload on PE-2, as follows:

```
# On PE-2:
enter candidate
    network-instance default protocols isis instance 0 {
                    overload {
                        immediate {
                            set-bit true
                            max-metric true    # set-bit must be true
```

The maximum link metric for each directly connected neighbor is advertised in the IS-IS link state database for LSP 0100.0000.0002.00-00 that corresponds with PE-2. This indicates to the other PEs that PE-2 is still available as a transit node and also as a backup node, but with maximum link metric.

```
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    level 2 {
                        metric-style wide
                        loopfree-alternate-exclude false
                        ---snip---
                        link-state-database {
                            lsp 0100.0000.0001.00-00 {
                                ---snip---
                            }
                            lsp 0100.0000.0002.00-00 {
                                ---snip---
```

```
                                pdu-type level-2
                                is-type 3
                                tlvs {
                                    ---snip---
                                    tlv extended-is-reachability {
                                        extended-is-reachability {
                                            neighbors {
                                                neighbor 0100.0000.0001 {
                                                    instances {
                                                        instance 0 {
                                                            metric 16777214
                                                            subtlvs {
                                                                subtlv is-reachability-ipv4-
interface-address {
                                                                    ipv4-interface-address {
                                                                        address [
                                                                            192.168.12.2
                                                                        ]
                                                                    }
                                                                }
                                                                subtlv is-reachability-ipv4-
neighbor-address {
                                                                    ipv4-neighbor-address {
                                                                        address [
                                                                            192.168.12.1
                                                                        ]
                                                                    }
                                                                }
                                                            }
                                                        }
                                                    }
                                                }
                                                neighbor 0100.0000.0003 {
                                                    instances {
                                                        instance 0 {
                                                            metric 16777214
                                                            subtlvs {
                                                                subtlv is-reachability-ipv4-
interface-address {
                                                                    ipv4-interface-address {
                                                                        address [
                                                                            192.168.23.1
                                                                        ]
                                                                    }
                                                                }
                                                                subtlv is-reachability-ipv4-
neighbor-address {
                                                                    ipv4-neighbor-address {
                                                                        address [
                                                                            192.168.23.2
                                                                        ]
                                                                    }
                                                                }
                                                            }
                                                        }
                                                    }
                                                }
                                                neighbor 0100.0000.0005 {
                                                    instances {
                                                        instance 0 {
                                                            metric 16777214
                                                            subtlvs {
                                                                subtlv is-reachability-ipv4-
interface-address {
```

```
                                                                ipv4-interface-address {
                                                                    address [
                                                                        192.168.25.1
                                                                    ]
                                                                }
                                                            }
                                                            subtlv is-reachability-ipv4-
neighbor-address {
                                                                ipv4-neighbor-address {
                                                                    address [
                                                                        192.168.25.2
                                                                    ]
                                                                }
                                                            }
                                                        }
                                                    }
                                                }
                                            }
                                        }
                                    }
                                }
                            }
                            lsp 0100.0000.0003.00-00 {
                                ---snip---
                            }
                            lsp 0100.0000.0004.00-00 {
                                ---snip---
                            }
                            lsp 0100.0000.0005.00-00 {
                                ---snip---
                            }
```

The primary path from PE-1 to PE-5 goes via PE-3 instead of via PE-2. This is also the case for the primary path from PE-1 to 192.168.45.0/30. There is no alternate path for the primary paths that go via PE-3. PE-3 still acts as the backup node for the primary paths that go via PE-2.

```
--{ running }--[  ]--
A:admin@PE-1# info from state with-context / network-instance default protocols ldp ipv4
 bindings received-prefix-fec prefix-fec * lsr-id * label-space-id 0 next-hop * |
 as table | filter fields *
+------------+-----------------+-------------+-----------------------+----------+-----------
--+-------------+----------------------+-------------+
|  Network-   |  Prefix-fec fec  | Prefix-fec  |   Prefix-fec label-    |  Index   |  Next-hop
  |  Next-hop-  |       Interface       | Outer-label |
|  instance   |                  |   lsr-id    |        space-id        |          |
  |    type     |                  |             |                        |          |
+============+==================+=============+========================+==========+===========
==+=============+======================+=============+
| default     | 192.0.2.2/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | primary     | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |                        |          |
| default     | 192.0.2.2/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | alternate   | ethernet-1/32.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |                        |          |
| default     | 192.0.2.3/32     | 192.0.2.2   |                      0 |        1 |
 192.168.12. | alternate   | ethernet-1/31.1       |             |
|             |                  |             |                        |          | 2
  |             |                  |             |                        |          |
| default     | 192.0.2.3/32     | 192.0.2.3   |                      0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
```

```
|             |                  |             |                         |          | 2
  |             |                  |             |             |
| default     | 192.0.2.4/32     | 192.0.2.3   |                       0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                         |          | 2
  |             |                  |             |             |
| default     | 192.0.2.5/32     | 192.0.2.2   |                       0 |        1 |
 192.168.12. | alternate   | ethernet-1/31.1       |             |
|             |                  |             |                         |          | 2
  |             |                  |             |             |
| default     | 192.0.2.5/32     | 192.0.2.3   |                       0 |        1 |
 192.168.13. | primary     | ethernet-1/32.1       |             |
|             |                  |             |                         |          | 2
  |             |                  |             |             |
+-------------+------------------+-------------+-------------------------+----------+-----------
--+-------------+----------------------+-------------+
```

When the destination node belongs to the set of direct neighbors of PE-2, the LFA computation uses the configured link metrics. Otherwise, the LFA computation uses the maximum metric value on the links to the transit nodes. In the given example, only PE-4 does not belong to the set of direct neighbors of PE-2. So, the node and link inequalities for PE-4 cannot be fullfilled. On the primary path, the 192.168.45.0/32 network is reached via PE-4. So the link inequality for the 192.168.45.0/32 network can also not be fullfilled.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default route-table all
-------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
|     Prefix      |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
    | Next-hop  | Next-hop  |  Backup   |  Backup   |
|                 |      |   Type    |                    |         | Network |        |
    |  (Type)   | Interface | Next-hop  | Next-hop  |
|                 |      |           |                    |         | Instanc |        |
    |           |           |  (Type)   | Interface |
|                 |      |           |                    |         |    e    |        |
    |           |           |           |           |
+=================+======+===========+====================+=========+=========+========+=======
====+===========+===========+===========+===========+
| 192.0.2.1/32    | 15   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.0.2.2/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.0.2.3/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                 |      |           |                    |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.0.2.4/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 3.2       | 1/32.1    |           |           |
```

```
|                  |      |           |                     |         |         |        |
    | (direct)  |           |           |           |
| 192.0.2.5/32     | 0    | isis      | isis_mgr            | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                  |      |           |                     |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                  |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.12.0/30 | 13   | local     | net_inst_mgr        | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                     |         |         |        |
    | 2.1       | 1/31.1    |           |           |
|                  |      |           |                     |         |         |        |
    | (direct)  |           |           |           |
| 192.168.12.1/32 | 13   | host      | net_inst_mgr        | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.12.3/32 | 13   | host      | net_inst_mgr        | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.0/30 | 14   | local     | net_inst_mgr        | True    | default | 0      | 0
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                     |         |         |        |
    | 3.1       | 1/32.1    |           |           |
|                  |      |           |                     |         |         |        |
    | (direct)  |           |           |           |
| 192.168.13.1/32 | 14   | host      | net_inst_mgr        | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.13.3/32 | 14   | host      | net_inst_mgr        | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.168.23.0/30 | 0    | isis      | isis_mgr            | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                  |      |           |                     |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                  |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.25.0/30 | 0    | isis      | isis_mgr            | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                  |      |           |                     |         |         |        |
    | 2.2       | 1/31.1    | 3.2       | 1/32.1    |
|                  |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.34.0/30 | 0    | isis      | isis_mgr            | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                  |      |           |                     |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                  |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.35.0/30 | 0    | isis      | isis_mgr            | True    | default | 20     | 18
    | 192.168.1 | ethernet- | 192.168.1 | ethernet- |
|                  |      |           |                     |         |         |        |
    | 3.2       | 1/32.1    | 2.2       | 1/31.1    |
|                  |      |           |                     |         |         |        |
    | (direct)  |           | (direct)  |           |
| 192.168.45.0/30 | 0    | isis      | isis_mgr            | True    | default | 30     | 18
    | 192.168.1 | ethernet- |           |           |
|                  |      |           |                     |         |         |        |
    | 3.2       | 1/32.1    |           |           |
|                  |      |           |                     |         |         |        |
    | (direct)  |           |           |           |
+-----------------+------+-----------+---------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------
IPv4 routes total                    : 16
IPv4 prefixes with active routes     : 16
```

```
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------
-----------------------------------------------------------
```

Considering all inequality 3 computations, only three out of four are valid (OK). So, the LFA node coverage on PE-1 is 3/4=75%.

Considering all inequality 1 computations, only seven out of nine are valid (OK). So, the LFA IPv4 link coverage on PE-1 is 7/9=78%.

Remove the overload configuration on PE-2, as follows:

```
# On PE-2:
enter candidate
    network-instance default protocols isis instance 0 {
                    delete overload
```

10.4 Conclusion

In production MPLS networks where LFA needs to be deployed, LDP LFA improves convergence in case of a single link or single node failure in the network. The two main advantages of using LDP LFA are the simple configuration and the fact that LFA next-hop computation is a local decision, which means there are no interoperability issues when working in a multi-vendor environment. The main disadvantage of using LDP LFA is that LFA next-hop computation has to deal with the source-route paradigm (inequality formulas exclude a path going over the original source router).

11 Security hardening using CPM filters

Protecting the control and management plane of each routing switch in the data center fabric (access leaf, border leaf, spine) from unauthorized or out-of-profile sources of traffic is important. Without control plane protection policies, routers are vulnerable to attacks on the data center infrastructure and performance degradation can occur because of misconfiguration.

The SR Linux supports a special Access Control List (ACL) type called a cpm-filter for control plane protection. There are separate Control Processing Module (CPM) filters for IPv4 traffic and for IPv6 traffic. The entries of each cpm-filter are installed on each line card and in the Control CPM software. There are different types of cpm-filter actions that can be applied and all actions are not relevant at all locations. ACL configuration for control plane protection defines each action and how to configure it.

11.1 ACL configuration for control plane protection

ACLs support the following actions:

- accept - Allows the packet through to the next processing function.
- drop - Discards the packet without Internet Control Message Protocol (ICMP) generation.
- log - Extracts information about each matching packet and sends it to the log application.
- distributed-policer - Sends the packet to a policer instance implemented in the forwarding ASIC of the ingress line card. This policer sends the packet to the CPM only if the policer token bucket does not go into the exceed/violate state. The rate of a distributed-policer is defined in units of kb/s and the bucket depth is defined in units of bytes.
- system-cpu-policer - Sends the packet to a policer instance implemented by CPM software when the packet reaches the CPM from any line card as source. This policer admits the packet to its owner application only if the policer token bucket does not go into the exceed/violate state. The rate of a system-cpu-policer is defined in units of packets-per-second and the bucket depth is defined in units of packets.

11.1.1 CPM filter rules

CPM filter rules that apply a system-cpu-policer or distributed-policer action do not directly specify the policer parameters. Instead, the rules refer to a generically defined policer under the ACL configuration tree. This allows different CPM filter entries, even across multiple ACLs, to use the same policer if needed. Optionally, each policer can be configured as entry-specific. This means that a different policer instance is used by each referring filter entry, even if they are part of the same ACL.

CPM filter ACL actions are applied to the following traffic flows:

- IPv4 and IPv6 traffic flows originating by external systems, arriving on any line card port, accepted by the interface ACLs applied to the ingress subinterface (if any), system ACLs applied globally, and determined to be locally terminating by lookup of the IP destination address
- IPv4 and IPv6 traffic flows originating by external systems, arriving on the Out-of-Band (OOB) management port and accepted by the interface ACLs applied to ingress traffic on the OOB port

subinterface, and system ACLs applied globally. If the CPM-filter policy has distributed-policer actions, these are ignored for inbound traffic on the OOB management port.

The startup configuration of a new SR Linux router includes a default IPv4 cpm-filter policy and a default IPv6 cpm-filter policy. These default policies block packets associated with any protocol that is not supported by the SR Linux operating system. However, they do not limit the sending sources or enforce any rate limits aside from ICMPv4/ICMPv6 traffic, which is subject to an aggregate rate limit of 1000 pps. The default policies should be modified to add these additional restrictions, and to allow protocols associated with NetOps Development Kit (NDK) applications, if applicable.

11.1.2 Restricting source subnets for incoming traffic using CPM filter

Procedure

Use the **acl cpm-filter** command to define how to restrict the source subnets for incoming SSH traffic associated with remotely originated TCP connections to a specified IP address.

Example: (IPv4 address of 192.0.2.0/24)

```
--{  candidate shared default }--[  ]--
# acl cpm-filter ipv4-filter
--{ candidate shared default }--[ acl cpm-filter ipv4-filter ]--
# entry 100 match
--{ candidate shared default }--[ acl cpm-filter ipv4-filter entry 100 match ]--
# source-ip address 192.0.2.0 mask 255.255.255.0
--{ * candidate shared default }--[ acl cpm-filter ipv4-filter entry 100 match ]--
# protocol tcp destination-port value ssh
--{ * candidate shared default }--[ acl cpm-filter ipv4-filter entry 100 match ]--
# exit
--{ * candidate shared default }--[ acl cpm-filter ipv4-filter entry 100 ]--
# action drop
--{ * candidate shared default }--[ acl cpm-filter ipv4-filter entry 100 ]--
# exit all
--{  candidate shared default }--[  ]--
# info acl cpm-filter ipv4-filter entry 100
    acl {
        cpm-filter {
            ipv4-filter {
                entry 100 {
                    description "Restrict the source subets 192.0.2.0/24 for incoming SSH
 Traffic"
                    action {
                        drop {
                        }
                    }
                    match {
                        protocol tcp
                        source-ip {
                            address 192.0.2.0
                            mask 255.255.255.0
                        }
                        destination-port {
                            value ssh
                        }
                    }
                }
            }
        }
    }
```

Example: (IPv6 address of 2001:db8:3200/48)

```
--{  candidate shared default }--[  ]--
# acl cpm-filter ipv6-filter entry 140
--{ candidate shared default }--[ acl cpm-filter ipv6-filter entry 140]--
# match next-header tcp destination-port value ssh operator eq
--{ candidate shared default }--[ acl cpm-filter ipv6-filter entry 140]--
# match source-ip address 2001:db8::1 mask FFFF:FFFF:FFFF:FFF8:FFFF:FFFF:FFFF:FFFF
--{ candidate shared default }--[ acl cpm-filter ipv6-filter entry 140]--
# action drop
--{ candidate shared default }--[ acl cpm-filter ipv6-filter entry 140]--
# exit all
--{  candidate shared default }--[  ]--
# info acl cpm-filter ipv6-filter entry 140
    acl {
        cpm-filter {
            ipv6-filter {
                entry 140 {
                    description "Restrict the source subets 2001:db8:32::/48 for incoming
 SSH Traffic"
                    action {
                        drop {
                        }
                    }
                    match {
                        next-header tcp
                        source-ip {
                            address 2001:db8::1
                            mask ffff:ffff:ffff:fff8:ffff:ffff:ffff:ffff
                        }
                        destination-port {
                            operator eq
                            value ssh
                        }
                    }
                }
            }
        }
    }
```

12 Segment Routing – Traffic Engineered Tunnels

This chapter provides information about Segment Routing – Traffic Engineered Tunnels.

Topics in this chapter include:

12.1 Applicability

The CLI in the current edition corresponds to SR Linux Release 25.10.R2.

12.2 Overview

Segment Routing (SR) is described in the Segment Routing with IS-IS Control Plane chapter, where the advertisement of node prefix segment identifiers (SIDs) cause the automatic creation of ECMP-aware shortest path MPLS tunnels on each SR-aware router. Each node prefix SID is a globally unique value and becomes an MPLS label in the MPLS data plane. The label is advertised and learned by each SR-capable router using control plane extensions to the IS-IS protocol.

It is also possible to create source-routed traffic-engineered (TE) end-to-end segment routing paths, where routing constraints such as strict or loose hops can be used to determine a data path to be taken through a network.

These SR-TE Label Switched Paths (LSPs) are implemented as uncolored SR-MPLS TE policies. The path can be computed locally by the head-end PE or by offloading the path computation to an external controller. The intermediate and tail-end router are unaware of the presence of an SR-TE LSP because there is no signaling protocol used to create the path. If a packet is forwarded through the SR tunnel, each router along the path reads the top label and forwards the packet according to the SR tunnel table entry for that label.

This chapter describes the configuration of uncolored SR-MPLS TE policies with locally-computed source-routed paths and how they can be used in the data plane of Layer 2 and Layer 3 services. In the cases described, an uncolored SR-MPLS TE policy containing an explicit path with a number of strict or loose hops is created at the head-end router and used to construct an SR-TE LSP by translating the IP addresses configured in the MPLS path to a SID. This results in an MPLS path with state at the head end only, comprising a stack of SIDs, where each SID is an MPLS label.

In this chapter, IS-IS is used to advertise the SIDs and a set of extensions to IS-IS have been defined, which require additional configuration on each network router.

The LSP is instantiated—the state is operationally "up"—and a tunnel table entry is created that is owned by the te-policy-sr-mpls-uncolored protocol. Any data packet that is resolved to use the resulting tunnel has

the label stack imposed at the head-end router and is forwarded out of the appropriate next-hop interface. This interface is determined by the topmost label in the stack.

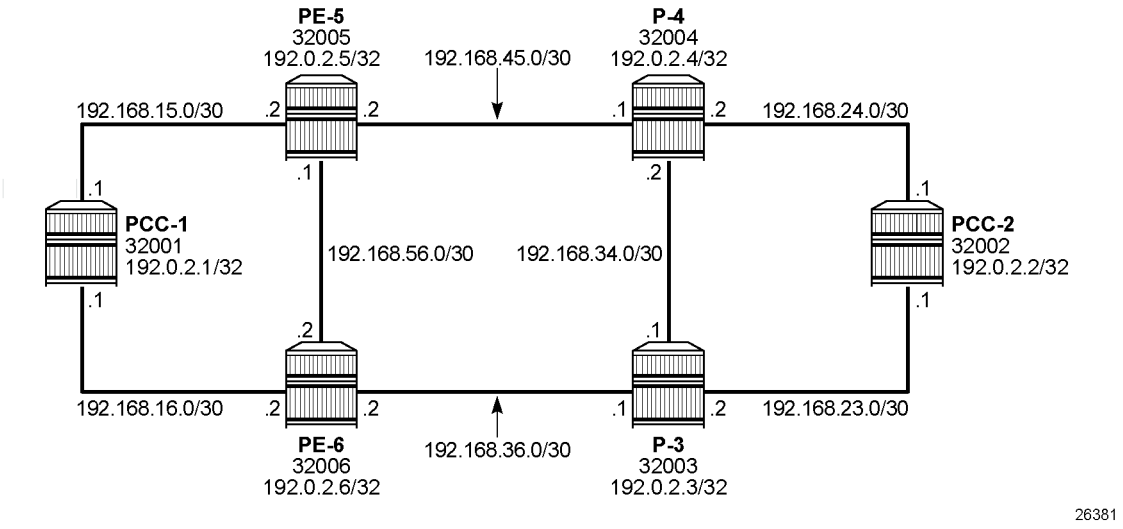
If the label is a node SID, the outgoing interface is determined by the IGP—the shortest path to the router that the node SID represents.

If the label is a local adjacency SID, the outgoing interface is the local interface for which this SID is generated by the IGP.

The segments referenced can be a prefix segment, such as a node segment or an adjacency segment, which represents a specific adjacency between two nodes. The SIDs are used as MPLS labels.

In the following configuration examples, the LSP path is created at the head-end router, and computed by translating a list of hops containing IP addresses into a list of SIDs, by examining the IS-IS TE database. The head-end router is referred to as a Path Computation Client (PCC). Figure 26: Segment routing network schematic shows the example topology used, and a pair of bidirectional connected SR-TE LSPs between PCC-1 and PCC-2 is configured to illustrate SR-TE LSPs. All interfaces between PCC-1 and its neighbors have the IS-IS metric set to 100. Similarly, for PCC-2, the IGP metric is also set to 100 between itself and its neighbors. The IS-IS metric on router interfaces between the core routers P-3, P-4, PE-5, and PE-6 is 10.

Figure 26: Segment routing network schematic



12.3 Configuration

12.3.1 MPLS label ranges

MPLS label ranges for adjacency SIDs and node SIDs must be configured. The Segment Routing Global Block (SRGB) is the MPLS label range from which node SIDs are allocated. The Segment Routing Local Block (SRLB) is the MPLS label range from which dynamic adjacency SIDs are allocated. In this example, a range of 1000 labels is chosen for the SRGB and another range of 1000 labels is chosen for the SRLB. For operational simplicity, Nokia recommends that the same MPLS label ranges are chosen for each

SR-capable router. However, this is not an explicit requirement. On all nodes, the SRGB and SRLB are configured as follows:

```
# on all nodes:
enter candidate
    system {
        mpls {
            label-ranges {
                static srgb-static-mpls {            # SRGB for node SIDs
                    shared true
                    start-label 32000
                    end-label 32999
                }
                dynamic srlb-dynamic-mpls {          # SRLG for adjacency SIDs
                    start-label 525000
                    end-label 525999
                }
```

When the SRGB and SRLB label ranges have been configured, the MPLS label ranges can be verified as follows:

```
--{ + running }--[  ]--
A:admin@PCC-1# info from state with-context / system mpls label-ranges static * | as table |
 filter fields *

+-----------------------------------------+--------+-------------+-----------+-----------------
-+-------------+----------------+
|                  Name                   | Shared | Start-label | End-label | Allocated-labels
 | Free-labels |     Status     |
+=========================================+========+=============+===========+=================
=+=============+================+
| srgb-static-mpls                        | true   |       32000 |     32999 |                0
 |        1000 | ready          |
+-----------------------------------------+--------+-------------+-----------+-----------------
-+-------------+----------------+

--{ + running }--[  ]--
A:admin@PCC-1# info from state with-context / system mpls label-ranges dynamic * | as table |
 filter fields *

+-------------------------------------------------+-------------+-----------+-----------------
-+-------------+----------------+
|                     Name                        | Start-label | End-label | Allocated-labels
 | Free-labels |     Status     |
+=================================================+=============+===========+=================
=+=============+================+
| srlb-dynamic-mpls                               |      525000 |    525999 |                0
 |        1000 | ready          |
+-------------------------------------------------+-------------+-----------+-----------------
-+-------------+----------------+
```

12.3.2 SR-ISIS configuration

The first step is to configure a single-level IS-IS instance on each router, as follows:

```
# on PCC-1:
    network-instance default {
        protocols {
            isis {
```

```
                instance 0 {
                    admin-state enable
                    level-capability L2
                    net [
                        49.0000.1920.0000.2001.00
                    ]
                    interface ethernet-1/5.1 {
                        admin-state enable
                        circuit-type point-to-point
                        level 2 {
                            metric 100
                        }
                    }
                    interface ethernet-1/6.1 {
                        admin-state enable
                        circuit-type point-to-point
                        level 2 {
                            metric 100
                        }
                    }
                    interface system0.0 {
                    }
                    level 2 {
                    }
                }
```

The configuration for all other nodes is similar, with different values for net, interfaces, and IGP metrics, as can be derived from Figure 26: Segment routing network schematic.

For each router to be segment-routing capable, additional configuration is required. On PCC-1, segment routing is configured as follows:

```
# on PCC-1:
    network-instance default {
         protocols {
            isis {
                dynamic-label-block srlb-dynamic-mpls       ## SRLB for adj SIDs
                instance 0 {
                    segment-routing {
                        mpls {
                            dynamic-adjacency-sids {
                                all-interfaces true
                            }
                        }
                    }
                }
            }
        }
        segment-routing {
            mpls {
                global-block {
                    label-range srgb-static-mpls            ## SRGB for node SIDs
                }
                local-prefix-sid 1 {
                    interface system0.0
                    ipv4-label-index 1        ## index 2 on PCC-2, 3 on P-3, 4 on P-4...
                    node-sid true
                }
```

The node SID is manually configured as an index. With the SRGB label base equal to 32000 and the IPv4 label index 1 on PCC-1, the node SID for PCC-1 is 32000 + 1 = 32001.

The following output taken from PCC-1 shows the prefix SIDs configured on the routers in the network and advertised using IS-IS.

```
--{ + running }--[  ]--
A:admin@PCC-1# info from state network-instance default segment-routing mpls sid-database

    prefix-sid 192.0.2.1/32 sid-label-value 32001 protocol direct protocol-instance 0 protocol-
multi-topology 0 algorithm 0 {
        active true
    }
    prefix-sid 192.0.2.2/32 sid-label-value 32002 protocol isis protocol-instance 0 protocol-
multi-topology 0 algorithm 0 {
        active true
    }
    prefix-sid 192.0.2.3/32 sid-label-value 32003 protocol isis protocol-instance 0 protocol-
multi-topology 0 algorithm 0 {
        active true
    }
    prefix-sid 192.0.2.4/32 sid-label-value 32004 protocol isis protocol-instance 0 protocol-
multi-topology 0 algorithm 0 {
        active true
    }
    prefix-sid 192.0.2.5/32 sid-label-value 32005 protocol isis protocol-instance 0 protocol-
multi-topology 0 algorithm 0 {
        active true
    }
    prefix-sid 192.0.2.6/32 sid-label-value 32006 protocol isis protocol-instance 0 protocol-
multi-topology 0 algorithm 0 {
        active true
    }
```

The output is similar for all routers in the network.

Adjacency SIDs are assigned to each interface link.

The following tunnel table shows 7 SR-ISIS tunnels: one to each other system IP prefix with tunnel ID equal to the node SID and one to each adjacency with tunnel ID equal to the adjacency SID. For each destination prefix, the tunnel table indicates the next hop and the interface via which it is reached, as well as the end-to-end metric for the tunnel.

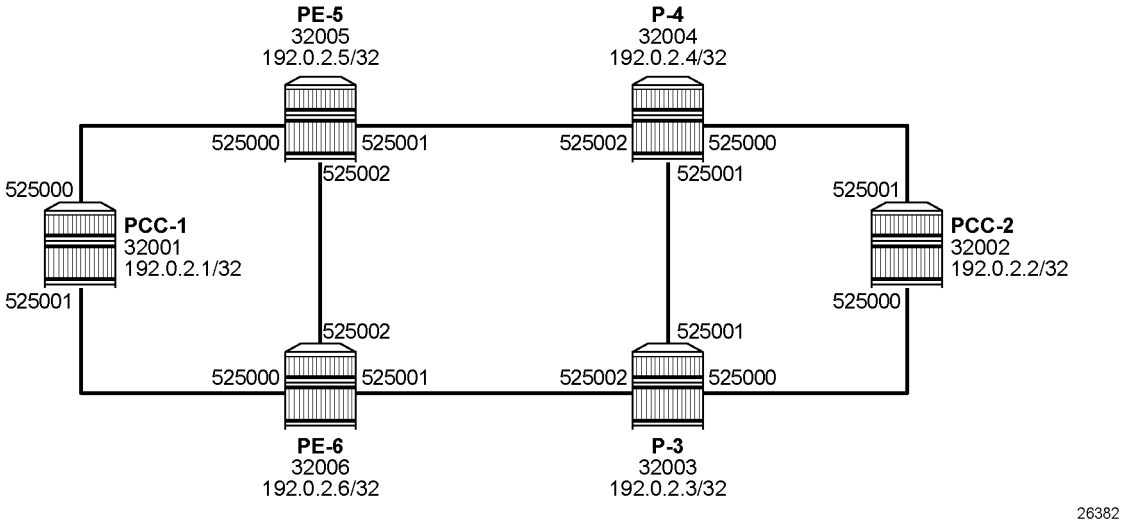
```
--{ + running }--[  ]--
A:admin@PCC-1# show network-instance default tunnel-table ipv4

------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------
---------
IPv4 tunnel table of network-instance "default"
------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------
---------
+----------------------------------+----------------+----------+-----+----------+---------+---
----------------------+----------------------+----------------------+-------------------------
--------+
|            IPv4 Prefix           |  Tunnel Type   |  Tunnel  | FIB |  Metric  | Prefere |
    Last Update        |   Backup Nexthops    |   Next-hop (Type)    |            Next-hop
        |
|                                  |                |    ID    |     |          |   nce   |
                       |                      |                      |
        |
+==================================+================+==========+=====+==========+=========+===
======================+======================+======================+=========================
========+
```

```
| 192.0.2.2/32                      | sr-isis        | 32002    | Y   | 210      | 11      |
 2026-02-17T13:02:35.444Z |                      | 192.168.15.2 (mpls)  | ethernet-1/5.1
          |
| 192.0.2.3/32                      | sr-isis        | 32003    | Y   | 110      | 11      |
 2026-02-17T13:02:42.972Z |                      | 192.168.16.2 (mpls)  | ethernet-1/6.1
          |
| 192.0.2.4/32                      | sr-isis        | 32004    | Y   | 110      | 11      |
 2026-02-17T13:02:49.544Z |                      | 192.168.15.2 (mpls)  | ethernet-1/5.1
          |
| 192.0.2.5/32                      | sr-isis        | 32005    | Y   | 100      | 11      |
 2026-02-17T13:02:56.175Z |                      | 192.168.15.2 (mpls)  | ethernet-1/5.1
          |
| 192.0.2.6/32                      | sr-isis        | 32006    | Y   | 100      | 11      |
 2026-02-17T13:03:04.667Z |                      | 192.168.16.2 (mpls)  | ethernet-1/6.1
          |
| 192.168.15.2/32                   | sr-isis        | 525000   | Y   | 0        | 11      |
 2026-02-17T12:51:42.019Z |                      | 192.168.15.2 (mpls)  | ethernet-1/5.1
          |
| 192.168.16.2/32                   | sr-isis        | 525001   | Y   | 0        | 11      |
 2026-02-17T12:51:42.019Z |                      | 192.168.16.2 (mpls)  | ethernet-1/6.1
          |
+-----------------------------------+----------------+----------+-----+----------+---------+---
-----------------------+----------------------+----------------------+-------------------------
--------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
---------
7 SR-ISIS tunnels, 7 active, 0 inactive
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
---------
```

On PCC-1, the adjacency SID for the interface toward PE-5 is 525000, and the adjacency SID for the interface toward PE-6 is 525001.

An overview of the SIDs for the whole network is shown in Figure 27: Node and adjacency SIDs.

Figure 27: Node and adjacency SIDs



12.3.3 Uncolored SR-MPLS TE policies

This section describes uncolored SR-MPLS TE policies that are configured on the head-end router (the PCC). The path taken through the network is computed locally by the PCC. To influence the path taken, a series of strict and loose hops is configured in an MPLS path.

Note:
SR-TE LSPs configured without an explicit path is effectively a shortest path tunnel to the destination node. The destination address is resolved to the node SID of the tail-end router.

Traffic engineering must be configured on the nodes. The TE configuration on PCC-1 is as follows:

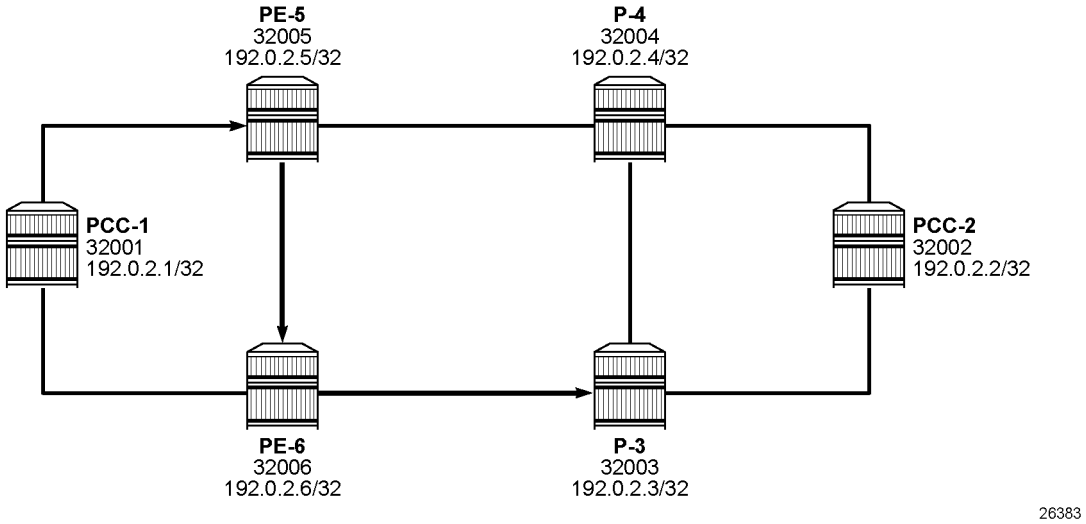
```
# on PCC-1:
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    admin-state enable
                    te-database-install {
                    }
                    traffic-engineering {
                        advertisement true
                        legacy-link-attribute-advertisement false
                        ipv4-te-router-id 192.0.2.1
                    }
                }
            }
        }
        traffic-engineering {
            ipv4-te-router-id 192.0.2.1
            interface ethernet-1/5.1 {
                interface-ref {
                    interface ethernet-1/5
                    subinterface 1
                }
            }
            interface ethernet-1/6.1 {
                interface-ref {
                    interface ethernet-1/6
                    subinterface 1
                }
            }
```

The TE configuration on the other nodes is similar, with different router ID and interfaces.

12.3.4 PCC-initiated and computed LSP – explicit path with strict hops

Consider an uncolored SR-MPLS TE policy configured on PCC-1, with tail end at PCC-2. Assume there is a requirement for the LSP to avoid the link from PE-5 to P-4 during normal working, so a strict path from PCC-1 via PE-5 to PE-6, and then on to P-3 is required before being forwarded to PCC-2. This is shown in Figure 28: Explicit path with strict hops from PCC-1 to PCC-2.

Figure 28: Explicit path with strict hops from PCC-1 to PCC-2



To meet these requirements, an explicit path is configured containing the following strict hops, using the system addresses to identify the hops. The following configures an uncolored SR-MPLS TE policy using the explicit path:

```
# on PCC-1:
    network-instance default {
        traffic-engineering-policies {
            explicit-paths {
                path PCC-controlled-strict-path {
                    hop 10 {
                        ip {
                            ip-address 192.0.2.5
                            hop-type strict
                        }
                    }
                    hop 20 {
                        ip {
                            ip-address 192.0.2.6
                            hop-type strict
                        }
                    }
                    hop 30 {
                        ip {
                            ip-address 192.0.2.3
                            hop-type strict
                        }
                    }
                }
            }
            policy pol_strict-to-PCC-2 {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.2
                segment-list 1 {
                    admin-state enable
                    explicit-path PCC-controlled-strict-path
                    segment-list-type primary
                }
```

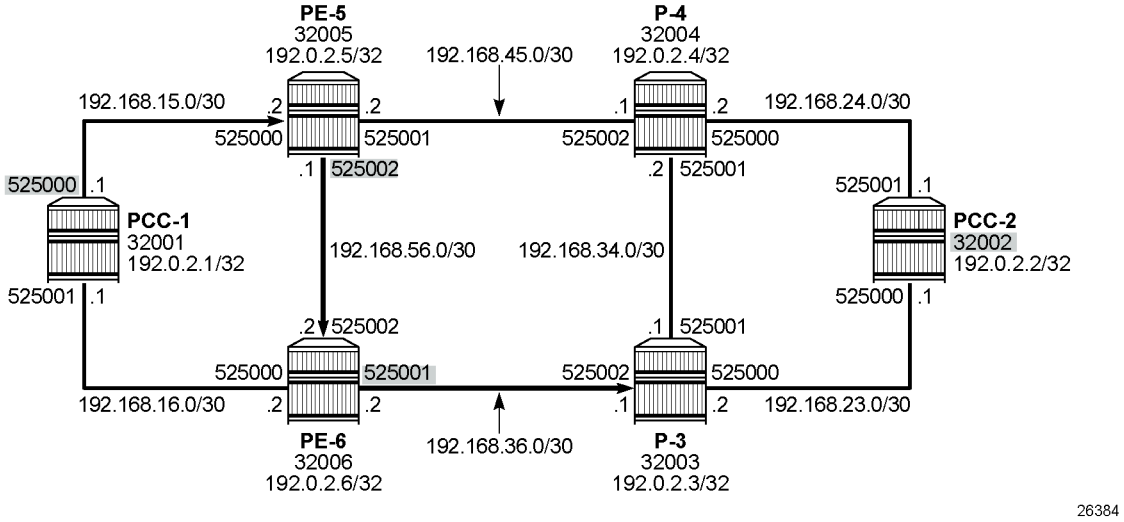
```
            }
```

The following shows the segments in segment list 1 of the uncolored SR-MPLS TE policy "pol_strict-to-PCC-2" with adjacency SIDs for the three strict hops in the explicit path and a node SID for the loose hop to the destination hop of 192.0.2.2:

```
--{ + running }--[  ]--
A:admin@PCC-1# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 1 computed-segments segment *
 | as table | filter fields ip-address router-id is-loose sid-type sid-value/mpls-label

+----------------------+----------------------+-----------------------+-------------+--------
-------+----------------------+----------------------+----------+---------------+-------------
---------+
|   Network-instance   |  Policy policy-name  | Policy protocol-origin | Segment-list |
 Segment-index |      Ip-address      |      Router-id       | Is-loose |    Sid-type    | Sid-
value mpls-label |
+======================+======================+=======================+==============+========
=======+======================+======================+==========+================+=============
=========+
| default              | pol_strict-to-PCC-2  | local                 |            1 |
     1 | 192.168.15.2         | 192.0.2.5            | false    | adjacency-sid  |
  525000 |
| default              | pol_strict-to-PCC-2  | local                 |            1 |
     2 | 192.168.56.2         | 192.0.2.6            | false    | adjacency-sid  |
  525002 |
| default              | pol_strict-to-PCC-2  | local                 |            1 |
     3 | 192.168.36.1         | 192.0.2.3            | false    | adjacency-sid  |
  525001 |
| default              | pol_strict-to-PCC-2  | local                 |            1 |
     4 | 192.0.2.2            | 192.0.2.2            | true     | node-sid       |
   32002 |
+----------------------+----------------------+-----------------------+-------------+--------
-------+----------------------+----------------------+----------+---------------+-------------
---------+
```

The head-end router PCC-1 uses the SIDs as MPLS labels. The node SIDs and adjacency SIDs are shown in Figure 29: PCC computed segment list hop-to-label translation.

Figure 29: PCC computed segment list hop-to-label translation



When the uncolored SR-MPLS TE policy is connected, the Tunnel Table Manager (TTM) adds an entry of type **te-policy-sr-mpls-uncolored**. This tunnel is available for the provisioning of services that use the TTM. The following output shows the tunnel table for PCC-1, which includes the shortest-path tunnels to all other routers in the network, plus the entry for the provisioned uncolored SR-MPLS TE policy. The default preference for an uncolored SR-MPLS TE policy in the tunnel table is 8.

```
--{ + running }--[  ]--
A:admin@PCC-1# show network-instance default tunnel-table ipv4

------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------
----------------------------------------
IPv4 tunnel table of network-instance "default"
------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------
----------------------------------------
+-------------------------------------------+----------------+----------+-----+----------+-----
----+-------------------------+-------------------------+-------------------------+---------
-----------------------------------+
|               IPv4 Prefix                 |  Tunnel Type   |  Tunnel  | FIB |  Metric  |
 Prefere |       Last Update        |     Backup Nexthops      |     Next-hop (Type)      |
               Next-hop                    |
|                                           |                |    ID    |     |          |
 nce   |                          |                          |                          |
                                     |
+===========================================+================+==========+=====+==========+=====
====+=========================+=========================+=========================+=========
====================================+
| 192.0.2.2/32                              | sr-isis        | 32002    | Y   | 210      |
 11      | 2026-02-17T13:02:35.444Z |                          | 192.168.15.2 (mpls)      |
 ethernet-1/5.1                                |
| 192.0.2.2/32                              | te-policy-sr-  | 1        | Y   | 220      | 8
       | 2026-02-17T13:15:17.526Z |                          | 192.168.15.2/32 (sr-     |
 ethernet-1/5.1                                |
|                                           | mpls-uncolored |          |     |          |
    |                          |                          | isis)                    |
                                     |
```

```
| 192.0.2.3/32                              | sr-isis        | 32003    | Y   | 110      |
 11      | 2026-02-17T13:02:42.972Z |                          | 192.168.16.2 (mpls)      |
 ethernet-1/6.1                               |
| 192.0.2.4/32                              | sr-isis        | 32004    | Y   | 110      |
 11      | 2026-02-17T13:02:49.544Z |                          | 192.168.15.2 (mpls)      |
 ethernet-1/5.1                               |
| 192.0.2.5/32                              | sr-isis        | 32005    | Y   | 100      |
 11      | 2026-02-17T13:02:56.175Z |                          | 192.168.15.2 (mpls)      |
 ethernet-1/5.1                               |
| 192.0.2.6/32                              | sr-isis        | 32006    | Y   | 100      |
 11      | 2026-02-17T13:03:04.667Z |                          | 192.168.16.2 (mpls)      |
 ethernet-1/6.1                               |
| 192.168.15.2/32                           | sr-isis        | 525000   | Y   | 0        |
 11      | 2026-02-17T12:51:42.019Z |                          | 192.168.15.2 (mpls)      |
 ethernet-1/5.1                               |
| 192.168.16.2/32                           | sr-isis        | 525001   | Y   | 0        |
 11      | 2026-02-17T12:51:42.019Z |                          | 192.168.16.2 (mpls)      |
 ethernet-1/6.1                               |
+-------------------------------------------+----------------+----------+-----+----------+-----
----+--------------------------+--------------------------+--------------------------+---------
-------------------------------------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
---------------------------------------
7 SR-ISIS tunnels, 7 active, 0 inactive
1 TE-POLICY-SR-MPLS-UNCOLORED tunnels, 1 active, 0 inactive
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
---------------------------------------
```

12.3.5 PCC-initiated and computed LSP – explicit path with loose hops

Consider an LSP configured on PCC-2, with the tail end at PCC-1. There is a requirement for traffic on the LSP to pass through PE-6 before reaching PCC-1, so a loose path of PCC-2 to PE-6 before being forwarded to PCC-1 is required.

Figure 30: Explicit path with loose hops from PCC-2 to PCC-1

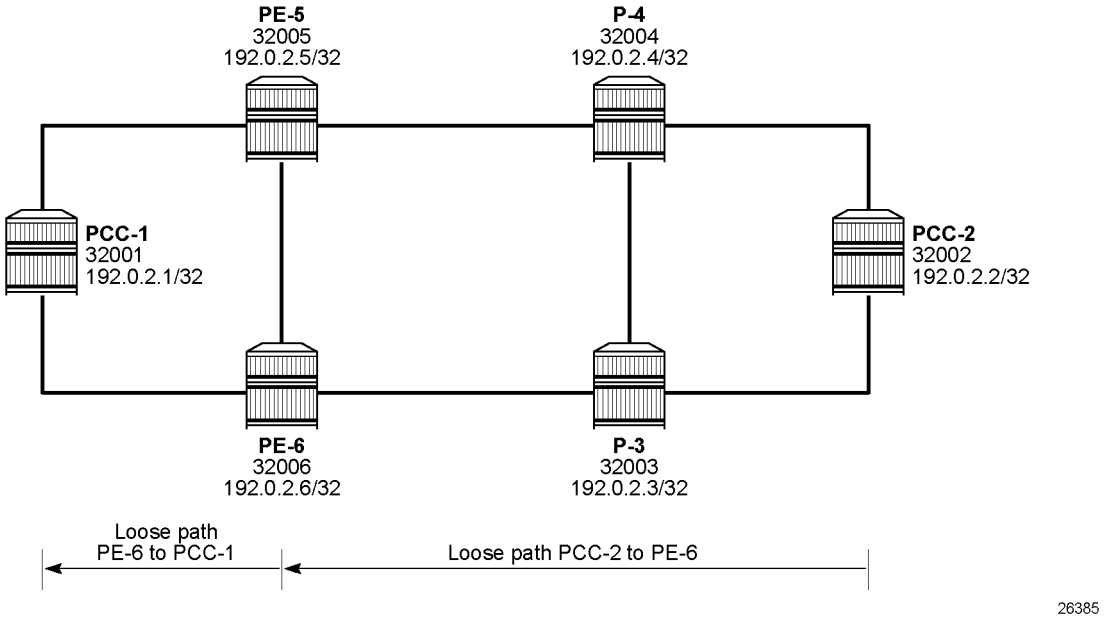


Figure 30: Explicit path with loose hops from PCC-2 to PCC-1 shows the concept of the loose path. The following configures the MPLS path containing a loose hop on PCC-2:

```
# on PCC-2:
    network-instance default {
        traffic-engineering-policies {
            explicit-paths {
                path PCC-controlled-loose-path {
                    hop 10 {
                        ip {
                            ip-address 192.0.2.6
                            hop-type loose
                        }
                    }
                }
            }
```

The following uncolored SR-MPLS TE policy references the explicit path with loose hops as the primary path:

```
# on PCC-2:
    network-instance default {
        traffic-engineering-policies {
            policy pol_loose-to-PCC-1 {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.1
                segment-list 1 {
                    admin-state enable
                    explicit-path PCC-controlled-loose-path
                    segment-list-type primary
                }
            }
```

The following shows the segments in segment list 1 of uncolored SR-MPLS TE policy "pol_loose-to-PCC-1":

```
--{ + running }--[  ]--
A:admin@PCC-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 1 computed-segments segment *
 | as table | filter fields ip-address router-id is-loose sid-type sid-value/mpls-label

+--------------------+--------------------+-----------------------+-------------+----------
-----+--------------------+--------------------+----------+---------------+----------------
-----+
|  Network-instance   | Policy policy-name  | Policy protocol-origin | Segment-list | Segment-
index |     Ip-address      |      Router-id      | Is-loose |    Sid-type    | Sid-value mpls-
label |
+====================+====================+=======================+=============+==========
=====+====================+====================+==========+===============+================
=====+
| default            | pol_loose-to-PCC-1  | local                 |           1 |
    1 | 192.0.2.6          | 192.0.2.6          | true     | node-sid       |
  32006 |
| default            | pol_loose-to-PCC-1  | local                 |           1 |
    2 | 192.0.2.1          | 192.0.2.1          | true     | node-sid       |
  32001 |
+--------------------+--------------------+-----------------------+-------------+----------
-----+--------------------+--------------------+----------+---------------+----------------
-----+
```

The first segment corresponds to the configured loose hop 192.0.2.6 and the second segment to the hop for the destination 192.0.2.1.

The head-end node PCC-2 translates the configured hop addresses into labels by examining the IS-IS TE database. The hop-to-label translation translates loose hops to node SIDs (N-SIDs).

The uncolored SR-MPLS TE policy is installed by the TTM into the tunnel table, alongside SR-ISIS advertised shortest path tunnels, for use by the TTM users, as follows:

```
--{ + running }--[  ]--
A:admin@PCC-2# show network-instance default tunnel-table ipv4

------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------
----------------------------------------
IPv4 tunnel table of network-instance "default"
------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------
----------------------------------------
+-----------------------------------------+----------------+----------+-----+----------+-----
----+--------------------------+-------------------------+-------------------------+---------
-------------------------------------+
|                IPv4 Prefix                |  Tunnel Type   |  Tunnel  | FIB |  Metric  |
 Prefere |       Last Update        |     Backup Nexthops      |     Next-hop (Type)      |
               Next-hop                    |
|                                           |                |    ID    |     |          |
 nce   |                          |                          |                          |
                                      |
+=========================================+================+==========+=====+==========+=====
====+==========================+=========================+=========================+=========
=====================================+
| 192.0.2.1/32                              | sr-isis        | 32001    | Y   | 210      |
 11      | 2026-02-17T13:02:25.153Z |                          | 192.168.23.2 (mpls)      |
 ethernet-1/3.1                               |
```

```
| 192.0.2.1/32                                | te-policy-sr-  | 1        | Y   | 210      |
 8       | 2026-02-17T13:15:46.827Z |                          | 192.0.2.6/32 (sr-isis)   |
 ethernet-1/3.1                                 |
|                                             | mpls-uncolored |          |     |          |
    |                          |                        |                          |
                                  |
| 192.0.2.3/32                                | sr-isis        | 32003    | Y   | 100      |
 11      | 2026-02-17T13:02:42.969Z |                          | 192.168.23.2 (mpls)      |
 ethernet-1/3.1                                 |
| 192.0.2.4/32                                | sr-isis        | 32004    | Y   | 100      |
 11      | 2026-02-17T13:02:49.491Z |                          | 192.168.24.2 (mpls)      |
 ethernet-1/4.1                                 |
| 192.0.2.5/32                                | sr-isis        | 32005    | Y   | 110      |
 11      | 2026-02-17T13:02:56.281Z |                          | 192.168.24.2 (mpls)      |
 ethernet-1/4.1                                 |
| 192.0.2.6/32                                | sr-isis        | 32006    | Y   | 110      |
 11      | 2026-02-17T13:03:04.725Z |                          | 192.168.23.2 (mpls)      |
 ethernet-1/3.1                                 |
| 192.168.23.2/32                             | sr-isis        | 525000   | Y   | 0        |
 11      | 2026-02-17T12:55:06.803Z |                          | 192.168.23.2 (mpls)      |
 ethernet-1/3.1                                 |
| 192.168.24.2/32                             | sr-isis        | 525001   | Y   | 0        |
 11      | 2026-02-17T12:55:06.803Z |                          | 192.168.24.2 (mpls)      |
 ethernet-1/4.1                                 |
+---------------------------------------------+----------------+----------+-----+----------+-----
----+--------------------------+--------------------------+--------------------------+---------
-------------------------------------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
---------------------------------------
7 SR-ISIS tunnels, 7 active, 0 inactive
1 TE-POLICY-SR-MPLS-UNCOLORED tunnels, 1 active, 0 inactive
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
---------------------------------------
```

12.3.5.1 Layer 3 service provisioning – IP-VRF

Uncolored SR-MPLS TE policy tunnels are another MPLS tunnel type, and can be used for resolving BGP next hops for IPv4 routes within an IP-VRF.

Figure 31: IP-VRF service schematic

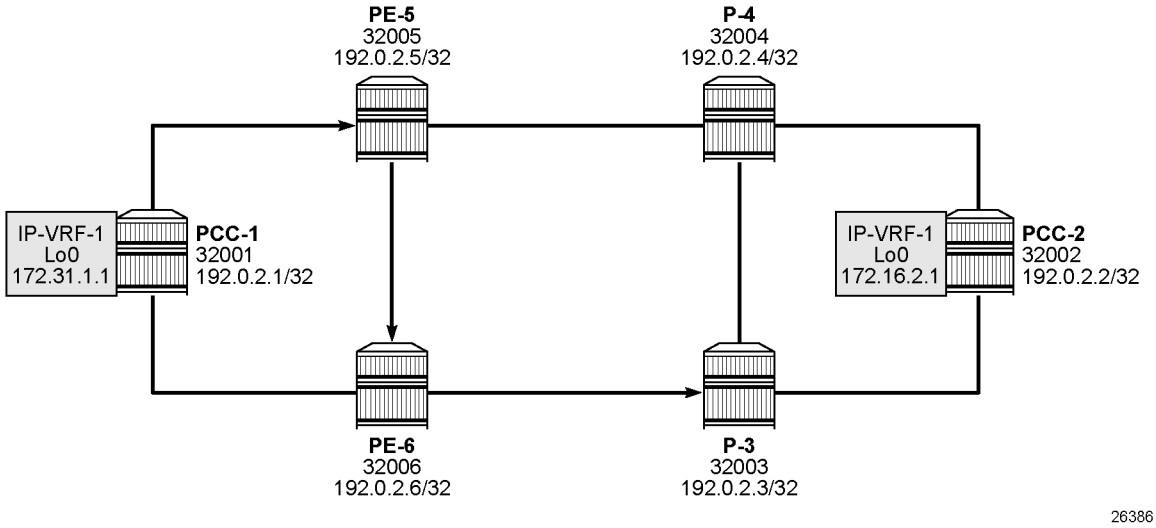


Figure 31: IP-VRF service schematic shows an IP-VRF service, configured on PCC-1 and PCC-2. The following configures the IP-VRF 1 on PCC-1. It includes a local interface using a /32 loopback address to be used to verify that routing is working correctly. The configuration on PCC-2 is similar.

```
# on PCC-1:
    network-instance "default" {
        protocols {
            bgp {
                admin-state enable
                autonomous-system 64496
                router-id 192.0.2.1            # on PCC-2: router-id 192.0.2.2
                afi-safi l3vpn-ipv4-unicast {
                    admin-state enable
                }
                group "IBGP" {
                    admin-state enable
                    peer-as 64496
                }
                neighbor 192.0.2.2 {            # on PCC-2: neighbor 192.0.2.1
                    admin-state enable
                    peer-group "IBGP"
                }
            }
        }
    }
    system {
        mpls {
            label-ranges {
                dynamic dynamic-services {      # label range for services
                    start-label 10000
                    end-label 19999
                }
            }
            services {
                network-instance {
                    dynamic-label-block dynamic-services
                }
            }
```

```
        }
    }
    interface lo0 {
        admin-state enable
        subinterface 0 {
            admin-state enable
            description "loopback interface in ip-vrf"
            ipv4 {
                admin-state enable
                address 172.31.1.1/32 {        # on PCC-2: 172.16.1.2/32
                    primary
                }
            }
        }
    }
    network-instance "ip-vrf-1" {
        type ip-vrf
        admin-state enable
        interface lo0.0 {
            interface-ref {
                interface lo0
                subinterface 0
            }
        }
        protocols {
            bgp-ipvpn {
                bgp-instance 1 {
                    admin-state enable
                    mpls {
                        next-hop-resolution {
                            allowed-tunnel-types [
                                te-policy-sr-mpls-uncolored
                            ]
                        }
                    }
                }
            }
            bgp-vpn {
                bgp-instance 1 {
                    route-distinguisher {
                        rd 192.0.2.1:1            # on PCC-2: rd 192.0.2.2:1
                    }
                    route-target {
                        export-rt target:64496:1
                        import-rt target:64496:1
                    }
                }
            }
```

The **network-instance "ip-vrf-1" protocols bgp-ipvpn bgp-instance 1 mpls next-hop-resolution allowed-tunnel-types** is set to **te-policy-sr-mpls-uncolored**, so that any BGP routes received have the next-hop resolved to an uncolored SR-MPLS TE policy LSP.

Examination of the IP-VRF route table on PCC-1 shows that the route prefix representing the IP address of the loopback address configured in IP-VRF 1 on PCC-2 is shown, and is resolved via the te-policy-sr-mpls-uncolored tunnel.

```
--{ + running }--[  ]--
A:admin@PCC-1# show network-instance "ip-vrf-1" route-table

-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------
```

```
IPv4 unicast route table of network instance ip-vrf-1
------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------
+-----------------------------------------+-------+------------+---------------------+----
------+----------+---------+------------+-------------------------+-------------------------
-+-------------------------+-------------------------+
|                  Prefix                 |  ID   | Route Type |     Route Owner     |
 Active  |  Origin  | Metric  |    Pref    |     Next-hop (Type)     |    Next-hop Interface
    |  Backup Next-hop (Type)   | Backup Next-hop Interface |
|                                         |       |            |                     |
      | Network  |         |            |                          |
 |                           |                          |
|                                         |       |            |                     |
      | Instance |         |            |                          |
 |                           |                          |
+=========================================+=======+============+=====================+====
======+==========+=========+============+=========================+=========================
=+=========================+=========================+
| 172.16.1.2/32                           | 0     | bgp-ipvpn  | bgp_ipvpn_mgr       |
 True     | ip-vrf-1 | 220     | 170        | 192.0.2.2/32            |
     |                           |                          |
|                                         |       |            |                     |
      |          |         |            | (indirect/te-policy-sr-   |
 |                           |                          |
|                                         |       |            |                     |
      |          |         |            | mpls-uncolored)           |
 |                           |                          |
| 172.31.1.1/32                           | 5     | host       | net_inst_mgr        |
 True     | ip-vrf-1 | 0       | 0          | None                      | None
     |                           |                          |
+-----------------------------------------+-------+------------+---------------------+----
------+----------+---------+------------+-------------------------+-------------------------
-+-------------------------+-------------------------+
------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------
IPv4 routes total                    : 2
IPv4 prefixes with active routes     : 2
IPv4 prefixes with active ECMP routes: 0
------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------
```

Connectivity is verified by sending a ping from the loopback interface within IP-VRF 1 on PCC-1 to the loopback address within IP-VRF 1 on PCC-2, as follows:

```
--{ + running }--[  ]--
A:admin@PCC-1# ping network-instance ip-vrf-1 172.16.1.2 -c 2

Using network instance ip-vrf-1
PING 172.16.1.2 (172.16.1.2) 56(84) bytes of data.
64 bytes from 172.16.1.2: icmp_seq=1 ttl=64 time=40.8 ms
64 bytes from 172.16.1.2: icmp_seq=2 ttl=64 time=49.3 ms

--- 172.16.1.2 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1002ms
rtt min/avg/max/mdev = 40.837/45.051/49.265/4.214 ms
```

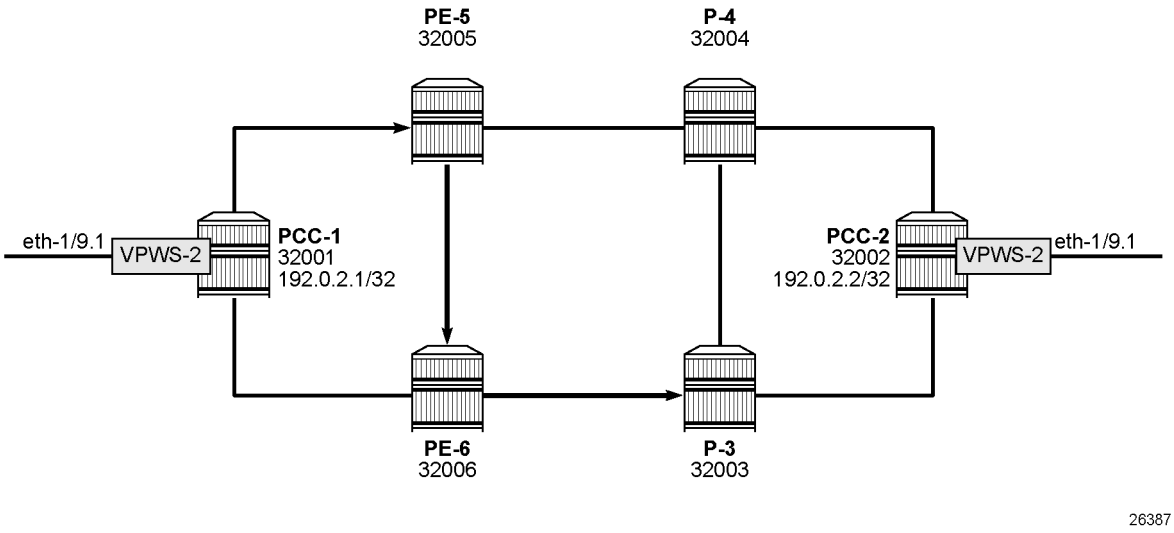
For completeness, a ping is sent in the opposite direction, between the PCC-2 IP-VRF 1 interface to PCC-1 IP-VRF 1, as follows:

```
--{ + running }--[  ]--
A:admin@PCC-2# ping network-instance ip-vrf-1 172.31.1.1 -c 2

Using network instance ip-vrf-1
PING 172.31.1.1 (172.31.1.1) 56(84) bytes of data.
64 bytes from 172.31.1.1: icmp_seq=1 ttl=64 time=48.8 ms
64 bytes from 172.31.1.1: icmp_seq=2 ttl=64 time=48.3 ms

--- 172.31.1.1 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1001ms
rtt min/avg/max/mdev = 48.277/48.514/48.752/0.237 ms
```

12.3.5.2 Layer 2 service provisioning – VPWS

Uncolored SR-MPLS TE policy tunnels can also be bound as a transport tunnel within pseudowires. To illustrate this, consider the following example of a simple VPWS connected between PCC-1 and PCC-2, as shown in Figure 32: VPWS service schematic.

Figure 32: VPWS service schematic



The pseudowires use T-LDP signaling, so an MPLS label range must be configured for LDP signaling, as follows:

```
# on all nodes:
    system {
        mpls {
            label-ranges {
                dynamic dynamic-ldp {
                    start-label 70000
                    end-label 79999
                }
                dynamic dynamic-services {      # same range as for IP-VRF
                    start-label 10000
```

```
                    end-label 19999
                }
            }
            services {
                network-instance {
                    dynamic-label-block dynamic-services
                }
            }
        }
    }
    network-instance default {
        protocols {
            ldp {
                admin-state enable
                dynamic-label-block dynamic-ldp
            }
```

The following shows the configuration of a PW on PCC-1 with far end on PCC-2 that can bind to an uncolored SR-MPLS TE policy. On PCC-2, a similar PW is configured.

```
# on PCC-1:
    tunnel {
        pseudowire-tunnel {
            tunnel pw-tunnel-PCC-1-PCC-2 {  # on PCC-2: tunnel pw-tunnel-PCC-2-PCC-1
                remote-system 192.0.2.2     # on PCC-2: remote-system 192.0.2.1
                allowed-tunnel-types [
                    te-policy-sr-mpls-uncolored
                ]
            }
        }
    }
```

The following VPWS is configured on PCC-1:

```
# on PCC-1:
    network-instance VPWS-2 {
        type vpws
        admin-state enable
        interface ethernet-1/9.1 {
            connection-point A
        }
        connection-point A {
        }
        connection-point B {
            pseudowire pw-PCC-1-PCC-2 {           # on PCC-2: pw-PCC-2-PCC-1
                admin-state enable
                pw-tunnel pw-tunnel-PCC-1-PCC-2   # on PCC-2: pw-tunnel-PCC-2-PCC-1
                signaling {
                    virtual-circuit-identifier 2  # must match on PCC-1 and PCC-2
                    tldp {
                    }
                }
            }
        }
```

12.3.5.3 Service verification

The following T-LDP session is established:

```
--{ + running }--[  ]--
A:admin@PCC-1# show network-instance default protocols ldp session

================================================================================================================
==============================
Net-Inst default LDP Sessions
----------------------------------------------------------------------------------------------------------------
------------------------------
+--------------------------------------------------------------------------------------------------------------
-----------------------------+
| Peer LDP ID                State           Adjacenc   Msg Sent   Msg Recv
 Last Oper State Change        |
|                                            y Type
                              |
+================================================================================================================
=============================+
| 192.0.2.2:0                operational     targeted   7          7
 2026-02-17T13:42:32.037Z      |
+--------------------------------------------------------------------------------------------------------------
-----------------------------+
No. of sessions: 1
================================================================================================================
==============================
```

The following PW tunnel information is retrieved on PCC-1:

```
--{ + running }--[  ]--
A:admin@PCC-1# info from state / tunnel pseudowire-tunnel tunnel *

    tunnel pw-tunnel-PCC-1-PCC-2 {
        remote-system 192.0.2.2
        operational-tunnel-type te-policy-sr-mpls-uncolored
        operational-tunnel-id 1
        allowed-tunnel-types [
            te-policy-sr-mpls-uncolored
        ]
    }
```

On PCC-1, the following output shows that VPWS-2 is operationally up:

```
--{ + running }--[  ]--
A:admin@PCC-1# show network-instance VPWS-2 summary

+------------------------+------------+------------+------------+------------------------+-----
-------------------------+
|          Name          |    Type    |   Admin    | Oper state |       Router id        |
    Description          |
|                        |            |   state    |            |                        |
                         |
+========================+============+============+============+========================+=====
=========================+
| VPWS-2                 | vpws       | enable     | up         |                        |
                         |
+------------------------+------------+------------+------------+------------------------+-----
-------------------------+
```

The following output shows information about the connection points:

```
--{ + running }--[  ]--
A:admin@PCC-1# info from state with-context network-instance "VPWS-2" | grep "connection-point
 A {" --after-context 30


        connection-point A {
            oper-state up
            index 1
        }
        connection-point B {
            oper-state up
            index 2
            pseudowire pw-PCC-1-PCC-2 {
                admin-state enable
                oper-state up
                index 1
                destination-index 2283093814
                pw-tunnel pw-tunnel-PCC-1-PCC-2
                control-word false
                flow-label false
                flow-label-oper-state down
                signaling {
                    virtual-circuit-identifier 2
                    tldp {
                        virtual-circuit-type ethernet
                        ignore-mtu-mismatch false
                    }
                }
                local {
                    operational-ingress-vc-label 10001
                }
                remote {
                    operational-egress-vc-label 10001
                }
            }
        }
```

Similar output can be obtained for VPWS-2 on PCC-2.

12.4 Conclusion

Uncolored SR-MPLS TE policies extend the use of MPLS labels into traffic engineering applications. This chapter provides the configuration for router instantiated and controlled uncolored SR-MPLS TE policies along with some examples of the application in a IP-VRF and VPWS. The chapter also shows the associated commands and outputs that can be used for verifying and troubleshooting.

13 Segment Routing with IS-IS Control Plane

This chapter provides information about Segment Routing (SR) with Intermediate System to Intermediate System (IS-IS) control plane.

Topics in this chapter include:

13.1 Applicability

This configuration in this chapter corresponds to SRL Release 25.10.R1.

13.2 Overview

Segment Routing (SR) is a technology for IP/Multi-Protocol Label Switching (MPLS) networks that enables source routing. With source routing, operators can specify a forwarding path, from ingress to egress, that is independent of the shortest path determined by the Interior Gateway Protocol (IGP).

The main benefit of SR compared to other source routing protocols is that, from a control plane perspective, no signaling protocol is required. SR provides a path or tunnel, encoded as a sequential list of sub-paths or segments that are advertised within the SR domain, using extensions to well-known link state routing protocols, such as Intermediate System to Intermediate System (IS-IS) or Open Shortest Path First (OSPF).

13.2.1 Implementation

An SR tunnel can contain a single segment that represents the destination node, or it can contain a list of segments that the tunnel must traverse. The tunnel can be established over an IPv4/IPv6 MPLS or IPv6 data plane, encoded as a stack of MPLS labels or as a number of IPv6 addresses contained in an IPv6 extension header.

Network elements are modeled as segments. For each segment, the IGP advertises an identifier referred to as a segment ID (SID).

The two segment types are:

- Prefix segment — A prefix segment is the Equal Cost Multi-Path ECMP-aware shortest path IGP route to a related prefix. A typical example of a prefix segment is a node segment. Prefix SIDs are globally unique and allocated from a Segment Routing Global Block (SRGB), typically multi-hop. The IGP signals the prefix SIDs. Within the SRL implementation, a node segment is either the system address

or another interface address of type loopback in the Global Routing Table (GRT). IS-IS advertises node SIDs using a prefix SID sub-TLV (Type Length Value).

- Adjacency segment — An adjacency segment represents a link between two routers. Adjacency SIDs are locally unique and allocated from a Segment Routing Local Block (SRLB), so that other routers in the SR domain can use the same label space. The IGP signals the adjacency SIDs. The SRL implementation allocates (dynamically or statically by configuration) adjacency SIDs and advertises them when the SR context within the IGP instance is enabled. IS-IS advertises adjacency SIDs in an adjacency SID sub-TLV.

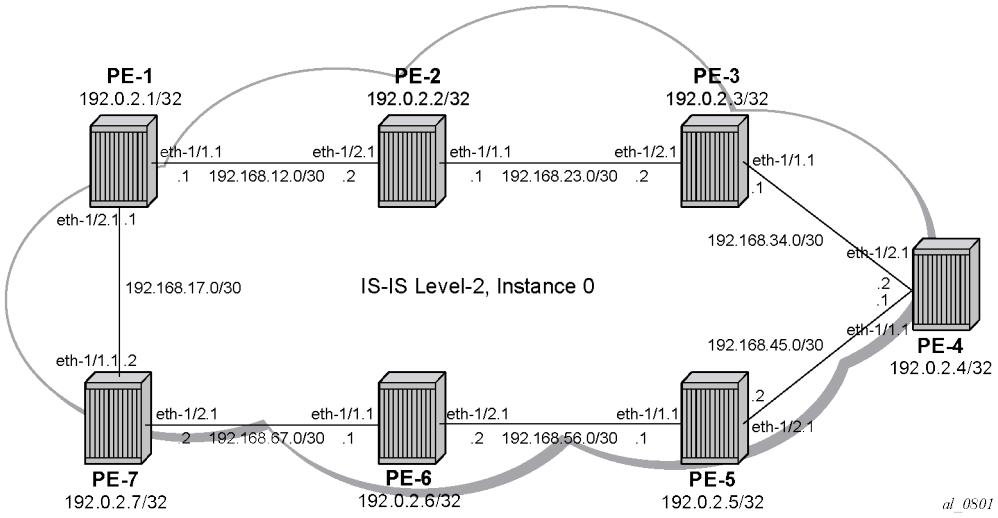
To make prefix SIDs globally unique within the SR domain, an indexing mechanism is required, because production networks consist of multiple vendors and multiple products. As a result, it is often difficult to agree on a common SRGB for the prefix SIDs.

All routers within the SR domain are expected to configure and advertise the same prefix SID range for an IGP instance. The label value used by each router to represent a prefix can be local to that router by the use of an offset label, referred to as a start label: Local label (for a prefix) = (local) start label + {prefix SID index}

Within the SRL implementation, prefix Loop-Free Alternate (LFA) is supported for SR to improve the Fast Reroute (FRR) coverage. Remote LFA (RLFA) and topology-independent LFA (TI-LFA) are also supported. With RLFA, SR shortest path tunnels are used as a virtual LFA or repair tunnel toward a PQ node. TI-LFA is beyond the scope of this chapter.

The following example uses IS-IS as an IGP protocol, with an MPLS data plane and a network instance enabled using LFA and RLFA. Figure 33: Example topology shows the example topology with seven PEs.

Figure 33: Example topology



13.3 Configuration

13.3.1 Initial configuration

Configure the interface and the system sub interface IP addresses according to Figure 33: Example topology.

Select IS-IS level 2 as the IGP to distribute routing information between all PEs. All IS-IS interfaces are of type point-to-point to avoid running the Designated Router/Backup Designated Router (DR/BDR) election process.

13.3.2 SR configuration

13.3.2.1 Define MPLS label ranges for node and adjacency SIDs

Before enabling SR, define a static SRGB. This SRGB is required on each individual router in the SR domain and is used to allocate the prefix SIDs from.

An SRGB is not instantiated by default. For simplicity, configure the same SRGB in this example for all SR domain routers. Within the command, a start value and an end value define the size of the SRGB. The following command configures an SRGB of 100 MPLS labels, from label 20000 to label 20099. Repeat this for all other nodes. The allocated MPLS labels are only for the prefix SIDs.

```
# on all PEs:
enter candidate
    system mpls label-ranges {
                static srgb-static-nsid {    # for SR node SIDs
                    shared true
                    start-label 20000
                    end-label 20099
                }
```

Define a dedicated SRLB. This SRLB is required on each individual router in the SR domain and is used to allocate the adjacency SIDs from.

An SRLB is not instantiated by default. When configured by the operator, it is taken from the system dynamic label range (for dynamically allocated adjacency SIDs) or from the system static label range (for statically allocated adjacency SIDs). For simplicity, the same dynamic SRLB is used in this example for all SR domain routers. Within the command, a start value and an end value define the size of the SRLB. The adjacency SIDs, which are only locally unique, are taken from the SRLB.

The following command configures an SRLB of 100 MPLS labels for dynamically allocated adjacency SIDs, from label 30000 to label 30099:

```
# on all PEs:
enter candidate
    system mpls label-ranges {
                dynamic srlb-dynamic-asid {  # for SR dynamic adjacency SIDs
                    start-label 30000
                    end-label 30099
                }
```

The following command configures an SRLB of 100 MPLS labels for statically allocated adjacency SIDs, from label 37000 to label 37099:

```
# on all PEs:
enter candidate
    system mpls label-ranges {
                static srlb-static-asid {  # for SR static adjacency SIDs
                    shared false
                    start-label 37000
                    end-label 37099
                }
```

13.3.2.2 Assign the label range for node SIDs

Assign the MPLS label range for the SRGB (**srgb-static-nsid**) to the SR MPLS global block on the default network instance, as follows:

```
# on all PEs:
enter candidate
    network-instance default segment-routing mpls {
                global-block {
                    label-range srgb-static-nsid
```

13.3.2.3 Enable SR

Enable the SR context within the IS-IS instance, as follows:

```
# on all PEs:
enter candidate
    network-instance default protocols isis instance 0 {
                    segment-routing {
                        mpls { }
```

13.3.2.4 Assign the label range for adjacency SIDs

Assign the MPLS label range for the SRLB for dynamically allocated adjacency SIDs to the dynamic label block in the **isis** context.

```
# on all PEs:
enter candidate
    network-instance default protocols isis {
                dynamic-label-block srlb-dynamic-asid
```

As an example, on PE-7 only, adjacency SIDs are allocated statically. Assign the MPLS label range for the SRLB for statically allocated adjacency SIDs to the static label block in the **isis instance 0 segment-routing mpls** context.

```
# on PE-7:
enter candidate
    network-instance default protocols isis {
                instance 0 {
                    segment-routing {
                        mpls {
```

```
                            static-label-block srlb-static-asid
```

13.3.2.5 Allocate node SIDs

Allocate a prefix SID to the prefix representing a node.

To be able to set up SR shortest path tunnels to all routers of the SR domain, each router needs to be uniquely defined within the SR domain. Therefore, allocate a node SID that is unique within the SR domain to the system address or other loopback interface in the GRT. Both an IPv4 and an IPv6 node SID can be configured, using an index. An IPv4 node SID has a label that is equal to the sum of the start label (20000), which is the first label of the SRGB on all nodes, and the index on the node.

It is possible to configure node SIDs that are protocol independent, or node SIDs that are specific for an IS-IS instance, or both. Protocol independent node SIDs can be used across multiple IGP instances. When both a protocol independent node SID and an IS-IS instance specific node SID are configured on the same node, the IS-IS instance specific node SID takes precedence and IS-IS advertises only the IS-IS instance specific node SID, not the protocol independent node SID.

Allocate a protocol independent node SID to the system address as follows:

```
# on all PEs:
enter candidate
    network-instance default segment-routing {
            mpls {
                local-prefix-sid 1 {
                    interface system0.0
                    ipv4-label-index x    # index x for PE-x
                    node-sid true
                }
```

As an example, on PE-7 only, allocate an IS-IS instance specific node SID to the system address as follows:

```
# on PE-7:
enter candidate
    network-instance default protocols isis instance 0 {
                    interface system0.0 {
                        segment-routing {
                            mpls {
                                ipv4-node-sid {
                                    index 77
                                }
```

13.3.2.6 Allocate adjacency SIDs

Enable dynamic adjacency SID allocation for all interfaces (labels from **srlb-dynamic-asid**) on all PEs, as follows:

```
# on all PEs:
enter candidate
    network-instance default protocols isis instance 0 {
                    segment-routing {
                        mpls {
                            dynamic-adjacency-sids {
                                all-interfaces true
```

As an example, only on PE-7, manually allocate static adjacency SIDs for all interfaces (labels from **srlb-static-asid**) as follows:

```
# on PE-7:
enter candidate
    network-instance default protocols isis instance 0 {
                    interface ethernet-1/1.1 {
                        segment-routing {
                            mpls {
                                ipv4-adjacency-sid {
                                    assignment static
                                    static 37001
                                }
                            }
                        }
                    }
                    interface ethernet-1/2.1 {
                        segment-routing {
                            mpls {
                                ipv4-adjacency-sid {
                                    assignment static
                                    static 37002
                                }
                            }
                        }
                    }
```

13.3.2.7 Outcome

The allocation of the node SIDs from **srgb-static-nsid** and of the adjacency SIDs from **srlb-dynamic-asid** or **srlb-static-asid** can be verified as follows. On all PEs, a protocol independent node SID is allocated from **srgb-static-nsid**. On PE-7, an additional IS-IS instance specific node SID is allocated from **srgb-static-nsid**. On all PEs except PE-7, **srlb-static-asid** is not used. On PE-7, the static adjacency SID allocation overrides the dynamic adjacency SID allocation, so that **srlb-dynamic-asid** is not used.

```
A:admin@PE-1# info from state with-context / system mpls label-ranges static * | as table |
 filter fields *
+-------------------------------------------------------------------+--------+-------------+------
-----+------------------+-------------+----------------+
|                            Name                                   | Shared | Start-label | End-
label | Allocated-labels | Free-labels |     Status     |
+===================================================================+========+=============+======
=====+==================+=============+================+
| srgb-static-nsid                                                  | true   |       20000 |
 20099 |                7 |          93 | ready          |
| srlb-static-asid                                                  | false  |       37000 |
 37099 |                0 |         100 | ready          |
+-------------------------------------------------------------------+--------+-------------+------
-----+------------------+-------------+----------------+

A:admin@PE-1# info from state with-context / system mpls label-ranges dynamic * | as table |
 filter fields *
+-------------------------------------------------------------------------+-------------+------
-----+------------------+-------------+----------------+
|                                Name                                     | Start-label | End-
label | Allocated-labels | Free-labels |     Status     |
+=========================================================================+=============+======
=====+==================+=============+================+
```

```
| srlb-dynamic-asid                                                                 |       30000 |
 30099 |                2 |          98 | ready          |
+-----------------------------------------------------------------------------------+-------------+------
-----+-----------------+-------------+----------------+
```

```
A:admin@PE-7# info from state with-context / system mpls label-ranges static * | as table |
 filter fields *
+-------------------------------------------------------------------+--------+-------------+------
-----+-----------------+-------------+----------------+
|                             Name                                  | Shared | Start-label | End-
label | Allocated-labels | Free-labels |     Status     |
+===================================================================+========+=============+======
=====+=================+=============+================+
| srgb-static-nsid                                                  | true   |       20000 |
 20099 |                8 |          92 | ready          |
| srlb-static-asid                                                  | false  |       37000 |
 37099 |                2 |          98 | ready          |
+-------------------------------------------------------------------+--------+-------------+------
-----+-----------------+-------------+----------------+

A:admin@PE-7# info from state with-context / system mpls label-ranges dynamic * | as table |
 filter fields *
+-----------------------------------------------------------------------------+-------------+------
-----+-----------------+-------------+----------------+
|                                Name                                         | Start-label | End-
label | Allocated-labels | Free-labels |     Status     |
+=============================================================================+=============+======
=====+=================+=============+================+
| srlb-dynamic-asid                                                           |       30000 |
 30099 |                0 |         100 | ready          |
+-----------------------------------------------------------------------------+-------------+------
-----+-----------------+-------------+----------------+
```

On SR enabled PEs, the SR module resolves received prefixes with prefix SID sub TLVs present. As a result, MPLS data plane resources are consumed. The ILM is programmed with a swap operation and the label-to-next-hop-label-forwarding-entry (LTN) with a push operation, both pointing to the primary and/or LFA next-hop label forwarding entry (NHLFE). Also, an SR tunnel is added in the Tunnel Table Manager (TTM). As a result, an SR shortest path tunnel is set up to each other router that is part of the SR domain. Now, SR shortest path tunnels can be used for all users of TTM.

Each SR enabled PE advertises the locally allocated prefix SID. After the advertisement of prefix SIDs, the PE's MPLS data plane Ingress Label Mapping (ILM) is programmed with a pop operation.

Each SR enabled PE also advertises, for each formed adjacency over an IP interface, the locally allocated adjacency SID. From a data plane perspective, one local adjacency SID consumes one ILM entry, programming a pop operation (swap to IMPLICIT_NULL).

Because, in the chosen configuration, the SRGB is the same on all nodes, each node in the network can be reached using the same MPLS label. For example, the node SID for PE-5 has label 20005 on all nodes: a start label (first label of the SRGB (= 20000) + **ipv4-label-index** value on node PE-5 (= 5)). The node SID for PE-7 has label 20077 on all nodes: a start label (first label of the SRGB (= 20000) + **ipv4-node-sid index** value on node PE-7 (= 77). The statically allocated adjacency SIDs (label range starting with 37000) are used on PE-7, while the dynamically allocated adjacency SIDs (label range starting with 30000) are used on all other PEs.

```
A:admin@PE-1# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
```

```
|         |           |             |                 |                         | Subinterface
       | labels           |
+=========+===========+=============+=================+=========================+==============
=======+==================+
| 20001   | POP       | sr-mpls     | default         |                         |
       |                  |
| 20002   | SWAP      | sr-mpls     | N/A             | 192.168.12.2 (mpls)     | ethernet-1/1.1
       | 20002            |
| 20003   | SWAP      | sr-mpls     | N/A             | 192.168.12.2 (mpls)     | ethernet-1/1.1
       | 20003            |
| 20004   | SWAP      | sr-mpls     | N/A             | 192.168.12.2 (mpls)     | ethernet-1/1.1
       | 20004            |
| 20005   | SWAP      | sr-mpls     | N/A             | 192.168.17.2 (mpls)     | ethernet-1/2.1
       | 20005            |
| 20006   | SWAP      | sr-mpls     | N/A             | 192.168.17.2 (mpls)     | ethernet-1/2.1
       | 20006            |
| 20077   | SWAP      | sr-mpls     | N/A             | 192.168.17.2 (mpls)     | ethernet-1/2.1
       | 20077            |
| 30000   | SWAP      | sr-mpls     | N/A             | 192.168.12.2 (mpls)     | ethernet-1/1.1
       | IMPLICIT_NULL    |
| 30001   | SWAP      | sr-mpls     | N/A             | 192.168.17.2 (mpls)     | ethernet-1/2.1
       | IMPLICIT_NULL    |
+---------+-----------+-------------+-----------------+-------------------------+--------------
-------+------------------+
```

```
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop *
 | as table | filter fields type ip-address subinterface mpls-encapsulation/pushed-mpls-label-
stack
+-------------------------+----------------------+--------------------+------------------------
-+-------------------------+-------------------------+
|    Network-instance     |        Index         |        Type        |       Ip-address
 |      Subinterface       |   Mpls-encapsulation    |
|                         |                      |                    |
 |                         | pushed-mpls-label-stack |
+=========================+======================+====================+========================
=+=========================+=========================+
| ---snip---
                                                  |
| default                 |             31593955 | mpls               | 192.168.12.2
 | ethernet-1/1.1          | 20002                   |
| default                 |             31593956 | mpls               | 192.168.12.2
 | ethernet-1/1.1          | 20003                   |
| default                 |             31593957 | mpls               | 192.168.12.2
 | ethernet-1/1.1          | 20004                   |
| default                 |             31593958 | mpls               | 192.168.17.2
 | ethernet-1/2.1          | 20005                   |
| default                 |             31593959 | mpls               | 192.168.17.2
 | ethernet-1/2.1          | 20006                   |
| default                 |             31593961 | mpls               | 192.168.17.2
 | ethernet-1/2.1          | 20077                   |
| default                 |             31593962 | mpls               | 192.168.12.2
 | ethernet-1/1.1          | IMPLICIT_NULL           |
| default                 |             31593963 | mpls               | 192.168.17.2
 | ethernet-1/2.1          | IMPLICIT_NULL           |
+-------------------------+----------------------+--------------------+------------------------
-+-------------------------+-------------------------+
```

```
A:admin@PE-7# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+-------------------------+--------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)      | Next-hop
       | Next-hop MPLS    |
```

```
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+==============
=======+==================+
| 20001   | SWAP      | sr-mpls     | N/A             | 192.168.17.1 (mpls)    | ethernet-1/1.1
       | 20001            |
| 20002   | SWAP      | sr-mpls     | N/A             | 192.168.17.1 (mpls)    | ethernet-1/1.1
       | 20002            |
| 20003   | SWAP      | sr-mpls     | N/A             | 192.168.17.1 (mpls)    | ethernet-1/1.1
       | 20003            |
| 20004   | SWAP      | sr-mpls     | N/A             | 192.168.67.1 (mpls)    | ethernet-1/2.1
       | 20004            |
| 20005   | SWAP      | sr-mpls     | N/A             | 192.168.67.1 (mpls)    | ethernet-1/2.1
       | 20005            |
| 20006   | SWAP      | sr-mpls     | N/A             | 192.168.67.1 (mpls)    | ethernet-1/2.1
       | 20006            |
| 20007   | POP       | sr-mpls     | default         |                        |
       |                  |
| 20077   | POP       | sr-mpls     | default         |                        |
       |                  |
| 37001   | SWAP      | sr-mpls     | N/A             | 192.168.17.1 (mpls)    | ethernet-1/1.1
       | IMPLICIT_NULL    |
| 37006   | SWAP      | sr-mpls     | N/A             | 192.168.67.1 (mpls)    | ethernet-1/2.1
       | IMPLICIT_NULL    |
+---------+-----------+-------------+-----------------+------------------------+--------------
-------+------------------+
```

```
A:admin@PE-7# info from state with-context / network-instance default route-table next-hop *
 | as table | filter fields type ip-address subinterface mpls-encapsulation/pushed-mpls-label-
stack
+-------------------------+----------------------+--------------------+------------------------
-+-------------------------+-------------------------+
|    Network-instance     |        Index         |        Type        |       Ip-address
 |      Subinterface       |   Mpls-encapsulation    |
|                         |                      |                    |
 |                          | pushed-mpls-label-stack |
+=========================+======================+====================+========================
=+=========================+=========================+
| ---snip---
                                                    |
| default                 |             32810855 | mpls               | 192.168.17.1
 | ethernet-1/1.1          | 20001                    |
| default                 |             32810856 | mpls               | 192.168.17.1
 | ethernet-1/1.1          | 20002                    |
| default                 |             32810857 | mpls               | 192.168.17.1
 | ethernet-1/1.1          | 20003                    |
| default                 |             32810858 | mpls               | 192.168.67.1
 | ethernet-1/2.1          | 20004                    |
| default                 |             32810859 | mpls               | 192.168.67.1
 | ethernet-1/2.1          | 20005                    |
| default                 |             32810860 | mpls               | 192.168.67.1
 | ethernet-1/2.1          | 20006                    |
| default                 |             32810861 | mpls               | 192.168.17.1
 | ethernet-1/1.1          | IMPLICIT_NULL            |
| default                 |             32810862 | mpls               | 192.168.67.1
 | ethernet-1/2.1          | IMPLICIT_NULL            |
+-------------------------+----------------------+--------------------+------------------------
-+-------------------------+-------------------------+
```

The tunnel table displays the prefix SIDs and adjacency SIDs, in order, within the SR domain. A tunnel with a label from **srgb-static-nsid** is used on each PE, to reach remote nodes. A tunnel with a label from **srlb-**

dynamic-asid is used on each PE, except PE-7, to reach remote interfaces on the local network, while a tunnel with a label from **srlb-static-asid** is used on PE-7 to reach remote interfaces on the local network.

```
A:admin@PE-1# show / network-instance default tunnel-table all
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
+----------------------+----------------+----------+-----+----------+---------+---------------
----------+--------------+---------------+
|      IPv4 Prefix      |  Tunnel Type   |  Tunnel  | FIB |  Metric  | Prefere |       Last
 Update        |   Next-hop    |   Next-hop    |
|                       |                |    ID    |     |          |   nce   |
           |    (Type)     |               |
+======================+================+==========+=====+==========+=========+===============
==========+==============+===============+
| 192.0.2.2/32          | sr-isis        | 20002    | Y   | 10       | 11      | 2025-12-
16T16:41:09.867Z | 192.168.12.2  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/1.1         |
| 192.0.2.3/32          | sr-isis        | 20003    | Y   | 20       | 11      | 2025-12-
16T16:41:19.386Z | 192.168.12.2  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/1.1         |
| 192.0.2.4/32          | sr-isis        | 20004    | Y   | 30       | 11      | 2025-12-
16T16:41:28.520Z | 192.168.12.2  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/1.1         |
| 192.0.2.5/32          | sr-isis        | 20005    | Y   | 30       | 11      | 2025-12-
16T16:41:40.688Z | 192.168.17.2  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/2.1         |
| 192.0.2.6/32          | sr-isis        | 20006    | Y   | 20       | 11      | 2025-12-
16T16:41:50.668Z | 192.168.17.2  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/2.1         |
| 192.0.2.7/32          | sr-isis        | 20077    | Y   | 10       | 11      | 2025-12-
16T16:42:27.960Z | 192.168.17.2  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/2.1         |
| 192.168.12.2/32       | sr-isis        | 30000    | Y   | 0        | 11      | 2025-12-
16T16:51:36.258Z | 192.168.12.2  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/1.1         |
| 192.168.17.2/32       | sr-isis        | 30001    | Y   | 0        | 11      | 2025-12-
16T16:51:36.258Z | 192.168.17.2  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/2.1         |
+----------------------+----------------+----------+-----+----------+---------+---------------
----------+--------------+---------------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
8 SR-ISIS tunnels, 8 active, 0 inactive
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv6 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
<no_entries>
```

```
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

The tunnel table on PE-1 also indicates that when traffic destined for PE-7 arrives on PE-1, PE-1 pushes the MPLS label 20077 to reach destination PE-7, via the SR IS-IS tunnel with tunnel ID 20077.

PE-1 can reach destination PE-7 (with node SID 20077) via only one SR path: via PE-7.

```
A:admin@PE-1# show / network-instance default tunnel-table ipv4 192.0.2.7/32 detail
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
Show report for network instance "default" tunnel table
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
=================================================================================================
=====================================================
Destination        : 192.0.2.7/32
Tunnel Type        : sr-isis
Tunnel ID          : 20077
Metric             : 10
Preference         : 11
Last Update        : 2025-12-16T16:42:27.960Z
FIB Status         : active
Next-hops
  192.168.17.2 (mpls) via [ethernet-1/2.1]
      pushed MPLS labels : [20077]
=================================================================================================
=====================================================
```

```
A:admin@PE-7# show / network-instance default tunnel-table all
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv4 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
+----------------------+----------------+----------+-----+----------+---------+---------------
-----------+--------------+---------------+
|      IPv4 Prefix      |  Tunnel Type   |  Tunnel  | FIB |  Metric  | Prefere |       Last
 Update        |   Next-hop    |   Next-hop    |
|                       |                |    ID    |     |          |   nce   |
           |    (Type)     |               |
+======================+================+==========+=====+==========+=========+===============
==========+==============+===============+
| 192.0.2.1/32          | sr-isis        | 20001    | Y   | 10       | 11      | 2025-12-
16T16:40:58.793Z | 192.168.17.1  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/1.1         |
| 192.0.2.2/32          | sr-isis        | 20002    | Y   | 20       | 11      | 2025-12-
16T16:41:09.899Z | 192.168.17.1  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/1.1         |
| 192.0.2.3/32          | sr-isis        | 20003    | Y   | 30       | 11      | 2025-12-
16T16:41:19.385Z | 192.168.17.1  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/1.1         |
| 192.0.2.4/32          | sr-isis        | 20004    | Y   | 30       | 11      | 2025-12-
16T16:41:28.540Z | 192.168.67.1  | ethernet-     |
|                       |                |          |     |          |         |
           | (mpls)        | 1/2.1         |
| 192.0.2.5/32          | sr-isis        | 20005    | Y   | 20       | 11      | 2025-12-
16T16:41:40.680Z | 192.168.67.1  | ethernet-     |
```

```
|                       |                |          |     |          |         |
          | (mpls)        | 1/2.1          |
| 192.0.2.6/32          | sr-isis        | 20006    | Y   | 10       | 11      | 2025-12-
16T16:41:50.666Z | 192.168.67.1  | ethernet-     |
|                       |                |          |     |          |         |
          | (mpls)        | 1/2.1          |
| 192.168.17.1/32       | sr-isis        | 37001    | Y   | 0        | 11      | 2025-12-
16T16:52:18.838Z | 192.168.17.1  | ethernet-     |
|                       |                |          |     |          |         |
          | (mpls)        | 1/1.1          |
| 192.168.67.1/32       | sr-isis        | 37006    | Y   | 0        | 11      | 2025-12-
16T16:52:18.838Z | 192.168.67.1  | ethernet-     |
|                       |                |          |     |          |         |
          | (mpls)        | 1/2.1          |
+-----------------------+----------------+----------+-----+----------+---------+---------------
-----------+--------------+--------------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
8 SR-ISIS tunnels, 8 active, 0 inactive
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv6 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
<no_entries>
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

The tunnel table on PE-7 also indicates that when traffic destined for PE-1 arrives on PE-7, PE-7 pushes the MPLS label 20001 to reach destination PE-1, via the SR IS-IS tunnel with tunnel ID 20001.

After enabling the SR context within an IS-IS instance, the IS-IS instance advertises SR support among the IS-IS adjacencies. It propagates the **router-capability-sr-capability** sub TLV of the **router-capability** TLV, which is used to indicate the index range and the start label. It also propagates the **router-capability-sr-algorithm** sub TLV of the **router-capability** TLV, which is used to indicate the algorithm used for path calculations. Only Shortest Path First (SPF) (value 0) is defined.

Verify this as follows:

```
A:admin@PE-1# info from state with-context / network-instance default protocols isis instance 0
 level 2
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    level 2 {
                        --snip---
                        link-state-database {
                            lsp 1920.0000.2001.00-00 {
                                ---snip---
                                tlvs {
                                    ---snip---
                                    tlv router-capability {
                                        router-capabilities {
                                            capability 0 {
                                                router-id 0.0.0.0
                                                subtlvs {
                                                    ---snip---
                                                    subtlv router-capability-sr-algorithm {
```

```
                                            segment-routing-algorithms {
                                                standard-algorithm [
                                                    spf
                                                ]
                                            }
                                        }
                                        subtlv router-capability-sr-capability {
                                            segment-routing-capability {
                                                flags [
                                                    ipv4-mpls
                                                    ipv6-mpls
                                                ]
                                                srgb-descriptors {
                                                    srgb-descriptor 100 {
                                                        label 20000
                                                    }
                                                }
                                            }
                                        }
                                    }
                                }
                            }
                        }
                    }
                }
                lsp 1920.0000.2002.00-00 {
                    ---snip---
                }
                lsp 1920.0000.2003.00-00 {
                    ---snip---
                }
                lsp 1920.0000.2004.00-00 {
                    ---snip---
                }
                lsp 1920.0000.2005.00-00 {
                    ---snip---
                }
                lsp 1920.0000.2006.00-00 {
                    ---snip---
                }
                lsp 1920.0000.2007.00-00 {
                    ---snip---
                }
```

A similar output occurs for each router in the SR domain.

For prefix SIDs, by default, the SRL implementation sets the **node** flag and the **no-php** flag inside the **ip-reachability-prefix-sid** sub TLV of the **extended-ipv4-reachability** TLV.

```
A:admin@PE-1# info from state with-context / network-instance default protocols isis instance 0
 level 2
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    level 2 {
                        ---snip---
                        link-state-database {
                            lsp 1920.0000.2001.00-00 {
                                ---snip---
                                tlvs {
                                    ---snip---
                                    tlv extended-ipv4-reachability {
```

```
                                    extended-ipv4-reachability {
                                        prefixes {
                                            prefix 192.0.2.1/32 {
                                                ---snip---
                                                subtlvs {
                                                    ---snip---
                                                    subtlv ip-reachability-prefix-sid {
                                                        prefix-sids {
                                                            prefix-sid 1 {
                                                                algorithm 0
                                                                flags [
                                                                    node
                                                                    no-php
                                                                ]
                                                            }
                                                        }
                                                    }
                                                }
                                            }
                                            ---snip---
```

Another useful flag that can be set is the **re-advertised** flag. This is set when a prefix SID is propagated between levels or areas, or redistribution is in place (from another protocol).

For adjacency SIDs, by default, the SRL implementation sets the **value** flag in the **is-reachability-adj-sid** sub TLV of the **extended-is-reachability** TLV, meaning that the adjacency SID carries a value (as opposed to an index). Also, the **local** flag is set by default in the **is-reachability-adj-sid** sub TLV of the **extended-is-reachability** TLV, meaning that the adjacency SID has only local significance.

```
A:admin@PE-1# info from state with-context / network-instance default protocols isis instance 0
 level 2
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    level 2 {
                        ---snip---
                        link-state-database {
                            lsp 1920.0000.2001.00-00 {
                                ---snip---
                                tlvs {
                                    ---snip---
                                    tlv extended-is-reachability {
                                        extended-is-reachability {
                                            neighbors {
                                                neighbor 1920.0000.2002 {
                                                    instances {
                                                        instance 0 {
                                                            metric 10
                                                            subtlvs {
                                                                subtlv is-reachability-adj-sid
 {
                                                                    adjacency-sids {
                                                                        adjacency-sid 30000 {
                                                                            weight 0
                                                                            flags [
                                                                                value
                                                                                local
                                                                            ]
                                                                        }
                                                                    }
                                                                }
```

```
                                                    subtlv is-reachability-ipv4-
interface-address {
                                                        ipv4-interface-address {
                                                            address [
                                                                192.168.12.1
                                                            ]
                                                        }
                                                    }
                                                    subtlv is-reachability-ipv4-
neighbor-address {
                                                        ipv4-neighbor-address {
                                                            address [
                                                                192.168.12.2
                                                            ]
                                                        }
                                                    }
                                                }
                                            }
                                        }
                                    }
                                    neighbor 1920.0000.2007 {
                                        ---snip---
                                                    subtlv is-reachability-adj-sid
 {
                                                        adjacency-sids {
                                                            adjacency-sid 30001 {
                                                                weight 0
                                                                flags [
                                                                    value
                                                                    local
                                                                ]
                                                            }
                                                        }
                                                    }
                                                    ---snip---
                                    }
```

13.3.3 Configuration of an IP VRF

In the network topology of Figure 33: Example topology, each router of the SR domain has a full mesh of SR shortest path tunnels to the other routers.

The objective is to configure an IP VRF between PE-1 and PE-7, using the SR shortest path tunnels or LDP LSPs as transport mechanism. Four scenarios are treated:

- Configuration with SR only
- Configuration with SR and LFA
- Configuration with SR, LFA, and RLFA
- Configuration with SR and LDP, without LFA and RLFA

13.3.3.1 Configuration with SR only

Configure BGP on PE-1 and PE-7:

```
# on PE-1 and PE-7:
enter candidate
    network-instance default protocols {
```

```
            bgp {
                admin-state enable
                autonomous-system 64496
                router-id 192.0.2.1    # 192.0.2.7 on PE-7
                afi-safi l3vpn-ipv4-unicast {
                    admin-state enable
                }
                group grp-IP-VRF-peers {
                    admin-state enable
                    peer-as 64496
                }
                neighbor 192.0.2.7 {    # 192.0.2.1 on PE-7
                    admin-state enable
                    peer-group grp-IP-VRF-peers
                }
```

Configure a loopback interface on PE-1 and PE-7:

```
# on PE-1 and PE-7:
enter candidate
    interface lo0 {
        admin-state enable
        subinterface 0 {
            admin-state enable
            description "loopback interface in IP-VRF"
            ipv4 {
                admin-state enable
                address 10.10.1.1/32 {    # 10.10.7.1/32 on PE-7
                    primary
                }
            }
        }
```

Define a dedicated dynamic MPLS label range for VRFs on all PEs that belong to **IP-VRF** (here PE-1 and PE-7):

```
# on PE-1 and PE-7:
enter candidate
    system mpls label-ranges {
                dynamic dynamic-vrfs {
                    start-label 40000
                    end-label 40099
                }
```

Assign the MPLS label range for VRFs to the network instance's dynamic label block:

```
# on PE-1 and PE-7:
enter candidate
    system mpls {
            services {
                network-instance {
                    dynamic-label-block dynamic-vrfs
```

Configure network instance **IP-VRF** on PE-1 and PE-7 that makes use of the loopback interface lo0.0 and SR IS-IS tunnels as next hop:

```
# on PE-1 and PE-7:
enter candidate
    network-instance IP-VRF {
        type ip-vrf
```

```
        admin-state enable
        interface lo0.0 {
            interface-ref {
                interface lo0
                subinterface 0
            }
        }
        protocols {
            bgp-ipvpn {
                bgp-instance 1 {
                    admin-state enable
                    ecmp 2
                    mpls {
                        next-hop-resolution {
                            allowed-tunnel-types [
                                sr-isis
                            ]
                        }
                    }
                }
            }
            bgp-vpn {
                bgp-instance 1 { }
            }
        }
```

Because, in the example, there is no explicit configuration for **bgp-vpn bgp-instance 1**, SR Linux automatically derives the necessary parameters (with EVI = 0). These parameters can also be configured manually.

```
A:admin@PE-1# show / network-instance IP-VRF protocols bgp-vpn bgp-instance 1
================================================================================================================
================================================================
Net Instance   : IP-VRF
    bgp Instance 1
----------------------------------------------------------------------------------------------------------------
----------------------------------------------------------
        route-distinguisher: 192.0.2.1:0, auto-derived-from-evi    # 192.0.2.7:0 on PE-7
        export-route-target: target:64496:0, auto-derived-from-evi
        import-route-target: target:64496:0, auto-derived-from-evi
================================================================================================================
================================================================
```

```
A:admin@PE-1# info from state with-context / network-instance IP-VRF protocols bgp-vpn bgp-
instance 1 | as table |filter fields *
+------------+------------+------------+------------+------------+------------+------------+---
---------+------------+------------+------------+
|  Network-  |     Id     | Oper-down- |  Export-   |  Import-   | Route-dist | Route-dist |
 Route-   |   Route-   |   Route-   |   Route-   |
|  instance  |            |   reason   |   policy   |   policy   | inguisher  | inguisher  |
 target   |   target   |   target   |   target   |
|            |            |            |            |            |     rd     | route-dist |
 export-rt  |  export-   | import-rt  |  import-   |
|            |            |            |            |            |            | inguisher- |
         |   route-   |            |   route-   |
|            |            |            |            |            |            |   origin   |
         |  target-   |            |  target-   |
|            |            |            |            |            |            |            |
         |   origin   |            |   origin   |
+============+============+============+============+============+============+============+===
=========+============+============+============+
```

```
| IP-VRF     |          1 |            |            |            | 192.0.2.1: | auto-      |
 target:644 | auto-      | target:644 | auto-      |
|            |            |            |            |            | 0          | derived-   |
 96:0       | derived-   | 96:0       | derived-   |
|            |            |            |            |            |            | from-evi   |
         | from-evi   |            | from-evi   |
+------------+------------+------------+------------+------------+------------+------------+---
---------+------------+------------+------------+
```

IP-VRF uses an MPLS label from **dynamic-vrfs**.

```
A:admin@PE-1# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+------------------------+--------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+==============
=======+==================+
| ---snip---
                            |
| 40000   |           | network-    | IP-VRF          |                        |
       |                   |
|         |           | instance    |                 |                        |
       |                   |
+---------+-----------+-------------+-----------------+------------------------+--------------
-------+------------------+
```

Verify the IP connectivity in **IP-VRF** as follows:

```
# on PE-1:
ping 10.10.7.1 -4 -I 10.10.1.1 -c 5 network-instance IP-VRF

Using network instance IP-VRF
PING 10.10.7.1 (10.10.7.1) from 10.10.1.1 : 56(84) bytes of data.
64 bytes from 10.10.7.1: icmp_seq=1 ttl=64 time=87.0 ms
---snip---

--- 10.10.7.1 ping statistics ---
5 packets transmitted, 5 received, 0% packet loss, time 4005ms
rtt min/avg/max/mdev = 3.962/36.385/87.000/30.876 ms
```

```
# on PE-1:
traceroute 10.10.7.1 -n -s 10.10.1.1 network-instance IP-VRF

Using network instance IP-VRF
traceroute to 10.10.7.1 (10.10.7.1), 30 hops max, 60 byte packets
 1  10.10.7.1  89.527 ms  89.496 ms  89.483 ms
```

The route table in **IP-VRF** indicates that traffic destined for 10.10.7.1/32 (connected to PE-7) runs via the SR IS-IS tunnel to PE-7.

```
A:admin@PE-1# show / network-instance IP-VRF route-table all
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv4 unicast route table of network instance IP-VRF
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
+-----------------+------+-----------+--------------------+---------+---------+--------+------
-----+----------+----------+----------+----------+
```

```
|     Prefix      |  ID  |   Route   |     Route Owner     | Active  | Origin  | Metric |
 Pref    | Next-hop | Next-hop |  Backup  |  Backup  |
|                 |      |   Type    |                     |         | Network |        |
     |  (Type)  | Interfac | Next-hop | Next-hop |
|                 |      |           |                     |         | Instanc |        |
     |          |    e     |  (Type)  | Interfac |
|                 |      |           |                     |         |    e    |        |
     |          |          |          |    e     |
+=================+======+===========+=====================+=========+=========+========+======
=====+==========+==========+==========+==========+
| 10.10.1.1/32    | 11   | host      | net_inst_mgr        | True    | IP-VRF  | 0      | 0
     | None     | None     |           |          |
| 10.10.7.1/32    | 0    | bgp-ipvpn | bgp_ipvpn_mgr       | True    | IP-VRF  | 10     | 170
     | 192.0.2. |          |           |          |
|                 |      |           |                     |         |         |        |
     | 7/32 (in |          |           |          |
|                 |      |           |                     |         |         |        |
     | direct/s |          |           |          |
|                 |      |           |                     |         |         |        |
     | r-isis)  |          |           |          |
+-----------------+------+-----------+---------------------+---------+---------+--------+------
-----+----------+----------+----------+----------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv4 routes total                    : 2
IPv4 prefixes with active routes     : 2
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

The detail of the route table in **IP-VRF** indicates the tunnel ID.

```
A:admin@PE-1# show / network-instance IP-VRF route-table ipv4-unicast prefix 10.10.7.1/32
 detail
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv4 unicast route table of network instance IP-VRF
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
Destination            : 10.10.7.1/32
ID                     : 0
Route Type             : bgp-ipvpn
Route Owner            : bgp_ipvpn_mgr
Origin Network Instance: IP-VRF
Metric                 : 10
Preference             : 170
Active                 : true
Last change            : 2025-12-16T17:05:06.303Z
Resilient hash         : false
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
Next hops: 1 entries
192.0.2.7 (indirect) resolved by tunnel to 192.0.2.7/32 (sr-isis/tunnel-id: 20077)
Backup Next hops: 0 entries
---snip---
```

The route in **IP-VRF** indicates the network instance label.

```
A:admin@PE-1# show / network-instance IP-VRF ipv4 route all
=================================================================================================
=====================================================
IPv4-unicast route table for ip-vrf network-instance: IP-VRF
```

```
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Flags: > (best), * (unviable), ! (failed)
     : L (leaked route from another network-instance)
     : B (backup NHG active and displayed)
     : S (statistics supported)
     : D (dynamic LB), R (resilient LB)
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Prefix              Route Type   Metric   Pref    Flags    Next-Hop(s)
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
10.10.7.1/32        bgp-ipvpn    10       170     >        192.0.2.7(tunnel:sr-
isis, label:40000)
```

13.3.3.2 Configuration with SR and LFA

Enable prefix LFA within the IS-IS context to enable LFA FRR protection. Extend the remote LFA next-hop resolution path entry to RTM so that the tunnel can be used in SPF decisions.

```
# on all PEs:
enter candidate
    network-instance default protocols isis instance 0 {
                    loopfree-alternate {
                        admin-state enable
                        augment-route-table true
                    }
```

On PE-1, next-hop LFA protection is present for node PE-4, node PE-5, and the link between PE-4 and PE-5, as follows. Similar next-hop LFA protection is present on the other PEs (for other nodes or links).

```
A:admin@PE-1# show / network-instance default route-table all
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
+-----------------+------+-----------+--------------------+---------+---------+--------+------
-----+----------+---------+----------+----------+
|     Prefix      |  ID  |   Route   |     Route Owner    | Active  | Origin  | Metric |
 Pref    | Next-hop | Next-hop |  Backup  |  Backup  |
|                 |      |   Type    |                    |         | Network |        |
     |  (Type)  | Interfac | Next-hop | Next-hop |
|                 |      |           |                    |         | Instanc |        |
     |          |    e     |  (Type)  | Interfac |
|                 |      |           |                    |         |    e    |        |
     |          |          |          |    e     |
+=================+======+===========+====================+=========+=========+========+======
=====+==========+==========+==========+==========+
| 192.0.2.1/32    | 10   | host      | net_inst_mgr       | True    | default | 0      | 0
     | None     | None     |          |          |
| 192.0.2.2/32    | 0    | isis      | isis_mgr           | True    | default | 10     | 18
     | 192.168. | ethernet |          |          |
|                 |      |           |                    |         |         |        |
     | 12.2     | -1/1.1   |          |          |
|                 |      |           |                    |         |         |        |
     | (direct) |          |          |          |
| 192.0.2.3/32    | 0    | isis      | isis_mgr           | True    | default | 20     | 18
     | 192.168. | ethernet |          |          |
```

```
|                  |      |           |                    |         |         |        |
    | 12.2     | -1/1.1   |          |          |
|                  |      |           |                    |         |         |        |
    | (direct) |          |          |          |
| 192.0.2.4/32     | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168. | ethernet | 192.168. | ethernet |
|                  |      |           |                    |         |         |        |
    | 12.2     | -1/1.1   | 17.2     | -1/2.1   |
|                  |      |           |                    |         |         |        |
    | (direct) |          | (direct) |          |
| 192.0.2.5/32     | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168. | ethernet | 192.168. | ethernet |
|                  |      |           |                    |         |         |        |
    | 17.2     | -1/2.1   | 12.2     | -1/1.1   |
|                  |      |           |                    |         |         |        |
    | (direct) |          | (direct) |          |
| 192.0.2.6/32     | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168. | ethernet |          |          |
|                  |      |           |                    |         |         |        |
    | 17.2     | -1/2.1   |          |          |
|                  |      |           |                    |         |         |        |
    | (direct) |          |          |          |
| 192.0.2.7/32     | 0    | isis      | isis_mgr           | True    | default | 10     | 18
    | 192.168. | ethernet |          |          |
|                  |      |           |                    |         |         |        |
    | 17.2     | -1/2.1   |          |          |
|                  |      |           |                    |         |         |        |
    | (direct) |          |          |          |
| 192.168.12.0/30  | 8    | local     | net_inst_mgr       | True    | default | 0      | 0
    | 192.168. | ethernet |          |          |
|                  |      |           |                    |         |         |        |
    | 12.1     | -1/1.1   |          |          |
|                  |      |           |                    |         |         |        |
    | (direct) |          |          |          |
| ---snip---
                                                |
| 192.168.23.0/30  | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168. | ethernet |          |          |
|                  |      |           |                    |         |         |        |
    | 12.2     | -1/1.1   |          |          |
|                  |      |           |                    |         |         |        |
    | (direct) |          |          |          |
| 192.168.34.0/30  | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168. | ethernet |          |          |
|                  |      |           |                    |         |         |        |
    | 12.2     | -1/1.1   |          |          |
|                  |      |           |                    |         |         |        |
    | (direct) |          |          |          |
| 192.168.45.0/30  | 0    | isis      | isis_mgr           | True    | default | 40     | 18
    | 192.168. | ethernet | 192.168. | ethernet |
|                  |      |           |                    |         |         |        |
    | 12.2     | -1/1.1   | 17.2     | -1/2.1   |
|                  |      |           |                    |         |         |        |
    | (direct) |          | (direct) |          |
| 192.168.56.0/30  | 0    | isis      | isis_mgr           | True    | default | 30     | 18
    | 192.168. | ethernet |          |          |
|                  |      |           |                    |         |         |        |
    | 17.2     | -1/2.1   |          |          |
|                  |      |           |                    |         |         |        |
    | (direct) |          |          |          |
| 192.168.67.0/30  | 0    | isis      | isis_mgr           | True    | default | 20     | 18
    | 192.168. | ethernet |          |          |
|                  |      |           |                    |         |         |        |
    | 17.2     | -1/2.1   |          |          |
```

```
|                 |      |           |                     |         |         |        |
     | (direct) |          |          |          |
+-----------------+------+-----------+---------------------+---------+---------+--------+------
-----+----------+----------+----------+----------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 routes total                    : 18
IPv4 prefixes with active routes     : 18
IPv4 prefixes with active ECMP routes: 0
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
```

PE-1 can reach destination PE-4 (with node SID 20004) via two different SR paths: one via PE-7 and one via PE-2. Similar for destination PE-5.

```
A:admin@PE-1# show / network-instance default tunnel-table ipv4 192.0.2.4/32 detail
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Show report for network instance "default" tunnel table
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
=================================================================================================
=======================================================
Destination        : 192.0.2.4/32
Tunnel Type        : sr-isis
Tunnel ID          : 20004
Metric             : 30
Preference         : 11
Last Update        : 2025-12-16T17:16:53.330Z
FIB Status         : active
Next-hops
  192.168.12.2 (mpls) via [ethernet-1/1.1]
      pushed MPLS labels : [20004]
Backup Next-hops
192.168.17.2 (mpls) via [ethernet-1/2.1]
      pushed MPLS labels : [20004]
=================================================================================================
=======================================================
```

```
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop *
 | as table | filter fields type ip-address subinterface mpls-encapsulation/pushed-mpls-label-
stack
+-------------------------+---------------------+--------------------+------------------------
-+-------------------------+-------------------------+
|    Network-instance     |        Index        |        Type        |       Ip-address
 |      Subinterface       |   Mpls-encapsulation    |
|                         |                     |                    |
 |                         | pushed-mpls-label-stack |
+=========================+=====================+====================+========================
=+=========================+=========================+
| ---snip---
                                                    |
| default                 |             31593955 | mpls               | 192.168.12.2
 | ethernet-1/1.1          | 20002                   |
| default                 |             31593956 | mpls               | 192.168.12.2
 | ethernet-1/1.1          | 20003                   |
| default                 |             31593959 | mpls               | 192.168.17.2
 | ethernet-1/2.1          | 20006                   |
| default                 |             31593961 | mpls               | 192.168.17.2
 | ethernet-1/2.1          | 20077                   |
| default                 |             31593962 | mpls               | 192.168.12.2
 | ethernet-1/1.1          | IMPLICIT_NULL           |
```

```
| default                 |             31593963 | mpls               | 192.168.17.2
 | ethernet-1/2.1          | IMPLICIT_NULL           |
| ---snip---
                                                    |
| default                 |             31593969 | mpls               | 192.168.17.2
 | ethernet-1/2.1          | 20004                   |
| default                 |             31593970 | mpls               | 192.168.12.2
 | ethernet-1/1.1          | 20004                   |
| default                 |             31593971 | mpls               | 192.168.12.2
 | ethernet-1/1.1          | 20005                   |
| default                 |             31593972 | mpls               | 192.168.17.2
 | ethernet-1/2.1          | 20005                   |
+-------------------------+----------------------+--------------------+-----------------------
-+-------------------------+-------------------------+
```

When a failure occurs on the primary SR path (only applicable for prefix PE-4/PE-5 and the link between PE-4 and PE-5), the traffic takes the LFA backup SR path to the destination using the same MPLS label value.

13.3.3.3 Configuration with SR, LFA, and RLFA

To extend the LFA FRR coverage, for example, to find an LFA protection for node PE-7, which is one of the **IP-VRF** endpoints, RLFA can be enabled. RLFA creates a virtual LFA by using a repair tunnel to carry packets to a point in the network from where they are not looped back to the source, but forwarded (SPF-based) toward the destination prefix.

The RLFA implementation uses the PQ algorithm. The node where RLFA is configured (PE-1 in this example) computes an extended P-space and a Q-space. The intersection of both spaces contains the PQ-nodes. This PQ node is the destination node of the repair tunnel using an SR shortest path tunnel. To compute both spaces, SPF is used.

In this example, IS-IS is used as the IGP, using a default metric value of 10 for all links. With the assumption that the link between PE-1 and PE-7 is broken, the calculation of both the extended P-space and the Q-space at PE-1 is as follows:

- extended P-space — An SPF computed from node PE-1 and rooted at PE-2. It is used to calculate the set of routers that are reachable without any path transiting the protected link between PE-1 and PE-7. The following nodes belong to the extended P-space: PE-2, PE-3, PE-4, and PE-5.
- Q-space — A reverse SPF computed from PE-1 and rooted from PE-7 (acting as destination proxy). It is used to calculate the set of routers that can reach PE-7 without transiting the protected link between PE-1 and PE-7. The nodes PE-4, PE-5, and PE-6 belong to the Q-space.

Possible PQ-nodes are PE-4 or PE-5, because they are in the intersection of both spaces.

RLFA is configured as follows:

```
# on all PEs:
enter candidate
    network-instance default protocols isis instance 0 {
                    loopfree-alternate {
                        admin-state enable
                        augment-route-table true
                        remote-lfa {
                            admin-state enable
                            node-protect {
                                admin-state enable
                            }
                        }
```

```
                    }
```

On PE-1, the nodes PE-2, PE-3, PE-6, and PE-7 now have RLFA protection, whereas PE-4 and PE-5 have LFA protection. Similar next-hop LFA or RLFA protection is present on the other PEs (for other nodes or links).

```
A:admin@PE-1# info from state with-context / network-instance default route-table next-hop *
 | as table | filter fields type ip-address subinterface mpls-encapsulation/pushed-mpls-label-
stack
+---------------------+---------------------+--------------------+----------------------+----
-----------------+----------------------+
|   Network-instance   |        Index         |        Type        |      Ip-address      |
 Subinterface     |  Mpls-encapsulation  |
|                      |                      |                    |                      |
                 |  pushed-mpls-label-  |
|                      |                      |                    |                      |
                 |       stack          |
+=====================+=====================+====================+======================+====
=================+======================+
| ---snip---
                                      |
| default              |             31593969 | mpls               | 192.168.17.2         |
 ethernet-1/2.1       | 20004                |
| default              |             31593970 | mpls               | 192.168.12.2         |
 ethernet-1/1.1       | 20004                |
| default              |             31593971 | mpls               | 192.168.12.2         |
 ethernet-1/1.1       | 20005                |
| default              |             31593972 | mpls               | 192.168.17.2         |
 ethernet-1/2.1       | 20005                |
| ---snip---
                                      |
| default              |             31593973 | mpls               | 192.168.17.2         |
 ethernet-1/2.1       | 20002 20005          |
| default              |             31593974 | mpls               | 192.168.12.2         |
 ethernet-1/1.1       | 20002                |
| default              |             31593975 | mpls               | 192.168.17.2         |
 ethernet-1/2.1       | 20003 20005          |
| default              |             31593976 | mpls               | 192.168.12.2         |
 ethernet-1/1.1       | 20003                |
| default              |             31593977 | mpls               | 192.168.12.2         |
 ethernet-1/1.1       | 20006 20004          |
| default              |             31593978 | mpls               | 192.168.17.2         |
 ethernet-1/2.1       | 20006                |
| default              |             31593979 | mpls               | 192.168.12.2
 | ethernet-1/1.1       | 20077 20004          |
| default              |             31593980 | mpls               | 192.168.17.2
 | ethernet-1/2.1       | 20077                |
| default              |             31593981 | mpls               | 192.168.12.2         |
 ethernet-1/1.1       | IMPLICIT_NULL        |
| default              |             31593982 | mpls               | 192.168.17.2         |
 ethernet-1/2.1       | IMPLICIT_NULL        |
+---------------------+---------------------+--------------------+----------------------+----
-----------------+----------------------+
```

PE-1 can reach destination PE-7 (with node SID 20077) via two different SR paths: one via PE-7 and one via PE-2, which excludes the link between PE-1 and PE-7. Similar for destination PE-6. PE-1 can reach destination PE-2 (with node SID 20002) via two different SR paths: one via PE-2 and one via PE-7, which excludes the link between PE-1 and PE-2. Similar for destination PE-3.

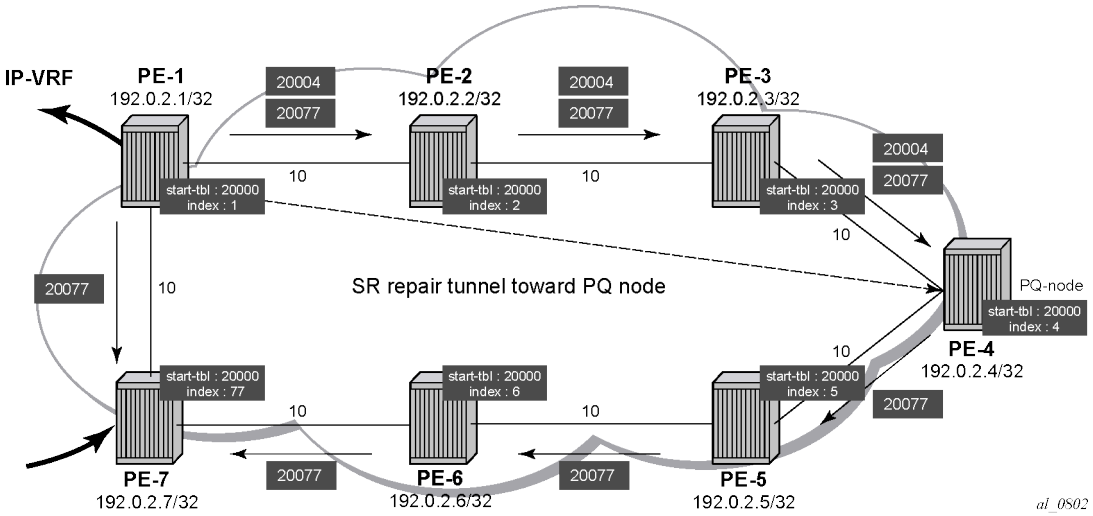
```
A:admin@PE-1# show / network-instance default tunnel-table ipv4 192.0.2.7/32 detail
```

```
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Show report for network instance "default" tunnel table
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
=================================================================================================
=======================================================
Destination        : 192.0.2.7/32
Tunnel Type        : sr-isis
Tunnel ID          : 20077
Metric             : 10
Preference         : 11
Last Update        : 2025-12-16T17:25:28.218Z
FIB Status         : active
Next-hops
  192.168.17.2 (mpls) via [ethernet-1/2.1]
      pushed MPLS labels : [20077]
Backup Next-hops
192.168.12.2 (mpls) via [ethernet-1/1.1]
      pushed MPLS labels : [20077, 20004]
=================================================================================================
=======================================================
```

The main difference between normal prefix LFA and RLFA is that for RLFA a two-MPLS label stack is pushed by the head-end node (PE-1). The top label is the SR-label to reach the PQ node (for example, 20004 for the PQ node PE-4) and the bottom label is the SR-label to reach the destination node (for example, 20077 for destination node PE-7). The notation inside the **show** command output is [bottom-label, top-label.].

Figure 34: RLFA traffic path during protection illustrates the RLFA traffic path protecting the link between PE-1 and PE-7 for traffic from PE-1 to PE-7:

Figure 34: RLFA traffic path during protection



13.3.3.4 Configuration with SR and LDP, without LFA and RLFA

To show the impact of protocol preference within TTM, configure LDP on PE-1 and PE-7, next to SR. This can be useful in case of migration scenarios from a non-SR environment toward a hybrid environment having LDP and SR enabled.

In the following, disable LFA and RLFA (to simplify the scenario):

```
# on all PEs:
enter candidate
    network-instance default protocols {
            isis {
                instance 0 {
                    loopfree-alternate {
                        remote-lfa {
                            admin-state disable
                            node-protect {
                                admin-state disable
                            }
                        }
                        admin-state disable
                        augment-route-table false
                    }
```

Define a dedicated dynamic MPLS label range for LDP on all PEs:

```
# on all PEs:
enter candidate
    system mpls label-ranges {
                dynamic dynamic-ldp {
                    start-label 10000
                    end-label 10099
                }
```

Assign the MPLS label range for LDP to the LDP dynamic label block and configure LDP discovery of interfaces on all PEs.

```
# on all PEs:
enter candidate
    network-instance default protocols {
            ldp {
                admin-state enable
                dynamic-label-block dynamic-ldp
                discovery {
                    interfaces {
                        interface ethernet-1/1.1 {
                            ipv4 {
                                admin-state enable
                            }
                        }
                        interface ethernet-1/2.1 {
                            ipv4 {
                                admin-state enable
                            }
                        }
                    }
                }
```

By enabling LDP, the MPLS label mapping includes entries for LDP, with labels from **dynamic-ldp**.

```
A:admin@PE-1# show / network-instance default route-table mpls
+---------+-----------+-------------+-----------------+-----------------------+--------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)    | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                       | Subinterface
       | labels           |
+=========+===========+=============+=================+=======================+==============
=======+==================+
| 10000   | POP       | ldp         | default         |                       |
       |                  |
| 10001   | SWAP      | ldp         | N/A             | 192.168.12.2 (mpls)   | ethernet-1/1.1
       | 10000            |
| 10002   | SWAP      | ldp         | N/A             | 192.168.12.2 (mpls)   | ethernet-1/1.1
       | 10002            |
| 10003   | SWAP      | ldp         | N/A             | 192.168.12.2 (mpls)   | ethernet-1/1.1
       | 10003            |
| 10004   | SWAP      | ldp         | N/A             | 192.168.17.2 (mpls)   | ethernet-1/2.1
       | 10004            |
| 10005   | SWAP      | ldp         | N/A             | 192.168.17.2 (mpls)   | ethernet-1/2.1
       | 10000            |
| 10006   | SWAP      | ldp         | N/A             | 192.168.17.2 (mpls)   | ethernet-1/2.1
       | 10001            |
| 20001   | POP       | sr-mpls     | default         |                       |
       |                  |
| 20002   | SWAP      | sr-mpls     | N/A             | 192.168.12.2 (mpls)   | ethernet-1/1.1
       | 20002            |
| 20003   | SWAP      | sr-mpls     | N/A             | 192.168.12.2 (mpls)   | ethernet-1/1.1
       | 20003            |
| 20004   | SWAP      | sr-mpls     | N/A             | 192.168.12.2 (mpls)   | ethernet-1/1.1
       | 20004            |
| 20005   | SWAP      | sr-mpls     | N/A             | 192.168.17.2 (mpls)   | ethernet-1/2.1
       | 20005            |
| 20006   | SWAP      | sr-mpls     | N/A             | 192.168.17.2 (mpls)   | ethernet-1/2.1
       | 20006            |
| 20077   | SWAP      | sr-mpls     | N/A             | 192.168.17.2 (mpls)   | ethernet-1/2.1
       | 20077            |
| 30000   | SWAP      | sr-mpls     | N/A             | 192.168.12.2 (mpls)   | ethernet-1/1.1
       | IMPLICIT_NULL    |
| 30001   | SWAP      | sr-mpls     | N/A             | 192.168.17.2 (mpls)   | ethernet-1/2.1
       | IMPLICIT_NULL    |
| 40000   |           | network-    | IP-VRF          |                       |
       |                  |
|         |           | instance    |                 |                       |
       |                  |
+---------+-----------+-------------+-----------------+-----------------------+--------------
-------+------------------+
```

Also the TTM changes. With **IP-VRF** between PE-1 and PE-7 as an example, only those two specific network instance endpoints are displayed.

An LDP LSP and an SR shortest path tunnel (using IS-IS) are present and active for the same destination.

```
A:admin@PE-1# show / network-instance default tunnel-table ipv4 192.0.2.7/32
------------------------------------------------------------------------------------------------
------------------------------------------------------
IPv4 tunnel table of network-instance "default"
------------------------------------------------------------------------------------------------
------------------------------------------------------
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
```

```
| IPv4 Prefix  | Tunnel Type  |  Tunnel ID   |     FIB      |    Metric    |  Preference  |
 Last Update  |    Backup    |   Next-hop   |   Next-hop   |
|              |              |              |              |              |              |
          |   Nexthops   |    (Type)    |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 192.0.2.7/32 | ldp          | 65540        | Y            | 10           | 9            |
 2025-12-     |              | 192.168.17.2 | ethernet-    |
|              |              |              |              |              |              |
 16T17:41:02. |              | (mpls)       | 1/2.1        |
|              |              |              |              |              |              |
 260Z         |              |              |              |
| 192.0.2.7/32 | sr-isis      | 20077        | Y            | 10           | 11           |
 2025-12-     |              | 192.168.17.2 | ethernet-    |
|              |              |              |              |              |              |
 16T17:33:28. |              | (mpls)       | 1/2.1        |
|              |              |              |              |              |              |
 195Z         |              |              |              |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
1 LDP tunnels, 1 active, 0 inactive
1 SR-ISIS tunnels, 1 active, 0 inactive
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

```
A:admin@PE-7# show / network-instance default tunnel-table ipv4 192.0.2.1/32
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv4 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
| IPv4 Prefix  | Tunnel Type  |  Tunnel ID   |     FIB      |    Metric    |  Preference  |
 Last Update  |    Backup    |   Next-hop   |   Next-hop   |
|              |              |              |              |              |              |
          |   Nexthops   |    (Type)    |              |
+==============+==============+==============+==============+==============+==============+====
==========+==============+==============+==============+
| 192.0.2.1/32 | ldp          | 65540        | Y            | 10           | 9            |
 2025-12-     |              | 192.168.17.1 | ethernet-    |
|              |              |              |              |              |              |
 16T17:41:02. |              | (mpls)       | 1/1.1        |
|              |              |              |              |              |              |
 659Z         |              |              |              |
| 192.0.2.1/32 | sr-isis      | 20001        | Y            | 10           | 11           |
 2025-12-     |              | 192.168.17.1 | ethernet-    |
|              |              |              |              |              |              |
 16T17:33:36. |              | (mpls)       | 1/1.1        |
|              |              |              |              |              |              |
 602Z         |              |              |              |
+--------------+--------------+--------------+--------------+--------------+--------------+----
----------+--------------+--------------+--------------+
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
1 LDP tunnels, 1 active, 0 inactive
1 SR-ISIS tunnels, 1 active, 0 inactive
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
```

The LDP LSP is preferred by default (lower preference value), but as long as the **allowed-tunnel-types** does not include **ldp**, it is not chosen.

```
A:admin@PE-1# show / network-instance IP-VRF route-table ipv4-unicast prefix 10.10.7.1/32
 detail
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 unicast route table of network instance IP-VRF
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Destination            : 10.10.7.1/32
ID                     : 0
Route Type             : bgp-ipvpn
Route Owner            : bgp_ipvpn_mgr
Origin Network Instance: IP-VRF
Metric                 : 10
Preference             : 170
Active                 : true
Last change            : 2025-12-16T17:05:06.303Z
Resilient hash         : false
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Next hops: 1 entries
192.0.2.7 (indirect) resolved by tunnel to 192.0.2.7/32 (sr-isis/tunnel-id: 20077)
Backup Next hops: 0 entries
---snip---
```

```
A:admin@PE-1# show / network-instance IP-VRF ipv4 route all
=================================================================================================
=======================================================
IPv4-unicast route table for ip-vrf network-instance: IP-VRF
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
---snip---
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Prefix               Route Type   Metric   Pref    Flags    Next-Hop(s)
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
10.10.7.1/32         bgp-ipvpn    10       170     >        192.0.2.7(tunnel:sr-isis,
 label:40000)
```

```
A:admin@PE-7# show / network-instance IP-VRF route-table ipv4-unicast prefix 10.10.1.1/32
 detail
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
IPv4 unicast route table of network instance IP-VRF
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Destination            : 10.10.1.1/32
ID                     : 0
Route Type             : bgp-ipvpn
Route Owner            : bgp_ipvpn_mgr
Origin Network Instance: IP-VRF
Metric                 : 10
Preference             : 170
Active                 : true
Last change            : 2025-12-16T17:05:07.395Z
Resilient hash         : false
-------------------------------------------------------------------------------------------------
-------------------------------------------------------
Next hops: 1 entries
```

```
192.0.2.1 (indirect) resolved by tunnel to 192.0.2.1/32 (sr-isis/tunnel-id: 20001)
Backup Next hops: 0 entries
---snip---
```

```
A:admin@PE-7# show / network-instance IP-VRF ipv4 route all
===============================================================================================================
=========================================================
IPv4-unicast route table for ip-vrf network-instance: IP-VRF
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------
---snip---
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------
Prefix              Route Type   Metric   Pref    Flags    Next-Hop(s)
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------
10.10.1.1/32        bgp-ipvpn    10       170     >        192.0.2.1(tunnel:sr-isis,
 label:40000)
```

The LDP LSP is chosen, when **allowed-tunnel-types** also includes **ldp**. Because this is an IP VRF specific parameter, the operator has the choice to only configure this on one specific IP VRF endpoint. From a migration point of view, a smooth and easy SR migration is possible, not affecting any other deployed network instances on this node.

```
# only on PE-7:
enter candidate
    network-instance IP-VRF protocols bgp-ipvpn bgp-instance 1 mpls {
                        next-hop-resolution {
                            allowed-tunnel-types [
                                sr-isis
                                ldp
                            ]
```

Because the change is only configured within **IP-VRF** on PE-7, only the direction from PE-7 to PE-1 is affected. **IP-VRF** on node PE-7 now uses the LDP LSP to reach node PE-1. **IP-VRF** on node PE-1 still uses the SR IS-IS tunnel to reach node PE-7.

```
A:admin@PE-7# show / network-instance IP-VRF route-table ipv4-unicast prefix 10.10.1.1/32
 detail
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------
IPv4 unicast route table of network instance IP-VRF
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------
Destination            : 10.10.1.1/32
ID                     : 0
Route Type             : bgp-ipvpn
Route Owner            : bgp_ipvpn_mgr
Origin Network Instance: IP-VRF
Metric                 : 10
Preference             : 170
Active                 : true
Last change            : 2025-12-16T18:01:06.327Z
Resilient hash         : false
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------
Next hops: 1 entries
192.0.2.1 (indirect) resolved by tunnel to 192.0.2.1/32 (ldp/tunnel-id: 65540)
```

```
Backup Next hops: 0 entries
```

```
A:admin@PE-7# show / network-instance IP-VRF ipv4 route all
===============================================================================================================
=======================================================
IPv4-unicast route table for ip-vrf network-instance: IP-VRF
---------------------------------------------------------------------------------------------------------------
-------------------------------------------------------
---snip---
---------------------------------------------------------------------------------------------------------------
-------------------------------------------------------
Prefix               Route Type   Metric   Pref    Flags    Next-Hop(s)
---------------------------------------------------------------------------------------------------------------
-------------------------------------------------------
10.10.1.1/32         bgp-ipvpn    10       170     >        192.0.2.1(tunnel:ldp, label:40000)
```

13.4 Conclusion

SR is a technique using extensions of the existing link state protocols, and using existing MPLS or IPv6 infrastructure as the data plane. It is a source routing technique without the need to run an extra signaling protocol. SR also avoids other scaling restrictions, such as midpoint state. SR is simple to control and operate because the intelligence and state are part of the packet, not held by the network. Other benefits are that SR can be introduced in an incremental way using different migration scenarios to assure a smooth transition.

14 Shared Risk Link Groups for Uncolored SR-MPLS Policy-based LSPs

This chapter provides information about Shared Risk Link Groups for uncolored SR-MPLS policy-based LSPs.

Topics in this chapter include:

14.1 Applicability

The configuration in the current edition corresponds to SRL Release 25.10.R2. There are no prerequisites.

14.2 Overview

14.2.1 Introduction

Shared Risk Link Group (SRLG) is a feature which allows the user to establish a standby or secondary label switched path (LSP) which is disjoint from the primary LSP. Links which are members of the same SRLG represent resources which share the same risk. For example, fiber links sharing the same conduit or multiple wavelengths sharing the same fiber.

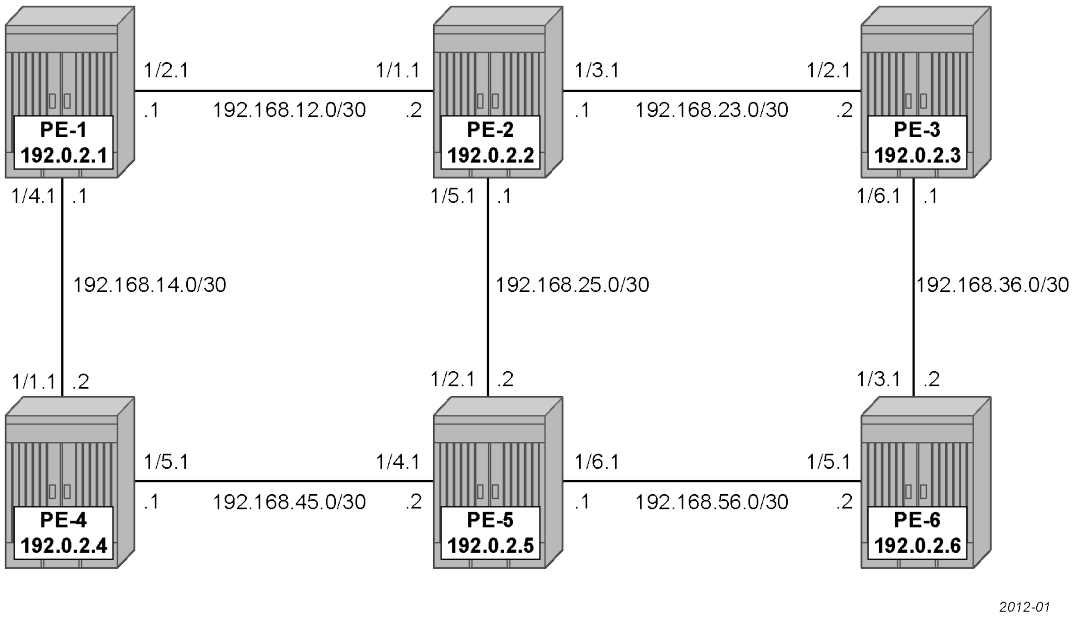
A typical application of the SRLG feature is to provide an automatic placement of standby LSPs that minimize the probability of fate sharing with the primary LSP.

SRLGs are used to indicate which links share the same fate. The mechanism is similar to Multi-Protocol Label Switching (MPLS) admin groups. To advertise SRLGs, the information is part of the IGP TE parameters in an opaque link state advertisement (LSA). In IS-IS (RFC 4205), the SRLG is advertised in a Shared Risk Link Group TLV (type 138).

14.2.2 SRLG

Figure 35: Example topology shows the example topology for this chapter.

Figure 35: Example topology



A single IGP area (IS-IS instance 0 in this case) with traffic engineering (TE) enabled is required for the SRLG feature to work properly.

14.3 Configuration

14.3.1 Configure the IP/MPLS network

IS-IS is configured on all interfaces. On PE-1, the initial configuration is the following:

```
# on PE-1:
    network-instance default {
        admin-state enable
        router-id 192.0.2.1
        interface ethernet-1/2.1 {
        }
        interface ethernet-1/4.1 {
        }
        interface system0.0 {
        }
        protocols {
            isis {
                instance 0 {
                    admin-state enable
                    level-capability L1
                    net [
                        49.0000.1920.0000.2001.00
                    ]
                    interface ethernet-1/2.1 {
                        admin-state enable
                        circuit-type point-to-point
```

```
                    }
                    interface ethernet-1/4.1 {
                        admin-state enable
                        circuit-type point-to-point
                    }
                    interface system0.0 {
                    }
                    level 1 {
                    }
                }
            }
        }
```

Segment routing is required on all nodes. The label ranges for the node SIDs and the adjacency SIDs are the following:

```
# on all nodes:
    system {
        mpls {
            label-ranges {
                static srgb-static-mpls {     # for protocol-independent node SIDs
                    shared true
                    start-label 100
                    end-label 799
                }
                dynamic srlb-dynamic-mpls {   # for dynamic adjacency SIDs
                    start-label 2100
                    end-label 2799
                }
```

Segment routing is configured on all nodes, as described in the Segment Routing with IS-IS Control Plane chapter. On PE-1, the segment routing configuration is as follows:

```
# on PE-1:
    network-instance default {
         protocols {
            isis {
                dynamic-label-block srlb-dynamic-mpls
                instance 0 {
                    segment-routing {
                        mpls {
                            dynamic-adjacency-sids {
                                all-interfaces true
                            }
                        }
                    }
                }
            }
        }
        segment-routing {
            mpls {
                global-block {
                    label-range srgb-static-mpls
                }
                local-prefix-sid 1 {
                    interface system0.0
                    ipv4-label-index 1
                    node-sid true
                }
```

TE is configured on all nodes; on PE-1, the TE configuration is as follows:

```
# on PE-1:
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    te-database-install {
                    }
                    traffic-engineering {
                        advertisement true
                        legacy-link-attribute-advertisement false  # optional
                        ipv4-te-router-id 192.0.2.1
                    }
                }
            }
        }
        traffic-engineering {
            ipv4-te-router-id 192.0.2.1
            interface ethernet-1/2.1 {
                interface-ref {
                    interface ethernet-1/2
                    subinterface 1
                }
            }
            interface ethernet-1/4.1 {
                interface-ref {
                    interface ethernet-1/4
                    subinterface 1
                }
            }
        }
```

Optionally, admin groups "adm-green" and "adm-red" are configured on the nodes. The configuration of admin groups is as follows:

```
# on all nodes:
    network-instance default {
        traffic-engineering {
            admin-groups {
                group adm-green {
                    bit-position 1
                }
                group adm-red {
                    bit-position 2
                }
            }
```

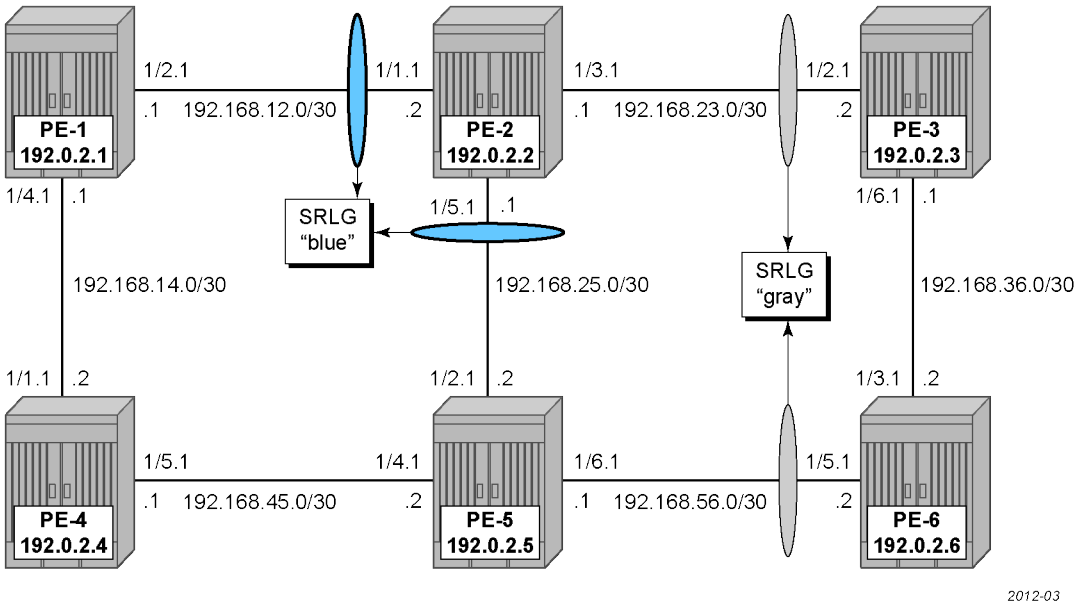
These admin groups can be assigned to interfaces in the TE context, as shown in the following section.

The configuration on the other nodes is similar.

14.3.2 Define SRLG groups

Two SRLG groups are defined, named srlg-blue and srlg-gray, as shown in Figure 36: SRLG topology.

Figure 36: SRLG topology



The configuration of the srlg-blue group is only mandatory on PE-1, PE-2, and PE-5, while the srlg-gray group is only mandatory on PE-2, PE-3, PE-5, and PE-6. However, it is good practice to configure both SRLG groups on all nodes, as follows:

```
# on all nodes:
    network-instance default {
        traffic-engineering {
            shared-risk-link-groups {
                group srlg-blue {
                    value 1
                }
                group srlg-gray {
                    value 2
                }
            }
```

The interfaces in the TE context need to be linked to the related SRLG group, which is a unidirectional indicator, applying only to the egress direction; therefore, it needs to be configured on both sides of the interface. For example on PE-1, the interface to PE-2 is part of the srlg-blue group. An interface can be part of multiple SRLG groups similar to the admin-group functionality. Admin groups are configured in parallel to indicate that both can be configured and can work independently.

```
# on PE-1:
    network-instance default {
        traffic-engineering {
            interface ethernet-1/2.1 {
                admin-group [
                    adm-green
                ]
                srlg-membership [
                    srlg-blue
                ]
            }
            interface ethernet-1/4.1 {
```

```
                admin-group [
                    adm-red
                ]
            }
```

On PE-2, the following SRLGs and admin groups are linked to the interfaces.

```
# on PE-2:
    network-instance default {
        traffic-engineering {
            interface ethernet-1/1.1 {
                admin-group [
                    adm-green
                ]
                srlg-membership [
                    srlg-blue
                ]
            }
            interface ethernet-1/3.1 {
                admin-group [
                    adm-green
                ]
                srlg-membership [
                    srlg-gray
                ]
            }
            interface ethernet-1/5.1 {
                srlg-membership [
                    srlg-blue
                ]
            }
```

The configuration on the other nodes is similar.

The SRLG configuration can be verified using the following commands. The SRLG groups on PE-1 are the following:

```
+-------------------------------------------------------+-----------------------------------------
-------------+------------+
|                  Network-instance                     |                         Name
             |   Value    |
+=======================================================+=========================================
=============+============+
| default                                               | srlg-blue
             |          1 |
| default                                               | srlg-gray
             |          2 |
+-------------------------------------------------------+-----------------------------------------
-------------+------------+
```

In the following list of TE interfaces on PE-2, admin groups and SRLG membership are indicated:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering interface * | as
 table | filter fields *

+------------+------------+-----------+------------+------------+-------------------------+----
------------------------+
|  Network-  | Interface- | Te-metric |   Admin-   |   Srlg-    | Interface-ref interface |
 Interface-ref subinterface |
|  instance  |    name    |           |   group    | membership |                         |
                       |
```

```
+============+============+===========+============+============+=========================+====
========================+
| default    | ethernet-  |           | adm-green  | srlg-blue  | ethernet-1/1            |
                    1 |
|            | 1/1.1      |           |            |            |                         |
                     |
| default    | ethernet-  |           | adm-green  | srlg-gray  | ethernet-1/3            |
                    1 |
|            | 1/3.1      |           |            |            |                         |
                     |
| default    | ethernet-  |           |            | srlg-blue  | ethernet-1/5            |
                    1 |
|            | 1/5.1      |           |            |            |                         |
                     |
+------------+------------+-----------+------------+------------+-------------------------+----
------------------------+
```

14.3.3 Standby or secondary path with SRLG constraint

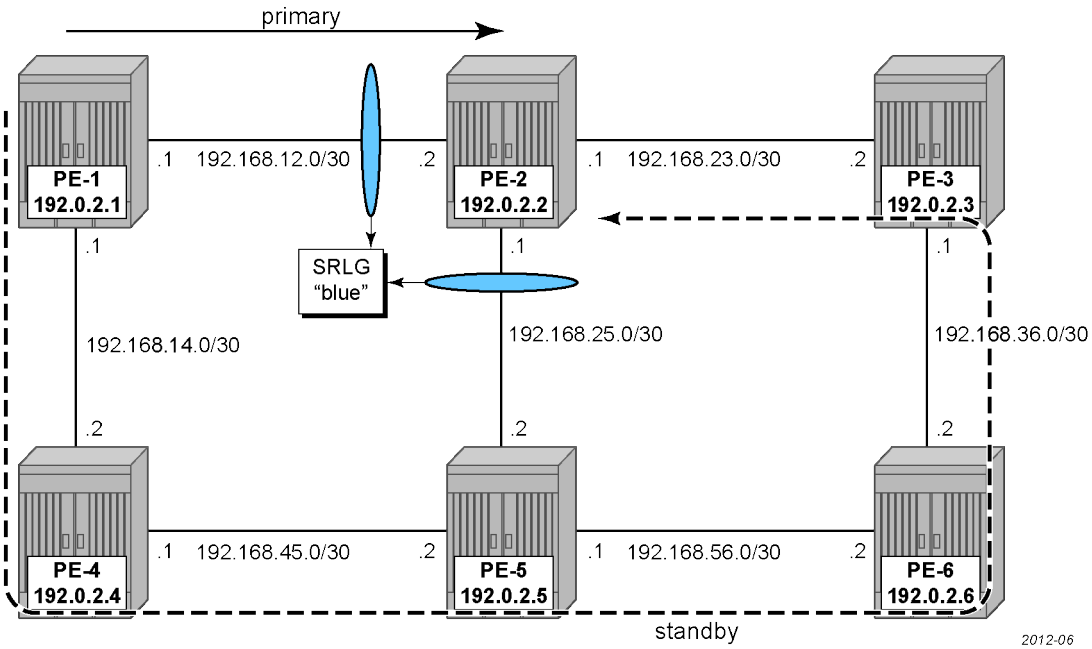
SRLG groups can be constraints to set up a standby path. The following uncolored SR-MPLS TE policy with an unconstrained primary path and a standby path with SRLG restriction is configured on PE-1:

```
# on PE-1:
    network-instance default {
        traffic-engineering-policies {
            policy pol-PE-1-PE-2_standby-srlg {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.2
                segment-list 12 {
                    admin-state enable
                    segment-list-type primary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            label-stack-reduction false   # optional; for verification purposes
                        }
                    }
                }
                segment-list 22 {
                    admin-state enable
                    segment-list-type standby           # or segment-list-type secondary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            label-stack-reduction false   # optional; for verification purposes
                            exclude-srlg [
                                srlg-blue
                            ]
                        }
                    }
                }
            }
```

Note:
The SRLG configuration for the standby or secondary path is similar. In this chapter, the standby path is chosen because the standby path is already computed and can be verified easily. The secondary path is only computed when no other path is operationally up.

Figure 37: SRLG for standby path shows that the primary path follows the direct link from PE-1 to PE-2, while the standby path excludes the interfaces in srlg-blue, so it follows the dashed line from PE-1 over PE-4, PE-5, PE-6, and PE-3 to PE-2 instead of passing over the direct link between PE-5 and PE-2.

Figure 37: SRLG for standby path



Both the primary and the standby segment lists are dynamic without any explicit hop. Without any constraint, PE-2 is only one hop away from PE-1 on the primary path. The following command shows the CSPF calculated hop in the primary path:

```
--{ + running }--[  ]--
A:admin@PE-1# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy
* protocol-origin local segment-list 12 computed-segments segment * | as table | filter fields
 *

+---------+---------+---------+---------+---------+---------+---------+---------+---------+----
-----+---------+---------+
| Network | Policy  | Policy  | Segment | Segment |  Hop-   |   Ip-   |   Is-   | Unnumbe |
 Router- |  Sid-   |  Sid-   |
| -instan | policy- | protoco |  -list  | -index  |  type   | address |  loose  | red-if- |
 id    |  type   |  value  |
|   ce    |  name   |   l-    |         |         |         |         |         |   id    |
     |         |  mpls-  |
|         |         | origin  |         |         |         |         |         |         |
     |         |  label  |
+=========+=========+=========+=========+=========+=========+=========+=========+=========+====
=====+=========+=========+
| default | pol-PE- | local   |      12 |       1 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2100 |
|         | 1-PE-   |         |         |         | .12.2   |         |         | .2
     | cy-sid  |         |
|         | 2_stand |         |         |         |         |         |         |         |
     |         |         |
|         | by-srlg |         |         |         |         |         |         |         |
     |         |         |
```

```
---snip---
```

Note:
When the segment lists in the SR-MPLS uncolored TE policy are configured with **dynamic te-constraints label-stack-reduction true** (which is the default setting), the label stack is reduced to the node SID of the destination and no intermediate hops are shown.

The following command shows the CSPF calculated hops in the standby path: over PE-4, PE-5, PE-6, and PE-3 to destination PE-2.

```
--{ + running }--[  ]--
A:admin@PE-1# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy
* protocol-origin local segment-list 22 computed-segments segment * | as table | filter fields
 *

+---------+---------+---------+---------+---------+---------+---------+---------+---------+----
-----+---------+---------+
| Network | Policy  | Policy  | Segment | Segment |  Hop-   |   Ip-   |   Is-   | Unnumbe |
 Router- |  Sid-   |  Sid-   |
| -instan | policy- | protoco |  -list  | -index  |  type   | address |  loose  | red-if- |
 id    |  type   |  value  |
|   ce    |  name   |   l-    |         |         |         |         |         |   id    |
     |         |  mpls-  |
|         |         | origin  |         |         |         |         |         |         |
     |         |  label  |
+=========+=========+=========+=========+=========+=========+=========+=========+=========+====
=====+=========+=========+
| default | pol-PE- | local   |      22 |       1 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2101 |
|         | 1-PE-   |         |         |         | .14.2   |         |         | .4
     | cy-sid  |         |
|         | 2_stand |         |         |         |         |         |         |
     |         |         |
|         | by-srlg |         |         |         |         |         |         |
     |         |         |
| default | pol-PE- | local   |      22 |       2 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2101 |
|         | 1-PE-   |         |         |         | .45.2   |         |         | .5
     | cy-sid  |         |
|         | 2_stand |         |         |         |         |         |         |
     |         |         |
|         | by-srlg |         |         |         |         |         |         |
     |         |         |
| default | pol-PE- | local   |      22 |       3 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2102 |
|         | 1-PE-   |         |         |         | .56.2   |         |         | .6
     | cy-sid  |         |
|         | 2_stand |         |         |         |         |         |         |
     |         |         |
|         | by-srlg |         |         |         |         |         |         |
     |         |         |
| default | pol-PE- | local   |      22 |       4 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2100 |
|         | 1-PE-   |         |         |         | .36.1   |         |         | .3
     | cy-sid  |         |
|         | 2_stand |         |         |         |         |         |         |
     |         |         |
|         | by-srlg |         |         |         |         |         |         |
     |         |         |
| default | pol-PE- | local   |      22 |       5 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2100 |
```

```
|         | 1-PE-   |         |         |         | .23.1   |         |         | .2
     | cy-sid  |         |
|         | 2_stand |         |         |         |         |         |         |
     |         |         |
|         | by-srlg |         |         |         |         |         |         |
     |         |         |
---snip---
```

Another way to verify the segments in the standby segment list 22, is the following OAM **lsp-trace** command where segment-list-index 22 corresponds to the standby path:

```
# on PE-1:
--{ + running }--[  ]--
A:admin@PE-1# tools oam lsp-trace te-policy sr-uncolored policy pol-PE-1-PE-2_standby-srlg
 protocol-origin local segment-list-index 22
/:
Initiated LSP Trace for TE-policy pol-PE-1-PE-2_standby-srlg with session id 49177.
Please check "info from state oam" for result
```

The following shows the result of the preceding **tools oam lsp-trace** command:

```
--{ + running }--[  ]--
A:admin@PE-1# info from state oam lsp-trace te-policy sr-uncolored policy pol-PE-1-PE-2_
standby-srlg protocol-origin local session-id 49177
    test-active false
    path-destination {
        ip-address 127.0.0.1
    }
    hop 1 {
        probe 1 {
            probe-size 220
            probes-sent 1
            reply {
                received true
                reply-sender 192.0.2.4
                udp-data-length 32
                mpls-ttl 1
                round-trip-time 4882
                return-code replying-router-is-egress-for-fec-at-stack-depth-n
                return-subcode 5
            }
        }
        probe 2 {
            probe-size 188
            probes-sent 1
            reply {
                received true
                reply-sender 192.0.2.4
                udp-data-length 72
                mpls-ttl 1
                round-trip-time 62860
                return-code label-switched-at-stack-depth-n
                return-subcode 4
            }
            downstream-detailed-mapping 1 {
                mtu 1500
                address-type ipv4-numbered
                downstream-router-address 192.168.45.2
                downstream-interface-address 192.168.45.2
                mpls-label 1 {
                    label IMPLICIT_NULL
                    protocol isis
```

```
                }
                mpls-label 2 {
                    label 2102
                    protocol isis
                }
                mpls-label 3 {
                    label 2100
                    protocol isis
                }
                mpls-label 4 {
                    label 2100
                    protocol isis
                }
            }
        }
    }
    hop 2 {
        probe 1 {
            probe-size 188
            probes-sent 1
            reply {
                received true
                reply-sender 192.0.2.5
                udp-data-length 32
                mpls-ttl 2
                round-trip-time 45874
                return-code replying-router-is-egress-for-fec-at-stack-depth-n
                return-subcode 4
            }
        }
        probe 2 {
            probe-size 156
            probes-sent 1
            reply {
                received true
                reply-sender 192.0.2.5
                udp-data-length 68
                mpls-ttl 2
                round-trip-time 45810
                return-code label-switched-at-stack-depth-n
                return-subcode 3
            }
            downstream-detailed-mapping 1 {
                mtu 1500
                address-type ipv4-numbered
                downstream-router-address 192.168.56.2
                downstream-interface-address 192.168.56.2
                mpls-label 1 {
                    label IMPLICIT_NULL
                    protocol isis
                }
                mpls-label 2 {
                    label 2100
                    protocol isis
                }
                mpls-label 3 {
                    label 2100
                    protocol isis
                }
            }
        }
    }
    hop 3 {
        probe 1 {
```

```
            probe-size 156
            probes-sent 1
            reply {
                received true
                reply-sender 192.0.2.6
                udp-data-length 32
                mpls-ttl 3
                round-trip-time 49904
                return-code replying-router-is-egress-for-fec-at-stack-depth-n
                return-subcode 3
            }
        }
        probe 2 {
            probe-size 124
            probes-sent 1
            reply {
                received true
                reply-sender 192.0.2.6
                udp-data-length 64
                mpls-ttl 3
                round-trip-time 43918
                return-code label-switched-at-stack-depth-n
                return-subcode 2
            }
            downstream-detailed-mapping 1 {
                mtu 1500
                address-type ipv4-numbered
                downstream-router-address 192.168.36.1
                downstream-interface-address 192.168.36.1
                mpls-label 1 {
                    label IMPLICIT_NULL
                    protocol isis
                }
                mpls-label 2 {
                    label 2100
                    protocol isis
                }
            }
        }
    }
    hop 4 {
        probe 1 {
            probe-size 124
            probes-sent 1
            reply {
                received true
                reply-sender 192.0.2.3
                udp-data-length 32
                mpls-ttl 4
                round-trip-time 8869
                return-code replying-router-is-egress-for-fec-at-stack-depth-n
                return-subcode 2
            }
        }
        probe 2 {
            probe-size 92
            probes-sent 1
            reply {
                received true
                reply-sender 192.0.2.3
                udp-data-length 60
                mpls-ttl 4
                round-trip-time 42864
                return-code label-switched-at-stack-depth-n
```

```
                return-subcode 1
            }
            downstream-detailed-mapping 1 {
                mtu 1500
                address-type ipv4-numbered
                downstream-router-address 192.168.23.1
                downstream-interface-address 192.168.23.1
                mpls-label 1 {
                    label IMPLICIT_NULL
                    protocol isis
                }
            }
        }
    }
    hop 5 {
        probe 1 {
            probe-size 92
            probes-sent 1
            reply {
                received true
                reply-sender 192.0.2.2
                udp-data-length 32
                mpls-ttl 5
                round-trip-time 7868
                return-code replying-router-is-egress-for-fec-at-stack-depth-n
                return-subcode 1
            }
        }
    }
```

14.3.4 Both primary and standby path with SRLG constraint

SRLG groups can be constraints to set up a primary as well as a standby path. The following SR-MPLS uncolored TE policy on PE-1 has a primary path that excludes srlg-blue and a standby path configured with **secondary-srlg true**:

```
# on PE-1:
    network-instance default {
        traffic-engineering-policies {
            policy pol-PE-1-PE-2_excl-standby-srlg {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.2
                segment-list 13 {
                    admin-state enable
                    segment-list-type primary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            label-stack-reduction false
                            exclude-srlg [
                                srlg-blue
                            ]
                        }
                    }
                }
                segment-list 23 {
                    admin-state enable
                    segment-list-type standby
                    dynamic {
                        path-algorithm local-cspf
```

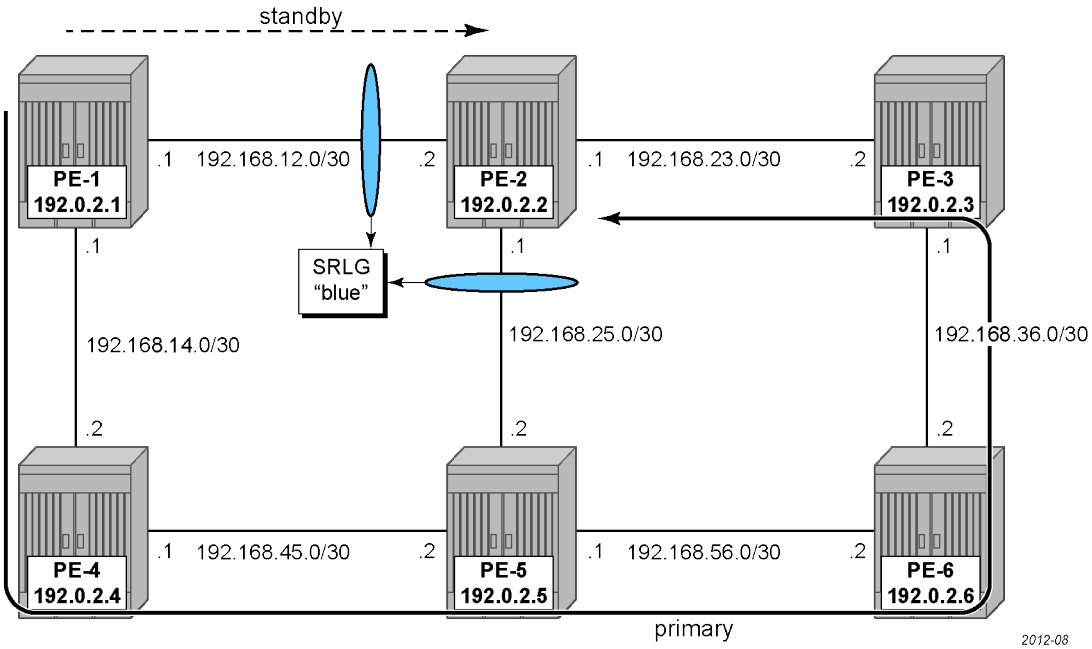
```
                    te-constraints {
                        label-stack-reduction false
                        secondary-srlg true
                    }
                }
            }
        }
```

In the segment list for the standby path, the **secondary-srlg true** setting tells CSPF to avoid SRLGs used by the primary segment-list when computing this segment list, ensuring SRLG disjointness. Therefore, when the primary path excludes srlg-blue, the links in srlg-blue can be used by the standby path, so the reverse situation may occur where the primary path is longer caused by a constraint that the standby path does not have, as shown in Figure 38: Primary path with exclude-srlg and standby path with secondary-srlg.

Note:
The **secondary-srlg** command has no effect on a secondary non-standby segment list. As soon as the primary path goes operationally down, the primary path and its attributes are deleted, so no information can be retrieved in runtime.

The primary path has the constraint not to use any TE interfaces in srlg-blue and is represented by the dashed line from PE-1 over PE-4, PE-5, PE-6, and PE-3 to PE-2, while the standby path has the constraint not to use any interfaces in an SRLG used by the primary path and it takes the direct link from PE-1 to PE-2.

Figure 38: Primary path with exclude-srlg and standby path with secondary-srlg



Both the primary and the standby segment lists are dynamic without any explicit hop. With the constraint not to use srlg-blue, PE-2 is five hops away from PE-1 on the primary path. The following command shows the CSPF calculated hop in the primary path with segment list 13:

```
--{ + running }--[  ]--
```

```
A:admin@PE-1# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy
* protocol-origin local segment-list 13 computed-segments segment * | as table | filter fields
 *

+---------+---------+---------+---------+---------+---------+---------+---------+---------+----
-----+---------+---------+
| Network | Policy  | Policy  | Segment | Segment |  Hop-   |   Ip-   |   Is-   | Unnumbe |
 Router- |  Sid-   |  Sid-   |
| -instan | policy- | protoco |  -list  | -index  |  type   | address |  loose  | red-if- |
 id    |  type   |  value  |
|   ce    |  name   |   l-    |         |         |         |         |         |   id    |
     |         |  mpls-  |
|         |         | origin  |         |         |         |         |         |         |
     |         |  label  |
+=========+=========+=========+=========+=========+=========+=========+=========+=========+====
=====+=========+=========+
| default | pol-PE- | local   |      13 |       1 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2101 |
|         | 1-PE-   |         |         |         | .14.2   |         |         | .4
     | cy-sid  |         |
|         | 2_excl- |         |         |         |         |         |         |
     |         |         |
|         | standby |         |         |         |         |         |         |
     |         |         |
|         | -srlg   |         |         |         |         |         |         |
     |         |         |
| default | pol-PE- | local   |      13 |       2 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2101 |
|         | 1-PE-   |         |         |         | .45.2   |         |         | .5
     | cy-sid  |         |
|         | 2_excl- |         |         |         |         |         |         |
     |         |         |
|         | standby |         |         |         |         |         |         |
     |         |         |
|         | -srlg   |         |         |         |         |         |         |
     |         |         |
| default | pol-PE- | local   |      13 |       3 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2102 |
|         | 1-PE-   |         |         |         | .56.2   |         |         | .6
     | cy-sid  |         |
|         | 2_excl- |         |         |         |         |         |         |
     |         |         |
|         | standby |         |         |         |         |         |         |
     |         |         |
|         | -srlg   |         |         |         |         |         |         |
     |         |         |
| default | pol-PE- | local   |      13 |       4 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2100 |
|         | 1-PE-   |         |         |         | .36.1   |         |         | .3
     | cy-sid  |         |
|         | 2_excl- |         |         |         |         |         |         |
     |         |         |
|         | standby |         |         |         |         |         |         |
     |         |         |
|         | -srlg   |         |         |         |         |         |         |
     |         |         |
| default | pol-PE- | local   |      13 |       5 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2100 |
|         | 1-PE-   |         |         |         | .23.1   |         |         | .2
     | cy-sid  |         |
|         | 2_excl- |         |         |         |         |         |         |
     |         |         |
```

```
|         | standby |         |         |         |         |         |         |         |
     |         |         |
|         | -srlg   |         |         |         |         |         |         |         |
     |         |         |
---snip---
```

The following command shows the CSPF calculated hops in the standby path with segment list 23: over the direct link from PE-1 to destination PE-2.

```
--{ + running }--[  ]--
A:admin@PE-1# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy
* protocol-origin local segment-list 23 computed-segments segment * | as table | filter fields
 *

+---------+---------+---------+---------+---------+---------+---------+---------+---------+----
-----+---------+---------+
| Network | Policy  | Policy  | Segment | Segment |  Hop-   |   Ip-   |   Is-   | Unnumbe |
 Router- |  Sid-   |  Sid-   |
| -instan | policy- | protoco |  -list  | -index  |  type   | address |  loose  | red-if- |
 id    |  type   |  value  |
|   ce    |  name   |   l-    |         |         |         |         |         |   id    |
     |         |  mpls-  |
|         |         | origin  |         |         |         |         |         |         |
     |         |  label  |
+=========+=========+=========+=========+=========+=========+=========+=========+=========+====
=====+=========+=========+
| default | pol-PE- | local   |      23 |       1 | ipv4    | 192.168 | false   |         |
 192.0.2 | adjacen |    2100 |
|         | 1-PE-   |         |         |         | .12.2   |         |         | .2
     | cy-sid  |         |
|         | 2_excl- |         |         |         |         |         |         |         |
     |         |         |
|         | standby |         |         |         |         |         |         |         |
     |         |         |
|         | -srlg   |         |         |         |         |         |         |         |
     |         |         |
---snip---
```

14.4 Conclusion

Interpreting the SRLG information in the TE database makes it possible to protect an LSP even when multiple TE interfaces fail as a result of an underlying transmission failure.

SRLGs can be a constraint for standby or secondary paths of an unconstrained primary path or SRLGs can be a constraint for primary and standby paths where the primary path avoids the SRLG and the standby path computes its segment list so that it avoids the SRLGs used by the primary path.

15 Static MPLS LSPs

This chapter provides information about manually configured static MPLS LSPs.

Topics in this chapter include:

- Applicability
- Overview
- Configuration
- Conclusion

15.1 Applicability

This chapter is applicable to SR Linux 25.7.R1. There are no prerequisites or conditions on the hardware for this configuration.

15.2 Overview

Because of the connectionless nature of the network layer protocol, IP packets travel through the network on a hop-by-hop basis with routing decisions made at each node. As a result, hyper aggregation of data on specific links may occur and it may impact the provider's ability to provide guaranteed service levels across the network end-to-end. To address these shortcomings, Multi-Protocol Label Switching (MPLS) was developed.

MPLS provides the capability to establish connection-oriented paths, called Label Switched Paths (LSPs), over a connectionless (IP) network. The LSP offers a mechanism to engineer network traffic independently from the underlying network routing protocol (mostly IP) to improve the network resiliency and recovery options and to permit delivery of services that are not readily supported by conventional IP routing techniques, such as Layer 2 Virtual Private Networks (VPNs). These benefits are essential for today's communication network explaining the wide deployment base of the MPLS technology.

RFC 3031 specifies the MPLS architecture whereas this chapter describes the configuration and troubleshooting of static MPLS LSPs on SR Linux.

MPLS LSPs can also be dynamically established using a label signaling protocol, such as Label Distribution Protocol (LDP), as described in LDP Point-to-Point LSPs or segment routing, as described in Segment Routing with IS-IS Control Plane and Segment Routing – Traffic Engineered Tunnels.

15.2.1 Packet forwarding

When a packet of a connectionless network layer protocol travels from one router to the next, each router in the network makes an independent forwarding decision by performing the following basic tasks:

1. analyzing the packet header

2. referencing the local routing table to find the longest prefix match based on the destination address in the IP header
3. sending out the packet on the corresponding interface

The first function partitions the entire set of incoming packets into a set of Forwarding Equivalence Classes (FECs). All packets associated to a particular FEC are forwarded along the same path to the same destination. The second function maps each FEC to a next hop destination router. Each router along the path performs these actions.

In MPLS, the assignment of a packet to a particular FEC is done only one time: when the packet enters the network. The FEC is mapped to an LSP, which is established prior to packet forwarding.

An MPLS egress label, representing the FEC to which the packet is assigned, is attached to the packet (push operation) and the labeled packet is forwarded to the next hop router along that LSP path.

At subsequent hops, the packet IP header is not analyzed. Instead, the ingress label is used as an index into a table which specifies the next hop and a new egress label. The ingress label is replaced with the new egress label (swap operation), and the packet is forwarded to the specified next hop.

At the MPLS network egress, the ingress label is removed from the packet (pop operation). If this router is the destination of the packet (based on the remaining packet), the packet is handed to the receiving application, such as a MAC VRF. If this router is not the destination of the packet, the packet is sent into a new MPLS tunnel or forwarded by conventional IP forwarding toward the Layer 3 destination.

15.2.2 Terminology

Figure 39: Generic MPLS network, MPLS label operations

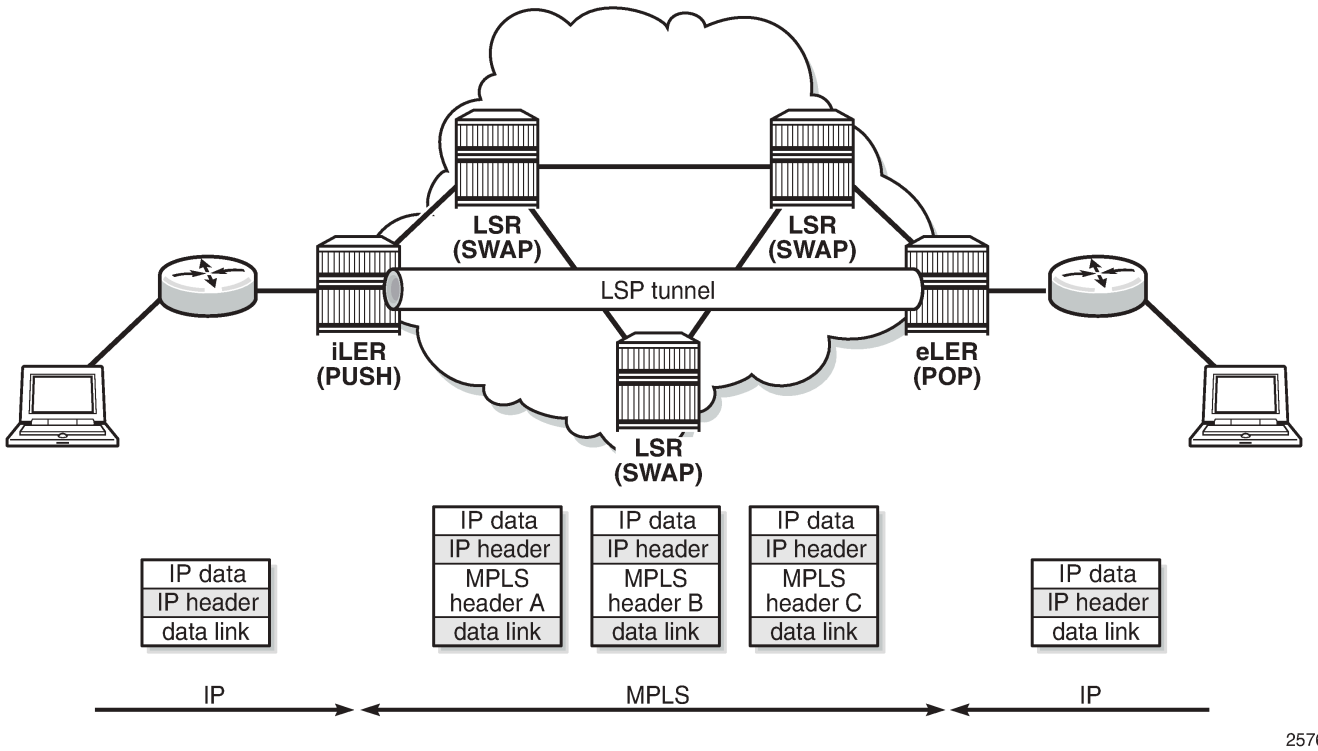


Figure 39: Generic MPLS network, MPLS label operations shows a general network topology clarifying the MPLS-related terms. A Label Edge Router (LER) is a device at the edge of an MPLS network, with at least one interface outside the MPLS domain. A router is usually defined as an LER based on its position relative to a particular LSP:

- The MPLS router at the head-end of an LSP is called the ingress Label Edge Router (ILER)
- The MPLS router at the tail-end of an LSP is called the egress Label Edge Router (ELER)

The ILER receives unlabeled packets from outside the MPLS domain, applies MPLS egress labels to the packets, and forwards the labeled packets into the MPLS domain.

The ELER receives labeled packets from the MPLS domain, removes the ingress labels, and forwards unlabeled packets outside the MPLS domain.

A Label Switching Router (LSR) is a device internal to an MPLS network, with all interfaces inside the MPLS domain. These devices switch labeled packets inside the MPLS domain. In the core of the network, LSRs ignore the packet's IP header and simply forward the packet using the MPLS label swapping mechanism. The last LSR before the ELER can be configured with an implicit null label. This informs that LSR to send MPLS packets without an outer egress label. This is known as Penultimate Hop Popping (PHP).

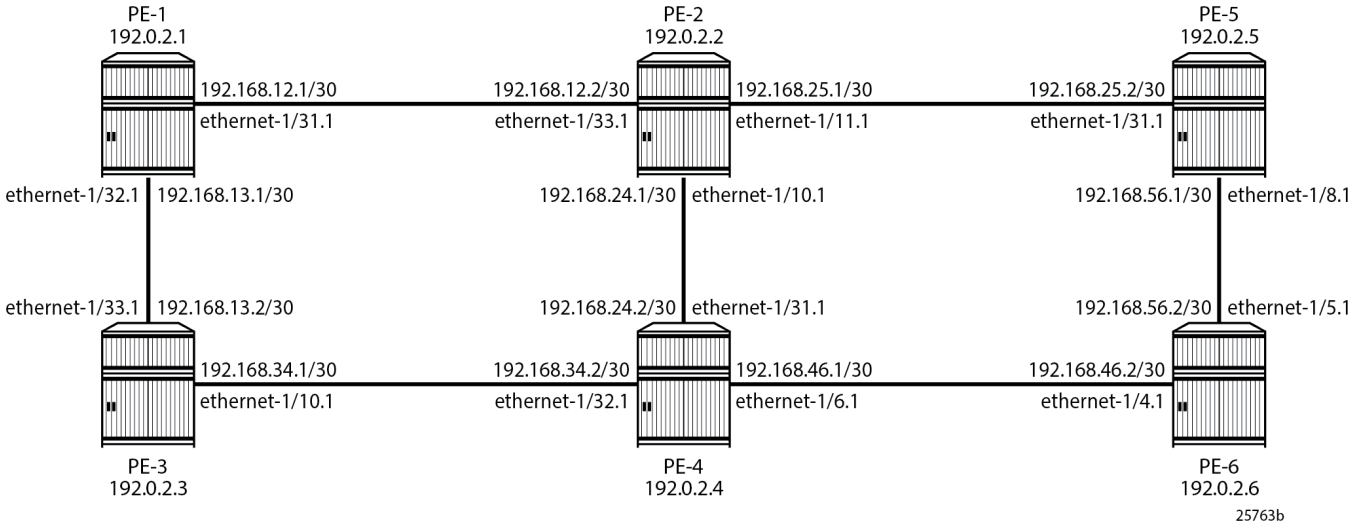
15.2.3 LSP establishment

The LSP must be established before any packets can be forwarded. To set up an LSP, labels need to be distributed for the path. For static LSPs, the label distribution is done manually by the network administrator. Although a high control level of the labels in use is achieved, static LSPs cannot enjoy the resilience and recovery functionality that the dynamic label signaling protocols can offer.

15.2.4 Example topology

Figure 40: MPLS example topology shows the example topology consisting of six SR Linux nodes located in a single autonomous system.

Figure 40: MPLS example topology

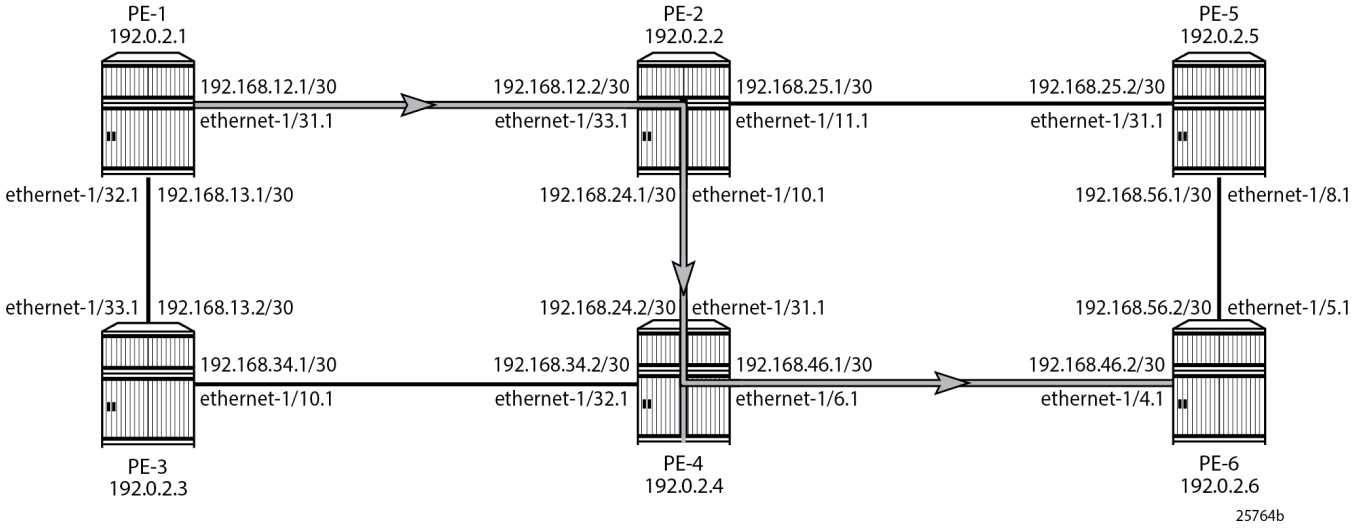


15.3 Configuration

Static LSPs are set up manually. Because they do not use a signaled label distribution protocol, an Interior Gateway Protocol (IGP) is not needed.

As an example, a static LSP is created starting from PE-1 (ILER; egress label 102), running over PE-2 (LSR; egress label 204) and PE-4 (LSR; egress label 406), and terminating on PE-6 (ELER) as shown in Figure 41: Static LSP running over PE-1, PE-2, PE-4, PE-6. A static LSP is also created for the return traffic, starting from PE-6 (ILER; egress label 604), running over PE-4 (LSR; egress label 402) and PE-2 (LSR; egress label 201), and terminating on PE-1 (ELER). For the return traffic, PE-6 becomes the ILER and PE-1 becomes the ELER. This is not explicitly shown further on.

Figure 41: Static LSP running over PE-1, PE-2, PE-4, PE-6



On each PE along the path, configure a static label range for MPLS that contains the chosen labels, as follows:

```
# on PE-1, PE-2, PE-4, PE-6:
enter candidate
    system mpls label-ranges static slb-mpls {
                    start-label 100
                    end-label 699
                    shared false
```

On each PE along the path, configure next hop groups, which define the next hop IP address and egress label that the PE pushes onto egress traffic that belongs to the group. The next hop IP address is the interface address of the next hop along the static path, facing the current node.

For PE-1 (ILER), this results in the following configuration:

```
# on PE-1:
enter candidate
    network-instance default next-hop-groups {
            group g-from-1-to-2 {
                admin-state enable
                nexthop 0 {
                    ip-address 192.168.12.2
                    admin-state enable
                    resolve false
                    pushed-mpls-label-stack [ 102 ]
                }
            }
```

For PE-2 (LSR), this results in the following configuration. The configuration for PE-4 (LSR) is similar.

```
# on PE-2:
enter candidate
    network-instance default next-hop-groups {
            group g-from-2-to-4 {
                admin-state enable
```

```
                nexthop 0 {
                    ip-address 192.168.24.2
                    admin-state enable
                    resolve false
                    pushed-mpls-label-stack [ 204 ]
                }
            }
```

On each PE along the path, configure static MPLS entries, which define the label switching operation on ingress traffic that matches the ingress label. The LSRs perform swap operations on the ingress label and forward the packet to the manually defined next hop. On the LSR on which the incoming packet arrives, the correct ingress label is selected and a swap operation with a new egress label and the new next hop is performed.

For PE-2 (LSR), this results in the following configuration.

```
# on PE-2:
enter candidate
    network-instance default mpls {
            static-label-block slb-mpls
            static-entry 102 preference 100 {
                operation swap
                next-hop-group g-from-2-to-4
            }
```

The configuration for PE-4 (LSR) is similar.

The terminating router performs a pop operation on the ingress label and forwards the now unlabeled packets external to the MPLS domain.

For PE-6 (ELER), this results in the following configuration:

```
# on PE-6:
enter candidate
    network-instance default mpls {
            static-label-block slb-mpls
            static-entry 406 preference 100 {
                operation pop
            }
```

The configuration of the static LSP from PE-6 (ILER) to PE-1 (ELER) via LSRs PE-4 and PE-2 is similar.

15.3.1 Verify the configuration

15.3.1.1 Label range

Verify the applicable label range for use with static configurations for each node, with the following **info from state** command:

```
--{ running }--[  ]--
A:admin@PE-2# info from state with-context / system mpls label-ranges
    system {
        mpls {
            label-ranges {
                static slb-mpls {
                    shared false
                    start-label 100
```

```
                    end-label 699
                    allocated-labels 2
                    free-labels 598
                    status ready
                    user 6 {
                        owner static-mpls
                    }
```

In the example, the label range for static LSPs extends from the value 100 to 699 and contains 600 labels. The allocated labels correspond with the ingress labels that a PE processes for ingress traffic (swap or pop operation). The ingress labels that a PE processes must belong to this PE's label range. On PE-2 (and on PE-4), two labels are allocated: one for ingress traffic in the LSP from PE-1 to PE-6 and one for ingress traffic in the LSP from PE-6 to PE-1. On PE-1, only 1 label is allocated: for the ingress traffic in the LSP from PE-6 to PE-1. On PE-6, only 1 label is allocated: for the ingress traffic in the LSP from PE-1 to PE-6. The allocated labels do not include the labels that a PE generates for egress traffic (push operation). A PE can push any egress label, even if it does not belong to this PE's label range.

15.3.1.2 Static LSPs

Verify the configuration of the static LSPs, with **show** commands, as follows:

PE-2 receives traffic with ingress label 102 (from PE-1) and forwards it to next hop 192.168.24.2 via ethernet-1/10.1, with MPLS encapsulation and egress label 204 (swap operation).

```
--{ running }--[  ]--
A:admin@PE-2# show / network-instance route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+===============
=======+==================+
| 102     | SWAP      | static-mpls | N/A             | 192.168.24.2 (mpls)    | ethernet-1/
10.1      | 204              |
| ---snip---
                           |
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
```

PE-6 receives traffic with ingress label 406 (from PE-4) and processes it locally (pop operation).

```
--{ running }--[  ]--
A:admin@PE-6# show / network-instance route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+===============
=======+==================+
| 406     | POP       | static-mpls | default         |                        |
       |                  |
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
```

PE-2 uses the next hop with index 122836192 to send the traffic to PE-4.

```
--{ running }--[  ]--
A:admin@PE-2# show / network-instance route-table next-hop
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------
Next-hop route table of network instance default
-------------------------------------------------------------------------------------------------------
-------------------------------------------------------
Index             : 3
  Type            : broadcast
  Subinterface    : N/A
  Resolving Route : None (None)
Index             : 122836184
  Type            : extract
  Subinterface    : N/A
  Resolving Route : None (None)
Index             : 122836185
  Next-hop        : 192.168.24.1
  Type            : direct
  Subinterface    : ethernet-1/10.1
Index             : 122836186
  Type            : extract
  Subinterface    : N/A
  Resolving Route : None (None)
Index             : 122836187
  Next-hop        : 192.168.25.1
  Type            : direct
  Subinterface    : ethernet-1/11.1
Index             : 122836188
  Type            : extract
  Subinterface    : N/A
  Resolving Route : None (None)
Index             : 122836189
  Next-hop        : 192.168.12.2
  Type            : direct
  Subinterface    : ethernet-1/33.1
Index             : 122836190
  Type            : extract
  Subinterface    : N/A
  Resolving Route : None (None)
Index             : 122836191
  Next-hop        : 192.168.24.2
  Type            : direct
  Subinterface    : ethernet-1/10.1
Index             : 122836192
  Next-hop        : 192.168.24.2
  Type            : mpls
  MPLS label stack: [204]
Index             : 122836193
  Next-hop        : 192.168.12.1
  Type            : direct
  Subinterface    : ethernet-1/33.1
Index             : 122836194
  Next-hop        : 192.168.12.1
  Type            : mpls
  MPLS label stack: [201]
```

PE-6 has no egress traffic in the MPLS network.

The same information, with more detail, can be obtained, with **info from state** commands, as follows:

PE-2 forwards traffic with ingress label 102 (from PE-1) using next hop group g-from-2-to-4, which has group-id 122836209.

```
--{ running }--[  ]--
A:admin@PE-2# info from state with-context / network-instance default mpls
    network-instance default {
        mpls {
            icmp-tunneling false
            static-label-block slb-mpls
            static-label-block-status available
            static-entry 102 preference 100 {
                admin-state enable
                operation swap
                installed true
                next-hop-group g-from-2-to-4
                resolved-next-hop-group-id 122836209
            }
```

```
--{ running }--[  ]--
A:admin@PE-2# info from state with-context / network-instance default route-table mpls
    network-instance default {
        route-table {
            mpls {
                label-entry 102 {
                    operation swap
                    entry-type static-mpls
                    last-app-update "2025-07-29T15:32:21.080Z (3 minutes ago)"
                    next-hop-group 122836209
                    fib-programming {
                        last-successful-operation-type add
                        last-successful-operation-timestamp "2025-07-29T15:32:21.080Z (3
 minutes ago)"
                        pending-operation-type none
                        last-failed-operation-type none
                    }
                }
                ---snip---
                statistics {
                    active-entries 2
                }
```

Next hop group g-from-2-to-4 uses next hop 122836192 to send the egress traffic.

```
--{ running }--[  ]--
A:admin@PE-2# info from state with-context / network-instance default route-table next-hop-
group *
    network-instance default {
        route-table {
            ---snip---
            next-hop-group 122836209 {
                group-name-alias g-from-2-to-4
                backup-next-hop-group 0
                backup-active false
                fib-programming {
                    last-successful-operation-type add
                    last-successful-operation-timestamp "2025-07-29T15:32:20.595Z (3 minutes
 ago)"
                    pending-operation-type none
                    last-failed-operation-type none
                }
                next-hop 0 {
                    next-hop 122836192
```

```
                    resolved not-applicable
                    resource-allocation-failed false
                }
```

PE-2 encapsulates the egress traffic as MPLS traffic with egress label 204 and sends it via next hop 122836192 to the IP address 192.168.24.2 of PE-4 via subinterface ethernet-1/10.1 on PE-2.

```
--{ running }--[  ]--
A:admin@PE-2# info from state with-context / network-instance default route-table next-hop *
    network-instance default {
        route-table {
            ---snip---
            next-hop 122836192 {
                resource-allocation-failed false
                type mpls
                ip-address 192.168.24.2
                subinterface ethernet-1/10.1
                mpls-encapsulation {
                    entropy-label-transmit false
                    pushed-mpls-label-stack [
                        204
                    ]
                }
```

15.3.2 Verify the operation

Verify the operation of the static LSPs with **ping** or **traceroute** from PE-1 to PE-6.

On PE-1, configure a static route to PE-6 that makes use of the LSP, as follows:

```
# on PE-1:
enter candidate
    network-instance default static-routes {
            admin-state enable
            route 192.0.2.6/32 {
                admin-state enable
                next-hop-group g-from-1-to-2
            }
```

On PE-6, configure a static route to PE-1 that makes use of a return LSP that is needed for the return traffic (not shown).

The IPv4 unicast route table on PE-1 has an additional entry (type **static**) for prefix 192.0.2.6/32 to PE-6, indicating that traffic to this prefix is sent with MPLS encapsulation to next hop 192.168.12.2 via subinterface ethernet-1/31.1 on PE-1. The IPv4 unicast route table on PE-6 has a similar additional entry for prefix 192.0.2.1 to PE-1.

```
--{ running }--[  ]--
A:admin@PE-1# show / network-instance default ipv4-unicast prefix
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------
-----------------------------------------------------
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
|     Prefix      |  ID  |   Route   |    Route Owner     | Active  | Origin  | Metric |   Pref
    | Next-hop  | Next-hop  |  Backup   |  Backup   |
```

```
|                 |      |   Type    |                    |         | Network |        |
    |  (Type)   | Interface | Next-hop  | Next-hop  |
|                 |      |           |                    |         | Instanc |        |
    |           |          |  (Type)   | Interface |
|                 |      |           |                    |         |    e    |        |
    |           |          |           |           |
+=================+======+===========+====================+=========+=========+========+=======
====+===========+===========+===========+===========+
| 192.0.2.1/32    | 18   | host      | net_inst_mgr       | True    | default | 0      | 0
    | None      | None      |           |           |
| 192.0.2.6/32    | 0    | static    | static_route_mgr   | True    | default | 1      | 5
    | 192.168.1 | ethernet- |           |           |
|                 |      |           |                    |         |         |        |
    | 2.2       | 1/31.1    |           |           |
|                 |      |           |                    |         |         |        |
    | (mpls)    |          |           |           |
| ---snip---
                                                  |
+-----------------+------+-----------+--------------------+---------+---------+--------+-------
----+-----------+-----------+-----------+-----------+
```

The **ping** from PE-1 to PE-6 succeeds:

```
# on PE-1:
enter running
    ping 192.0.2.6 network-instance default -c 7 -I 192.0.2.1 -4

Using network instance default
PING 192.0.2.6 (192.0.2.6) from 192.0.2.1 : 56(84) bytes of data.
64 bytes from 192.0.2.6: icmp_seq=1 ttl=64 time=3.64 ms
64 bytes from 192.0.2.6: icmp_seq=2 ttl=64 time=3.19 ms
64 bytes from 192.0.2.6: icmp_seq=3 ttl=64 time=4.95 ms
64 bytes from 192.0.2.6: icmp_seq=4 ttl=64 time=4.95 ms
64 bytes from 192.0.2.6: icmp_seq=5 ttl=64 time=3.18 ms
64 bytes from 192.0.2.6: icmp_seq=6 ttl=64 time=4.07 ms
64 bytes from 192.0.2.6: icmp_seq=7 ttl=64 time=3.20 ms

--- 192.0.2.6 ping statistics ---
7 packets transmitted, 7 received, 0% packet loss, time 6008ms
rtt min/avg/max/mdev = 3.180/3.882/4.953/0.738 ms
```

The output of the **traceroute** from PE-1 to PE-6 indicates that the traffic reaches the destination via three hops. The intermediate hops are not identified, because they do not have a route to PE-1.

```
# on PE-1:
enter running
    traceroute 192.0.2.6 network-instance default -s 192.0.2.1 -n

Using network instance default
traceroute to 192.0.2.6 (192.0.2.6), 30 hops max, 60 byte packets
 1  * * *
 2  * * *
 3  192.0.2.6  3.336 ms  4.311 ms  4.297 ms
```

When static routes are also defined on the LSRs for return traffic to PE-1, the intermediate hops are identified as PE-2 and PE-4.

```
# on PE-1:
enter running
    traceroute 192.0.2.6 network-instance default -s 192.0.2.1 -n
```

```
Using network instance default
traceroute to 192.0.2.6 (192.0.2.6), 30 hops max, 60 byte packets
 1  192.168.12.2  2.687 ms  2.661 ms  2.649 ms
 2  192.168.24.2  2.635 ms  2.621 ms  2.609 ms
 3  192.0.2.6  3.531 ms  3.522 ms  3.509 ms
```

15.3.3 Penultimate Hop Popping

Penultimate Hop Popping (PHP) can be used with static LSPs. This is achieved by configuring the last LSR (PE-4) before the ELER (PE-6) to swap the ingress label to IMPLICIT_NULL instead of a specific egress label value.

```
# on PE-4:
enter candidate
    network-instance default next-hop-groups {
            group g-from-4-to-6 {
                nexthop 0 {
                    pushed-mpls-label-stack [ IMPLICIT_NULL ]
                }
            }
```

The previous configuration causes PE-4 to pop the top label from the incoming labeled frame received from PE-2 and send it to PE-6 without adding another outer label. The IMPLICIT_NULL egress label is not actually pushed onto a frame.

Prior to the configuration of PHP, the egress label on PE-4 is 406.

```
--{ running }--[  ]--
A:admin@PE-4# show / network-instance route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+===============
=======+==================+
| 204     | SWAP      | static-mpls | N/A             | 192.168.46.2 (mpls)    | ethernet-1/6.1
       | 406              |
| ---snip---
                           |
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
```

When PHP is configured on PE-4, the egress label on PE-4 is IMPLICIT_NULL.

```
--{ running }--[  ]--
A:admin@PE-4# show / network-instance route-table mpls
+---------+-----------+-------------+-----------------+------------------------+---------------
-------+------------------+
| Label   | Operation | Type        | Next Net-Inst   | Next-hop IP (Type)     | Next-hop
       | Next-hop MPLS    |
|         |           |             |                 |                        | Subinterface
       | labels           |
+=========+===========+=============+=================+========================+===============
=======+==================+
| 204     | SWAP      | static-mpls | N/A             | 192.168.46.2 (mpls)    | ethernet-1/6.1
       | IMPLICIT_NULL    |
```

```
| ---snip---
                          |
+---------+-----------+-------------+-----------------+-----------------------+--------------
-------+------------------+
```

If the traffic arriving at PE-4 was IP with a single label, then it would arrive at PE-6 as unlabeled IP traffic.

If the static LSP spans a single hop, for example from PE-1 to PE-2, the ILER PE-1 pushes the IMPLICIT_NULL instead of a label. The configuration on PE-1 is as follows:

```
# on PE-1:
enter candidate
    network-instance default {
        next-hop-groups {
            group g-from-1-to-2-php {
                admin-state enable
                nexthop 0 {
                    ip-address 192.168.12.2
                    admin-state enable
                    resolve false
                    pushed-mpls-label-stack [ IMPLICIT_NULL ]
                }
            }
        }
        static-routes {
            admin-state enable
            route 192.0.2.2/32 {
                admin-state enable
                next-hop-group g-from-1-to-2-php
            }
        }
```

```
--{ + running }--[  ]--
A:admin@PE-1# show / network-instance default route-table ipv4-unicast prefix 192.0.2.2/32
 detail
-------------------------------------------------------------------------------------------------
---------
IPv4 unicast route table of network instance default
-------------------------------------------------------------------------------------------------
---------
Destination            : 192.0.2.2/32
ID                     : 0
Route Type             : static
Route Owner            : static_route_mgr
Origin Network Instance: default
Metric                 : 1
Preference             : 5
Active                 : true
Last change            : 2026-03-04T07:46:30.527Z
Resilient hash         : false
-------------------------------------------------------------------------------------------------
---------
Next hops: 1 entries
192.168.12.2 (mpls) via [ethernet-1/2.1]
    pushed MPLS labels : [IMPLICIT_NULL]
Backup Next hops: 0 entries
---snip---
-------------------------------------------------------------------------------------------------
---------
```

In this case, no MPLS operation (swap or pop) is required for this LSP on PE-2.

15.4 Conclusion

MPLS provides the capability to establish connection-oriented paths over a connectionless network. The static LSP offers a mechanism to engineer network traffic. This chapter describes the configuration of static LSPs and the associated show output which can be used to verify and troubleshoot.

16 Uncolored SR-MPLS TE policies with local CSPF path computation

This chapter describes the uncolored SR-MPLS TE policies with local CSPF path computation.

Topics in this chapter include:

16.1 Applicability

The configuration in this chapter is based on SRL Release 25.10.R2.

16.2 Overview

Segment Routing with Traffic Engineering Label Switched Paths (SR-TE LSPs) in SR Linux are implemented as uncolored SR-MPLS TE policies whose segment lists can be computed using:

- hop-to-label (IP-to-label) translation
- Path Computation Element (PCE) path computation
- local Constrained Shortest Path First (CSPF) computation

16.2.1 Hop-to-label path computation

Segment lists in an uncolored SR-MPLS TE policy use hop-to-label translation as the default computation method. The Path Computation Client (PCC) interrogates the TE database, and translates any hop configured in the applied path statement to a Node SID (N-SID) or Adjacency SID (A-SID), to produce a list of segment IDs. Strict hops are mapped to adjacency SIDs; loose hops are mapped to node SIDs. The destination address in the LSP configuration implies a final loose hop.

16.2.2 PCE path computation

Segment list computation can also be performed using an external PCE controller. In this case, the PCC maintains a Path Computation Element Protocol (PCEP) session with the PCE and the path computation is done as follows:

- the PCC sends a PCReq requesting a path
- the PCE replies with a PCReply including a path (if available). This path contains a segment list.

- Optionally, the PCC sends a path status report (PCRpt) to the PCE. However, the PCC may also delegate the control of the path to the PCE.

PCE path computation is beyond the scope of this chapter.

16.2.3 Local CSPF path computation

Segment lists in an uncolored SR-MPLS TE policy can be computed using local CSPF in single-level IS-IS IGP instances. More complex SR-TE LSP path computations, or when the network is expanded into multiple IGP areas or instances, require an external PCE.

SR-TE does not require each router on the path to be TE enabled: the links do not have to be TE links. Provided that the routers at both ends of each link are SR enabled, local CSPF computes an end-to-end path.

Full CSPF path computation on the head-end router (PCC) results in a full explicit path to the destination. The PCC computes an end-to-end path and the following applies:

- The computed path is a full explicit TE path.
- Each link is represented by an adjacency SID or adjacency set SID.
- CSPF returns a label stack list of adjacency SIDs or adjacency set SIDs.

For local CSPF, a TE-policy segment list can be resignaled when a timer expires, when an operator issues a command, or in case of IGP events.

Paths computed by local CSPF contain an adjacency SID for each link in the path and the stack may contain numerous labels. When a **network-instance traffic-engineering-policies policy segment-list dynamic path-algorithm local-cspf te-constraints segment-depth** value exceeds the computed LSP label stack size or the maximum segment depth of a downstream router is lower than the computed LSP label stack size, the label stack can be reduced. The label stack reduction capability can replace a series of adjacency SIDs with a node SID. For loose-hop path computation, node SIDs or a combination of node and adjacency SIDs can be used.

Local CSPF is supported on primary, standby, and secondary segment lists of an uncolored SR-MPLS TE policy.

16.2.3.1 Local CSPF path computation and SR protected interfaces

When SR is enabled and IGP adjacency is established over a link, the router advertises an adjacency SID in the adjacency SID sub-TLV. When Loop-Free Alternate (LFA), Remote LFA (RLFA), or Topology-Independent LFA (TI-LFA) is enabled, protected adjacencies have the backup flag set in the adjacency SID sub-TLV. Each adjacency is available for SID protection when LFA, RLFA, or TI-LFA is enabled.

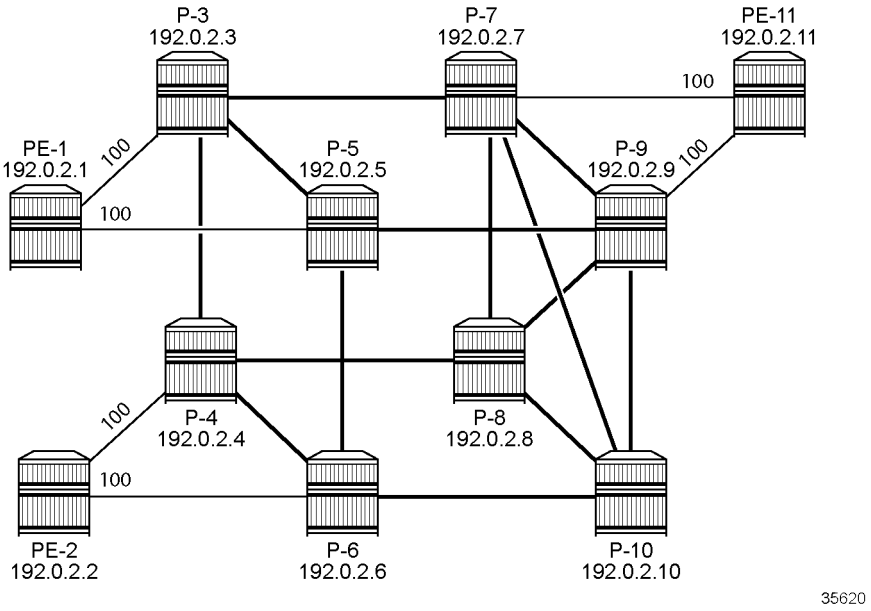
Local CSPF path compution can set up a path that:

- only includes protected adjacencies (**local-sr-protection mandated**)
- only includes unprotected adjacencies (**local-sr-protection none**)
- can include both protected and unprotected adjacencies (**local-sr-protection preferred** (default))

16.3 Configuration

Figure 42: Example topology shows the example topology.

Figure 42: Example topology



The initial configuration on each of the nodes includes:

- Cards, MDAs, ports
- Router interfaces
- IS-IS enabled on all router interfaces
  - The interfaces in the core (between P-3, P-4, P-5, P-6, P-7, P-8, P-9, and P-10) have metric 10.
  - The access interfaces to and from PE-1, PE-2, and PE-11 have metric 100.

On PE-2, the initial IS-IS configuration is as follows:

```
# on PE-2:
    network-instance default {
        admin-state enable
        router-id 192.0.2.2
        interface ethernet-1/4.1 {                  # interface to P-4
        }
        interface ethernet-1/6.1 {                  # interface to P-6
        }
        interface system0.0 {
        }
        protocols {
            isis {
                instance 0 {
                    admin-state enable
                    level-capability L2             # single-level IS-IS instance
                    net [
```

```
                    49.0000.1920.0000.2002.00
                ]
                interface ethernet-1/4.1 {
                    admin-state enable
                    circuit-type point-to-point
                    level 2 {
                        metric 100
                    }
                }
                interface ethernet-1/6.1 {
                    admin-state enable
                    circuit-type point-to-point
                    level 2 {
                        metric 100
                    }
                }
                interface system0.0 {
                }
                level 2 {
                }
            }
        }
    }
```

For segment routing, label ranges must be defined for the node SIDs and adjacency SIDs. For an in-depth description of the configuration of SR-ISIS, see the Segment Routing with IS-IS Control Plane chapter. On all nodes, the following MPLS label ranges are configured:

```
# on all nodes:
    system {
        mpls {
            label-ranges {
                static srgb-static-mpls {         # for protocol-independent node SIDs
                    shared true
                    start-label 10000
                    end-label 10999
                }
                dynamic srlb-dynamic-mpls {       # for dynamic adjacency SIDs
                    start-label 525000
                    end-label 525999
                }
```

On PE-2, segment routing is configured as follows:

```
# on PE-2:
    network-instance default {
         protocols {
            isis {
                dynamic-label-block srlb-dynamic-mpls        # label range for dynamic adj SIDs
                instance 0 {
                    segment-routing {
                        mpls {
                            dynamic-adjacency-sids {
                                all-interfaces true
                            }
                        }
                    }
                }
            }
        }
        segment-routing {
            mpls {
```

```
                global-block {
                    label-range srgb-static-mpls    # label range for node SIDs
                }
                local-prefix-sid 1 {                # protocol-independent SID
                    interface system0.0
                    ipv4-label-index 2              # index 2 on PE-2, 3 on P-3, 4 on P-4...
                    node-sid true
                }
```

With this configuration, the node SID on PE-2 is 10000 + index 2 = 10002. The configuration is similar on the other nodes.

Traffic engineering is enabled on head-end nodes only: PE-2 and PE-11. In this chapter, only the uncolored SR-MPLS TE policies that originate in PE-2 are shown. The corresponding TE policies in the opposite direction are not included. The TE configuration on PE-2 as follows:

```
# on PE-2:
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    te-database-install {
                    }
                    traffic-engineering {
                        advertisement true
                        legacy-link-attribute-advertisement false
                        ipv4-te-router-id 192.0.2.2
                    }
                }
            }
        }
        traffic-engineering {
            ipv4-te-router-id 192.0.2.2
            interface ethernet-1/4.1 {
                interface-ref {
                    interface ethernet-1/4
                    subinterface 1
                }
            }
            interface ethernet-1/6.1 {
                interface-ref {
                    interface ethernet-1/6
                    subinterface 1
                }
            }
        }
```

On PE-2, the following SR-TE LSPs are configured toward PE-11:

- uncolored SR-MPLS TE policy without explicit path and:
  - hop-to-label path computation
  - local CSPF path computation without label stack reduction
  - local CSPF path computation with label stack reduction
- uncolored SR-MPLS TE policy with path with two strict hops—P-4 and P-3—and:
  - hop-to-label path computation
  - local CSPF path computation without label stack reduction
  - local CSPF path computation with label stack reduction

- uncolored SR-MPLS TE policy with path with two loose hops—P-3 and P-9—and:
  - hop-to-label path computation
  - local CSPF path computation without label stack reduction
  - local CSPF path computation with label stack reduction

16.3.1 SR-TE LSPs without explicit path

The configuration of SR-TE LSPs is described in the Segment Routing – Traffic Engineered Tunnels chapter. On PE-2, the following SR-TE LSPs toward PE-11 are configured without explicit path. The path computation method is hop-to-label for the first uncolored SR-MPLS TE policy and local CSPF for the second TE policy. TE policy "LSP_no-expl-path_CSPF_no-LSR" has no label stack reduction, so the segment list contains only adjacency SIDs.

```
# on PE-2:
    network-instance default
        traffic-engineering-policies {
            policy "LSP_no-expl-path_no-dynamic" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 1 {        # no dynamic context in segment-list 1
                    admin-state enable
                    segment-list-type primary
                }
            }
            policy "LSP_no-expl-path_CSPF_no-LSR" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 3 {       # or segment-list 1 (the numbering can start from 1)
                    admin-state enable
                    segment-list-type primary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            label-stack-reduction false     # only adjacency SIDs
                        }
                    }
                }
            }
```

With hop-to-label path computation, the destination 192.0.2.11 is an implied loose hop to be mapped to the node SID 10011 of the destination PE-11, as follows:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 1 computed-segments segment *
 | as table | filter fields *

+---------------------------------------+---------------------------------------+------------
------------+-------------+---------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+----------------+------
----------------+
|            Network-instance           |           Policy policy-name          | Policy
 protocol-origin | Segment-list | Segment-index | Hop-type |               Ip-address
      | Is-loose | Unnumbered-if-id |               Router-id               |    Sid-type    |
 Sid-value mpls-label |
```

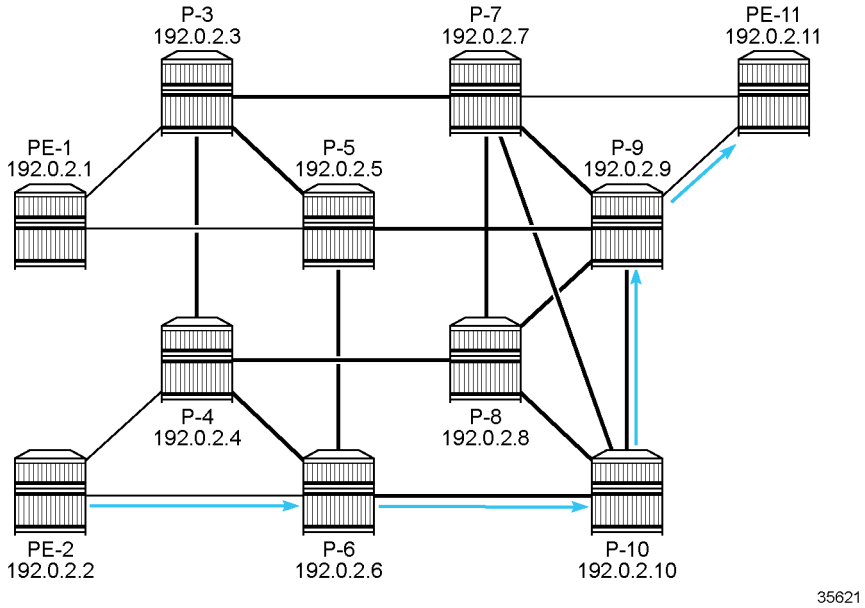
```
+=======================================+=======================================+===========
===========+=============+==============+==========+=======================================
+==========+=================+=======================================+===============+======
================+
| default                               | LSP_no-expl-path_no-dynamic           | local
           |           1 |            1 | ipv4     | 192.0.2.11
 | true     |                | 192.0.2.11                            | node-sid      |
          10011 |
+---------------------------------------+---------------------------------------+-----------
-----------+-------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+---------------+------
---------------+
```

With local CSPF path computation, the SR-TE path contains contiguous strict hops with A-SIDs. Several equal cost paths are available and, in this case, the path goes from PE-2 via P-6, P-10, and P-9 to the destination PE-11, as follows:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 3 computed-segments segment *
 | as table | filter fields *

+---------------------------------------+---------------------------------------+-----------
-----------+-------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+---------------+------
---------------+
|            Network-instance           |           Policy policy-name          | Policy
 protocol-origin | Segment-list | Segment-index | Hop-type |              Ip-address
      | Is-loose | Unnumbered-if-id |              Router-id               |    Sid-type    |
 Sid-value mpls-label |
+=======================================+=======================================+===========
===========+=============+==============+==========+=======================================
+==========+=================+=======================================+===============+======
================+
| default                               | LSP_no-expl-path_CSPF_no-LSR          | local
           |           3 |            1 | ipv4     | 192.168.26.2
 | false    |                | 192.0.2.6                             | adjacency-sid  |
          525001 |
| default                               | LSP_no-expl-path_CSPF_no-LSR          | local
           |           3 |            2 | ipv4     | 192.168.106.2
 | false    |                | 192.0.2.10                            | adjacency-sid  |
          525000 |
| default                               | LSP_no-expl-path_CSPF_no-LSR          | local
           |           3 |            3 | ipv4     | 192.168.109.1
 | false    |                | 192.0.2.9                             | adjacency-sid  |
          525003 |
| default                               | LSP_no-expl-path_CSPF_no-LSR          | local
           |           3 |            4 | ipv4     | 192.168.119.2
 | false    |                | 192.0.2.11                            | adjacency-sid  |
          525001 |
+---------------------------------------+---------------------------------------+-----------
-----------+-------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+---------------+------
---------------+
```

The path is shown in Figure 43: Local CSFP computed path from PE-2 to PE-11 without explicit path constraint.

Figure 43: Local CSFP computed path from PE-2 to PE-11 without explicit path constraint



The label stack of Adjacency SIDs (A-SIDs) is reduced to a smaller number of Node SIDs (N-SIDs), or a combination of N-SIDs and A-SIDs, when **label-stack-reduction** is enabled (which is the default setting), as follows:

```
network-instance default
    traffic-engineering-policies {
        policy "LSP_no-expl-path_CSPF_LSR" {        ## LSR = label stack reduction
            policy-type sr-mpls-uncolored
            admin-state enable
            endpoint 192.0.2.11
            segment-list 2 {
                admin-state enable
                segment-list-type primary
                dynamic {
                    path-algorithm local-cspf
                    te-constraints {
                        label-stack-reduction true     # default
                    }
                }
            }
        }
```

Label stack reduction reduces the label stack to one or more node SIDs, with each segment delimited by configured path hops. The path computed to the node SID must satisfy any required path constraints. In this example, the only restriction is the loose hop of the destination PE-11, so the label stack is reduced to the N-SID of PE-11, as follows:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 2 computed-segments segment *
 | as table | filter fields *
```

```
+---------------------------------------+---------------------------------------+-----------
-----------+-------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+----------------+------
---------------+
|            Network-instance           |           Policy policy-name          | Policy
 protocol-origin | Segment-list | Segment-index | Hop-type |              Ip-address
      | Is-loose | Unnumbered-if-id |               Router-id               |    Sid-type    |
 Sid-value mpls-label |
+=======================================+=======================================+===========
===========+=============+==============+==========+=======================================
+==========+=================+=======================================+================+======
================+
| default                               | LSP_no-expl-path_CSPF_LSR             | local
            |           2 |            1 | ipv4     | 192.0.2.11
 | true     |                 | 192.0.2.11                            | node-sid       |
          10011 |
+---------------------------------------+---------------------------------------+-----------
-----------+-------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+----------------+------
----------------+
```

16.3.2 SR-TE LSPs using path with strict hops

In the following example, the SR-TE LSP path includes strict hops—that must be contiguous hops from the head-end router—and an implicit loose hop to the destination 192.0.2.11. The SR-TE LSPs on PE-2 are configured as follows:

```
# on PE-2:
    network-instance default
        traffic-engineering-policies {
            explicit-paths {
                path path-via-P-4-P-3_S {
                    hop 10 {
                        ip {
                            ip-address 192.0.2.4
                            hop-type strict
                        }
                    }
                    hop 20 {
                        ip {
                            ip-address 192.0.2.3
                            hop-type strict
                        }
                    }
                }
            }
            policy "LSP_w-strict-hops_no-dynamic" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 11 {
                    admin-state enable
                    explicit-path path-via-P-4-P-3_S
                    segment-list-type primary
                }
            }
            policy "LSP_w-strict-hops_CSPF_no-LSR" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 13 {
```

```
                admin-state enable
                explicit-path path-via-P-4-P-3_S
                segment-list-type primary
                dynamic {
                    path-algorithm local-cspf
                    te-constraints {
                        label-stack-reduction false     # only A-SIDs
                    }
                }
            }
        }
```

With hop-to-label path computation, strict hops are translated into adjacency SIDs, whereas loose hops are translated into node SIDs. In this example, the path has an A-SID to P-4 and an A-SID to P-3 followed by an N-SID to the destination PE-11, as follows:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 11 computed-segments segment
 * | as table | filter fields *

+---------------------------------------+---------------------------------------+------------
------------+-------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+---------------+------
----------------+
|            Network-instance           |           Policy policy-name          | Policy
 protocol-origin | Segment-list | Segment-index | Hop-type |              Ip-address
      | Is-loose | Unnumbered-if-id |              Router-id               |    Sid-type    |
 Sid-value mpls-label |
+=======================================+=======================================+============
============+=============+==============+==========+=======================================
+==========+=================+=======================================+===============+======
================+
| default                               | LSP_w-strict-hops_no-dynamic          | local
            |          11 |            1 | ipv4     | 192.168.24.2
 | false    |                 | 192.0.2.4                             | adjacency-sid  |
         525000 |
| default                               | LSP_w-strict-hops_no-dynamic          | local
            |          11 |            2 | ipv4     | 192.168.34.1
 | false    |                 | 192.0.2.3                             | adjacency-sid  |
         525001 |
| default                               | LSP_w-strict-hops_no-dynamic          | local
            |          11 |            3 | ipv4     | 192.0.2.11
 | true     |                 | 192.0.2.11                            | node-sid       |
          10011 |
+---------------------------------------+---------------------------------------+------------
------------+-------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+---------------+------
----------------+
```

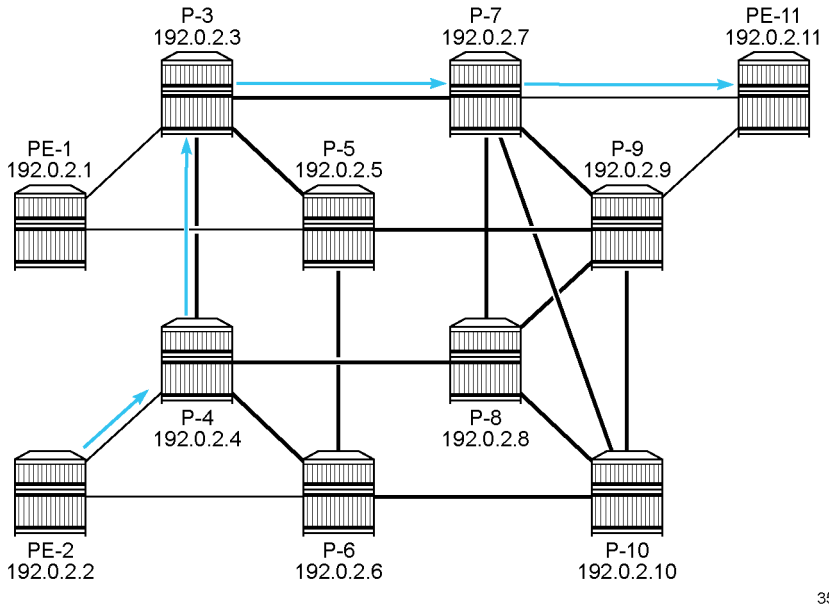
With local CSPF path computation, the path is a sequence of A-SIDs, as follows:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 13 computed-segments segment
 * | as table | filter fields *

+---------------------------------------+---------------------------------------+------------
------------+-------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+---------------+------
----------------+
```

```
|            Network-instance            |          Policy policy-name          | Policy
 protocol-origin | Segment-list | Segment-index | Hop-type |              Ip-address
      | Is-loose | Unnumbered-if-id |              Router-id               |    Sid-type    |
 Sid-value mpls-label |
+========================================+======================================+============
============+=============+==============+==========+======================================
+==========+=================+======================================+===============+======
================+
| default                                | LSP_w-strict-hops_CSPF_no-LSR        | local
            |           13 |            1 | ipv4     | 192.168.24.2
 | false    |                | 192.0.2.4                                | adjacency-sid  |
          525000 |
| default                                | LSP_w-strict-hops_CSPF_no-LSR        | local
            |           13 |            2 | ipv4     | 192.168.34.1
 | false    |                | 192.0.2.3                                | adjacency-sid  |
          525001 |
| default                                | LSP_w-strict-hops_CSPF_no-LSR        | local
            |           13 |            3 | ipv4     | 192.168.37.2
 | false    |                | 192.0.2.7                                | adjacency-sid  |
          525003 |
| default                                | LSP_w-strict-hops_CSPF_no-LSR        | local
            |           13 |            4 | ipv4     | 192.168.117.2
 | false    |                | 192.0.2.11                               | adjacency-sid  |
          525001 |
+----------------------------------------+--------------------------------------+------------
------------+-------------+--------------+----------+--------------------------------------
+----------+-----------------+--------------------------------------+---------------+------
---------------+
```

The path from PE-2 to PE-11 must go via P-4 and P-3. The loose hop from P-3 to the destination PE-11 is translated into an A-SID to P-7 followed by an A-SID to PE-11, as shown in Figure 44: Path from PE-2 to PE-11 via strict hops P-4 and P-3.

Figure 44: Path from PE-2 to PE-11 via strict hops P-4 and P-3



With label stack reduction, the configuration of the SR-TE LSP is as follows:

```
# on PE-2:
    network-instance default
        traffic-engineering-policies {
            policy "LSP_w-strict-hops_CSPF_LSR" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 12 {
                    admin-state enable
                    explicit-path path-via-P-4-P-3_S
                    segment-list-type primary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            label-stack-reduction true     # default
                        }
                    }
                }
            }
```

Label stack reduction reduces the label stack to one or more node SIDs, with each segment delimited by configured path hops. The computed path to the node SID must satisfy any required path constraints. The computed path from PE-2 to PE-11 via the strict hops P-4 and P-3 shows a series of N-SIDs, as follows:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 12 computed-segments segment
 * | as table | filter fields ip-address router-id is-loose sid-type sid-value/mpls-label

+-----------------------------------------------+-----------------------------------------------
-+-------------------------+--------------+---------------+-----------------------------------
----------+-----------------------------------------------+----------+----------------+--------
--------------+
|              Network-instance                 |              Policy policy-name
  | Policy protocol-origin | Segment-list | Segment-index |                  Ip-address
           |                  Router-id                   | Is-loose |    Sid-type    | Sid-
value mpls-label |
+===============================================+===============================================
=+=========================+==============+===============+===================================
==========+===============================================+==========+================+========
==============+
| default                                       | LSP_w-strict-hops_CSPF_LSR
 | local                  |          12 |             1 | 192.0.2.4
          | 192.0.2.4                                     | true     | node-sid       |
        10004 |
| default                                       | LSP_w-strict-hops_CSPF_LSR
 | local                  |          12 |             2 | 192.0.2.3
          | 192.0.2.3                                     | true     | node-sid       |
        10003 |
| default                                       | LSP_w-strict-hops_CSPF_LSR
 | local                  |          12 |             3 | 192.0.2.11
          | 192.0.2.11                                    | true     | node-sid       |
        10011 |
+-----------------------------------------------+-----------------------------------------------
-+-------------------------+--------------+---------------+-----------------------------------
----------+-----------------------------------------------+----------+----------------+--------
--------------+
```

16.3.3 SR-TE LSPs using path with loose hops

The following uncolored SR-MPLS TE policies on PE-2 toward PE-11 use an explicit path with loose hops P-3 and P-9:

```
# on PE-2:
    network-instance default
        traffic-engineering-policies {
            explicit-paths {
                path path-via-P-3-P-9_L {
                    hop 10 {
                        ip {
                            ip-address 192.0.2.3
                            hop-type loose
                        }
                    }
                    hop 20 {
                        ip {
                            ip-address 192.0.2.9
                            hop-type loose
                        }
                    }
                }
            }
            policy "LSP_w-loose-hops_no-dynamic" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 21 {
                    admin-state enable
                    explicit-path path-via-P-3-P-9_L
                    segment-list-type primary
                }
            }
            policy "LSP_w-loose-hops_CSPF_no-LSR" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 23 {
                    admin-state enable
                    explicit-path path-via-P-3-P-9_L
                    segment-list-type primary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            label-stack-reduction false     # only A-SIDs
                        }
                    }
                }
            }
```

With hop-to-label path compution, loose hops are translated into N-SIDs. In this example, the actual hops are the N-SIDs of P-3, P-9, and PE-11, as follows:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 21 computed-segments segment
 * | as table | filter fields *

+---------------------------------------+---------------------------------------+------------
------------+-------------+---------------+----------+---------------------------------------
```

```
+----------+-----------------+---------------------------------------+---------------+------
---------------+
|            Network-instance            |           Policy policy-name           | Policy
 protocol-origin | Segment-list | Segment-index | Hop-type |               Ip-address
      | Is-loose | Unnumbered-if-id |               Router-id               |    Sid-type    |
 Sid-value mpls-label |
+========================================+=======================================+============
============+==============+==============+==========+=======================================
+==========+=================+=======================================+===============+======
================+
| default                                | LSP_w-loose-hops_no-dynamic           | local
             |          21 |            1 | ipv4     | 192.0.2.3
 | true     |                | 192.0.2.3                             | node-sid       |
          10003 |
| default                                | LSP_w-loose-hops_no-dynamic           | local
             |          21 |            2 | ipv4     | 192.0.2.9
 | true     |                | 192.0.2.9                             | node-sid       |
          10009 |
| default                                | LSP_w-loose-hops_no-dynamic           | local
             |          21 |            3 | ipv4     | 192.0.2.11
 | true     |                | 192.0.2.11                            | node-sid       |
          10011 |
+----------------------------------------+---------------------------------------+------------
------------+--------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+---------------+------
---------------+
```

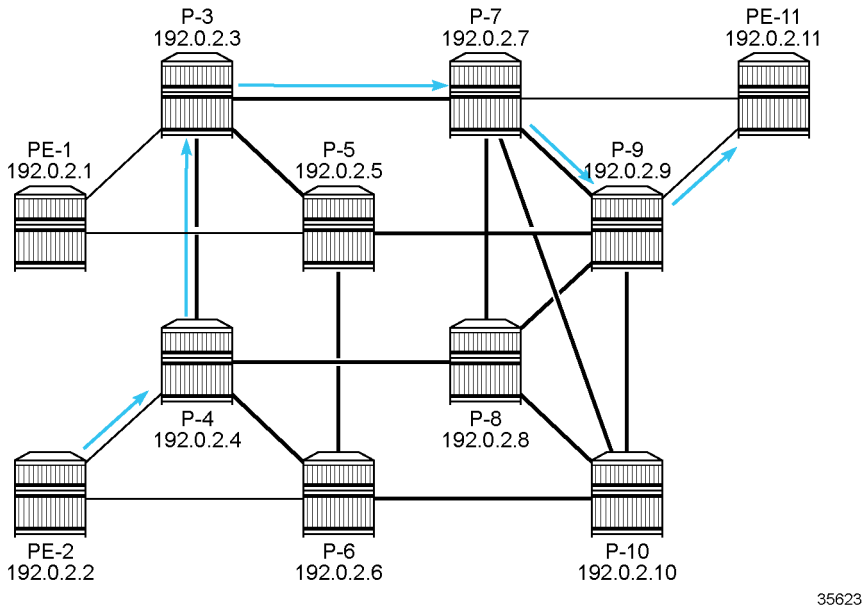
With local CSPF path compution, the actual hops are the A-SIDs toward P-4, P-3, P-7, P-9, and PE-11, as follows:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 23 computed-segments segment
 * | as table | filter fields *

+----------------------------------------+---------------------------------------+------------
------------+--------------+--------------+----------+---------------------------------------
+----------+-----------------+---------------------------------------+---------------+------
---------------+
|            Network-instance            |           Policy policy-name           | Policy
 protocol-origin | Segment-list | Segment-index | Hop-type |               Ip-address
      | Is-loose | Unnumbered-if-id |               Router-id               |    Sid-type    |
 Sid-value mpls-label |
+========================================+=======================================+============
============+==============+==============+==========+=======================================
+==========+=================+=======================================+===============+======
================+
| default                                | LSP_w-loose-hops_CSPF_no-LSR          | local
             |          23 |            1 | ipv4     | 192.168.24.2
 | false    |                | 192.0.2.4                             | adjacency-sid  |
          525000 |
| default                                | LSP_w-loose-hops_CSPF_no-LSR          | local
             |          23 |            2 | ipv4     | 192.168.34.1
 | false    |                | 192.0.2.3                             | adjacency-sid  |
          525001 |
| default                                | LSP_w-loose-hops_CSPF_no-LSR          | local
             |          23 |            3 | ipv4     | 192.168.37.2
 | false    |                | 192.0.2.7                             | adjacency-sid  |
          525003 |
| default                                | LSP_w-loose-hops_CSPF_no-LSR          | local
             |          23 |            4 | ipv4     | 192.168.79.2
 | false    |                | 192.0.2.9                             | adjacency-sid  |
          525004 |
```

```
| default                                  | LSP_w-loose-hops_CSPF_no-LSR          | local
            |          23 |             5 | ipv4     | 192.168.119.2
 | false    |                 | 192.0.2.11                              | adjacency-sid  |
         525001 |
+------------------------------------+---------------------------------------+------------
------------+-------------+--------------+----------+-------------------------------------
+----------+-----------------+---------------------------------------+---------------+------
---------------+
```

Figure 45: Path from PE-2 to PE-11 via loose hops P-3 and P-9 shows the path from PE-2 to PE-11 via loose hops P-3 and P-9.

Figure 45: Path from PE-2 to PE-11 via loose hops P-3 and P-9



Label stack reduction is configured as follows, but it is also the default setting:

```
# on PE-2:
    network-instance default
        traffic-engineering-policies {
            policy "LSP_w-loose-hops_CSPF_LSR" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 22 {
                    admin-state enable
                    explicit-path path-via-P-3-P-9_L
                    segment-list-type primary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            label-stack-reduction true     # default
                        }
                    }
                }
            }
```

With label stack reduction, the actual hops in the path are the following:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 22 computed-segments segment
 * | as table | filter fields *

+-----------------------------------------+-----------------------------------------+------------
------------+--------------+--------------+----------+-----------------------------------------
+----------+-----------------+-----------------------------------------+----------------+------
----------------+
|            Network-instance             |           Policy policy-name            | Policy
 protocol-origin | Segment-list | Segment-index | Hop-type |               Ip-address
      | Is-loose | Unnumbered-if-id |               Router-id                |    Sid-type    |
 Sid-value mpls-label |
+=========================================+=========================================+============
============+==============+==============+==========+=========================================
+==========+=================+=========================================+================+======
================+
| default                                 | LSP_w-loose-hops_CSPF_LSR               | local
            |           22 |             1 | ipv4     | 192.0.2.3
 | true     |                 | 192.0.2.3                               | node-sid       |
          10003 |
| default                                 | LSP_w-loose-hops_CSPF_LSR               | local
            |           22 |             2 | ipv4     | 192.0.2.9
 | true     |                 | 192.0.2.9                               | node-sid       |
          10009 |
| default                                 | LSP_w-loose-hops_CSPF_LSR               | local
            |           22 |             3 | ipv4     | 192.0.2.11
 | true     |                 | 192.0.2.11                              | node-sid       |
          10011 |
+-----------------------------------------+-----------------------------------------+------------
------------+--------------+--------------+----------+-----------------------------------------
+----------+-----------------+-----------------------------------------+----------------+------
----------------+
```

16.3.4 Tunnel tables

The following command on PE-2 lists the uncolored SR-MPLS TE tunnels. By default, te-policy-sr-mpls-uncolored tunnels have preference 8. For all SR-TE LSPs with next-hop 192.168.24.2 or 192.168.26.2., the first hop is mapped to an adjacency SID. All paths computed with local CSPF without label stack reduction only have adjacency SIDs. For hop-to-label path computation, only the strict hops are translated into adjacency SIDs. Paths computed using local CSPF with label stack reduction only have node SIDs in this example and the next hop is a system IP address 192.0.2.x/32.

```
--{ + running }--[  ]--
A:admin@PE-2# show network-instance default tunnel-table ipv4 type te-policy-sr-mpls-uncolored

-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
IPv4 tunnel table of network-instance "default"
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
+---------------------------+----------------+----------+-----+----------+---------+----------
---------------+-----------------+-----------------+--------------------+
|        IPv4 Prefix        |  Tunnel Type   |  Tunnel  | FIB |  Metric  | Prefere |
 Last Update        | Backup Nexthops | Next-hop (Type) |      Next-hop      |
|                           |                |    ID    |     |          |   nce   |
               |                 |                 |                    |
```

```
+============================+===============+==========+=====+==========+=========+==========
===============+================+================+====================+
| 192.0.2.11/32              | te-policy-sr-  | 1        | Y   | 220      | 8       | 2026-02-
16T06:55:37.446Z |                 | 192.0.2.11/32   | ethernet-1/4.1     |
|                            | mpls-uncolored |          |     |          |         |
                 |                 | (sr-isis)       |                    |
| 192.0.2.11/32              | te-policy-sr-  | 2        | Y   | 220      | 8       | 2026-02-
16T06:55:37.446Z |                 | 192.168.26.2/32 | ethernet-1/6.1     |
|                            | mpls-uncolored |          |     |          |         |
                 |                 | (sr-isis)       |                    |
| 192.0.2.11/32              | te-policy-sr-  | 3        | Y   | 220      | 8       | 2026-02-
16T06:55:37.446Z |                 | 192.0.2.11/32   | ethernet-1/4.1     |
|                            | mpls-uncolored |          |     |          |         |
                 |                 | (sr-isis)       |                    |
| 192.0.2.11/32              | te-policy-sr-  | 4        | Y   | 230      | 8       | 2026-02-
16T06:55:37.446Z |                 | 192.0.2.3/32    | ethernet-1/4.1     |
|                            | mpls-uncolored |          |     |          |         |
                 |                 | (sr-isis)       |                    |
| 192.0.2.11/32              | te-policy-sr-  | 5        | Y   | 230      | 8       | 2026-02-
16T06:55:37.446Z |                 | 192.168.24.2/32 | ethernet-1/4.1     |
|                            | mpls-uncolored |          |     |          |         |
                 |                 | (sr-isis)       |                    |
| 192.0.2.11/32              | te-policy-sr-  | 6        | Y   | 230      | 8       | 2026-02-
16T06:55:37.446Z |                 | 192.0.2.3/32    | ethernet-1/4.1     |
|                            | mpls-uncolored |          |     |          |         |
                 |                 | (sr-isis)       |                    |
| 192.0.2.11/32              | te-policy-sr-  | 7        | Y   | 220      | 8       | 2026-02-
16T06:55:37.446Z |                 | 192.0.2.4/32    | ethernet-1/4.1     |
|                            | mpls-uncolored |          |     |          |         |
                 |                 | (sr-isis)       |                    |
| 192.0.2.11/32              | te-policy-sr-  | 8        | Y   | 220      | 8       | 2026-02-
16T06:55:37.446Z |                 | 192.168.24.2/32 | ethernet-1/4.1     |
|                            | mpls-uncolored |          |     |          |         |
                 |                 | (sr-isis)       |                    |
| 192.0.2.11/32              | te-policy-sr-  | 9        | Y   | 220      | 8       | 2026-02-
16T06:55:37.446Z |                 | 192.168.24.2/32 | ethernet-1/4.1     |
|                            | mpls-uncolored |          |     |          |         |
                 |                 | (sr-isis)       |                    |
+----------------------------+---------------+----------+-----+----------+---------+----------
---------------+----------------+----------------+--------------------+
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
9 TE-POLICY-SR-MPLS-UNCOLORED tunnels, 9 active, 0 inactive
-------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
```

The following command on PE-2 shows the tunnel table for te-policy-sr-mpls-uncolored LSP tunnels including the pushed MPLS labels to be used from the next hop. Compared to the preceding output with the SID values for each of the uncolored SR-MPLS TE policies, the following pushed MPLS labels do not include the first label to the next hop. When the next hop is PE-11, no MPLS label is shown in the following tunnel table.

```
--{ + running }--[  ]--
A:admin@PE-2# show network-instance default tunnel-table ipv4 type te-policy-sr-mpls-uncolored
 detail

-------------------------------------------------------------------------------
Show report for network instance "default" tunnel table
-------------------------------------------------------------------------------
===============================================================================
Destination        : 192.0.2.11/32
Tunnel Type        : te-policy-sr-mpls-uncolored
```

```
Tunnel ID          : 1
Metric             : 220
Preference         : 8
Last Update        : 2026-02-16T06:55:37.446Z
FIB Status         : active
Next-hops
  192.0.2.11/32 (mpls)
      pushed MPLS labels : [IMPLICIT_NULL]
===============================================================================
Destination        : 192.0.2.11/32
Tunnel Type        : te-policy-sr-mpls-uncolored
Tunnel ID          : 2
Metric             : 220
Preference         : 8
Last Update        : 2026-02-16T06:55:37.446Z
FIB Status         : active
Next-hops
  192.168.26.2/32 (mpls)
      pushed MPLS labels : [525001, 525003, 525000]
===============================================================================
Destination        : 192.0.2.11/32
Tunnel Type        : te-policy-sr-mpls-uncolored
Tunnel ID          : 3
Metric             : 220
Preference         : 8
Last Update        : 2026-02-16T06:55:37.446Z
FIB Status         : active
Next-hops
  192.0.2.11/32 (mpls)
      pushed MPLS labels : [IMPLICIT_NULL]
===============================================================================
Destination        : 192.0.2.11/32
Tunnel Type        : te-policy-sr-mpls-uncolored
Tunnel ID          : 4
Metric             : 230
Preference         : 8
Last Update        : 2026-02-16T06:55:37.446Z
FIB Status         : active
Next-hops
  192.0.2.3/32 (mpls)
      pushed MPLS labels : [10011, 10009]
===============================================================================
Destination        : 192.0.2.11/32
Tunnel Type        : te-policy-sr-mpls-uncolored
Tunnel ID          : 5
Metric             : 230
Preference         : 8
Last Update        : 2026-02-16T06:55:37.446Z
FIB Status         : active
Next-hops
  192.168.24.2/32 (mpls)
      pushed MPLS labels : [525001, 525004, 525003, 525001]
===============================================================================
Destination        : 192.0.2.11/32
Tunnel Type        : te-policy-sr-mpls-uncolored
Tunnel ID          : 6
Metric             : 230
Preference         : 8
Last Update        : 2026-02-16T06:55:37.446Z
FIB Status         : active
Next-hops
  192.0.2.3/32 (mpls)
      pushed MPLS labels : [10011, 10009]
===============================================================================
```

```
Destination        : 192.0.2.11/32
Tunnel Type        : te-policy-sr-mpls-uncolored
Tunnel ID          : 7
Metric             : 220
Preference         : 8
Last Update        : 2026-02-16T06:55:37.446Z
FIB Status         : active
Next-hops
  192.0.2.4/32 (mpls)
      pushed MPLS labels : [10011, 10003]
===============================================================================
Destination        : 192.0.2.11/32
Tunnel Type        : te-policy-sr-mpls-uncolored
Tunnel ID          : 8
Metric             : 220
Preference         : 8
Last Update        : 2026-02-16T06:55:37.446Z
FIB Status         : active
Next-hops
  192.168.24.2/32 (mpls)
      pushed MPLS labels : [525001, 525003, 525001]
===============================================================================
Destination        : 192.0.2.11/32
Tunnel Type        : te-policy-sr-mpls-uncolored
Tunnel ID          : 9
Metric             : 220
Preference         : 8
Last Update        : 2026-02-16T06:55:37.446Z
FIB Status         : active
Next-hops
  192.168.24.2/32 (mpls)
      pushed MPLS labels : [10011, 525001]
===============================================================================
```

16.3.5 Resignaling segment lists in an uncolored SR-MPLS TE policy

Uncolored SR-MPLS TE policies have a re-optimization timer with a default value of 30 minutes. It is possible to disable the re-optimization timer. The following command can be used to configure the re-optimization timer for a TE policy:

```
--{ + candidate shared default }--[ network-instance default traffic-engineering-policies
 policy "LSP_no-expl-path_CSPF_no-LSR" ]--
A:admin@PE-2# re-optimization-timer ?
usage: re-optimization-timer <value>

Re-optimizaion timer for the TE policy

Positional arguments:
  value             [number, range 30..10800, units minutes, default 30]|[disable, units
 minutes, default 30]
```

The following **tools** command can be used to either clear or resignal a segment list in an uncolored SR-MPLS TE policy:

```
--{ + running }--[  ]--
A:admin@PE-2# tools network-instance default traffic-engineering-policies sr-uncolored policy
 "LSP_no-expl-path_CSPF_no-LSR" protocol-origin local segment-list 3 ?
usage: segment-list <segment-list-index>
```

```
Positional arguments:
  segment-list-index
                    [number, range 1..32] Index to enumerate the different segment lists of a
 TE policy.

Local commands:
  clear*            Clear segment-list
  resignal*         Trigger resignal for segment-list
```

The following command triggers a manual re-optimization for segment list 3 in uncolored SR-MPLS TE policy "LSP_no-expl-path_CSPF_no-LSR":

```
tools network-instance default traffic-engineering-policies sr-uncolored policy "LSP_no-expl-
path_CSPF_no-LSR" protocol-origin local segment-list 3 resignal
```

The following command shows the timestamp of the last retry attempt and the next reoptimization attempt for segment 3 in the TE policy:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state with-context network-instance default traffic-engineering-
policies policy-database sr-uncolored | grep 'segment-list
 3' --after-context 10

                        segment-list 3 {
                            oper-state up
                            forwarding-state active
                            last-oper-state-change "2026-02-16T06:55:37.445Z (2 hours ago)"
                            oper-state-change-count 1
                            segment-list-type primary
                            metric 215
                            igp-metric 215
                            lsp-id 68
                            last-retry-attempt "2026-02-16T09:23:47.262Z (5 seconds ago)"
                            next-reoptimization-attempt "2026-02-16T09:53:47.264Z (29 minutes
 from now)"
```

16.3.6 Local CSPF and SR protected adjacencies

In this example, protected and unprotected links are present. The following command enables TI-LFA with link protection on all nodes, except on P-4:

```
# on PE-1, PE-2, P-3, P-5, P-6, P-7, P-8, P-9, P-10, PE-11:
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    loopfree-alternate {
                        admin-state enable
                        ti-lfa {
                            admin-state enable
```

As a result of this, each adjacency is available for SID protection on all nodes, except for the adjacencies on P-4. The following command shows that the adjacency SID sub-TLV for both links on PE-2 has the backup flag set:

```
--{ + running }--[  ]--
```

```
A:admin@PE-2# info from state / network-instance default protocols isis instance 0 level 2
 link-state-database lsp 1920.0000.2002.00-00 | grep flags --before-context 10 --after-context
 4
---snip---

--
                neighbors {
                    neighbor 1920.0000.2004 {
                        instances {
                            instance 0 {
                                metric 100
                                subtlvs {
                                    subtlv is-reachability-adj-sid {
                                        adjacency-sids {
                                            adjacency-sid 525000 {
                                                weight 0
                                                flags [
                                                    backup        # backup flag on adjacency to
 P-4
                                                    value
                                                    local
                                                ]
--
                    }
                    neighbor 1920.0000.2006 {
                        instances {
                            instance 0 {
                                metric 100
                                subtlvs {
                                    subtlv is-reachability-adj-sid {
                                        adjacency-sids {
                                            adjacency-sid 525001 {
                                                weight 0
                                                flags [
                                                    backup        # backup flag on adjacency to
 P-6
                                                    value
                                                    local
                                                ]
---snip---
```

Because LFA is disabled on P-4, the four adjacencies on P-4 are not protected and the adjacency SID sub-TLV for the four links on P-4 does not have the backup flag set, as follows:

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default protocols isis instance 0 level 2
 link-state-database lsp 1920.0000.2004.00-00 | grep flags --before-context 10 --after-context
 4
---snip---

--
                neighbors {
                    neighbor 1920.0000.2002 {
                        instances {
                            instance 0 {
                                metric 100
                                subtlvs {
                                    subtlv is-reachability-adj-sid {
                                        adjacency-sids {
                                            adjacency-sid 525000 {
                                                weight 0
                                                flags [        # no backup flag on adjacency to
 PE-2
```

```
                                                value
                                                local
                                            ]
                                        }
--
                    }
                    neighbor 1920.0000.2003 {
                        instances {
                            instance 0 {
                                metric 10
                                subtlvs {
                                    subtlv is-reachability-adj-sid {
                                        adjacency-sids {
                                            adjacency-sid 525001 {
                                                weight 0
                                                flags [        # no backup flag on adjacency to
 P-3
                                                value
                                                local
                                            ]
                                        }
--
                    }
                    neighbor 1920.0000.2006 {
                        instances {
                            instance 0 {
                                metric 10
                                subtlvs {
                                    subtlv is-reachability-adj-sid {
                                        adjacency-sids {
                                            adjacency-sid 525002 {
                                                weight 0
                                                flags [        # no backup flag on adjacency to
 P-6
                                                value
                                                local
                                            ]
                                        }
--
                    }
                    neighbor 1920.0000.2008 {
                        instances {
                            instance 0 {
                                metric 5
                                subtlvs {
                                    subtlv is-reachability-adj-sid {
                                        adjacency-sids {
                                            adjacency-sid 525003 {
                                                weight 0
                                                flags [        # no backup flag on adjacency to
 P-8
                                                value
                                                local
                                            ]
                                        }
--
---snip---
```

Local CSPF computes, by default, an end-to-end path by selecting protected adjacencies, which have the backup flag set. If no such path is available, the local CSPF may select an unprotected adjacency with the assumption that all other path constraints are met.

On PE-2, the following uncolored SR-MPLS TE policies to PE-11 are configured without explicit path constraint and using local CSPF path computation:

- an uncolored SR-MPLS TE policy with local SR protection preferred (= default setting)
- an uncolored SR-MPLS TE policy with mandatory local SR protection, where all adjacencies must have a backup
- an uncolored SR-MPLS TE policy without local SR protection (none), where all adjacencies are unprotected

```
# on PE-2:    network-instance default {
        traffic-engineering-policies {
            policy "LSP_no-expl-path_CSPF_no-LSR_pref" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 4 {
                    admin-state enable
                    segment-list-type primary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            local-sr-protection preferred       # default
                            label-stack-reduction false
                        }
                    }
                }
            }
            policy "LSP_no-expl-path_CSPF_no-LSR_mand" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 5 {
                    admin-state enable
                    segment-list-type primary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            local-sr-protection mandated       # all adjacencies protected
                            label-stack-reduction false
                        }
                    }
                }
            }
            policy "LSP_no-expl-path_CSPF_no-LSR_none" {
                policy-type sr-mpls-uncolored
                admin-state enable
                endpoint 192.0.2.11
                segment-list 6 {
                    admin-state enable
                    segment-list-type primary
                    dynamic {
                        path-algorithm local-cspf
                        te-constraints {
                            local-sr-protection none       # all adjacencies unprotected
                            label-stack-reduction false
                        }
                    }
                }
            }
```

For test purposes, the metric on one of the unprotected adjacencies from P-4 is lowered to 5, so the shortest path to PE-11 includes the unprotected interface when allowed:

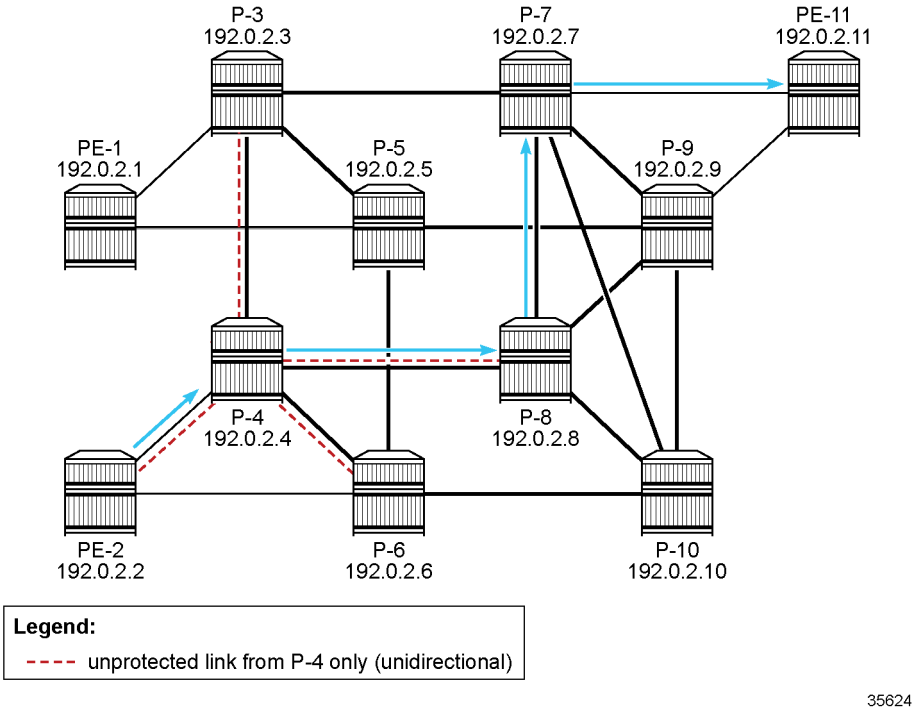
```
# on P-4:
    network-instance default {
        protocols {
            isis {
                instance 0 {
                    interface ethernet-1/8.1 {              # int-P-4-P-8
                        level 2 {
                            metric 5
                        }
                    }
```

For uncolored SR-MPLS TE policy "LSP_no-exp-path_CSPF_no-LSR_pref", a path can be established from PE-2 via P-4, P-8, and P-7 to PE-11, but for the same metric, P-7 can be replaced by P-9. The direct link between P-4 and P-8 is unprotected, while all other adjacencies in the path have a backup.

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 4 computed-segments segment *
 | as table | filter fields *

+-----------------------------------+-----------------------------------+-----------------
------+-------------+--------------+----------+-----------------------------------+--------
--+-----------------+-----------------------------------+---------------+-----------------
----+
|          Network-instance         |         Policy policy-name        | Policy protocol-
origin | Segment-list | Segment-index | Hop-type |            Ip-address             | Is-
loose | Unnumbered-if-id |             Router-id             |    Sid-type    | Sid-value
 mpls-label |
+===================================+===================================+=================
======+=============+==============+==========+===================================+========
==+=================+===================================+===============+=================
====+
| default                           | LSP_no-expl-path_CSPF_no-LSR_pref   | local
      |           4 |            1 | ipv4     | 192.168.24.2                      | false
   |                | 192.0.2.4                         | adjacency-sid  |
 525000 |
| default                           | LSP_no-expl-path_CSPF_no-LSR_pref   | local
      |           4 |            2 | ipv4     | 192.168.48.2                      | false
   |                | 192.0.2.8                         | adjacency-sid  |
 525003 |
| default                           | LSP_no-expl-path_CSPF_no-LSR_pref   | local
      |           4 |            3 | ipv4     | 192.168.78.1                      | false
   |                | 192.0.2.7                         | adjacency-sid  |
 525002 |
| default                           | LSP_no-expl-path_CSPF_no-LSR_pref   | local
      |           4 |            4 | ipv4     | 192.168.117.2                     | false
   |                | 192.0.2.11                        | adjacency-sid  |
 525001 |
+-----------------------------------+-----------------------------------+-----------------
------+-------------+--------------+----------+-----------------------------------+--------
--+-----------------+-----------------------------------+---------------+-----------------
----+
```

Figure 46: Path from PE-2 to PE-11 including unprotected link shows the established path from PE-2 to PE-11, which uses protected and unprotected links.

Figure 46: Path from PE-2 to PE-11 including unprotected link



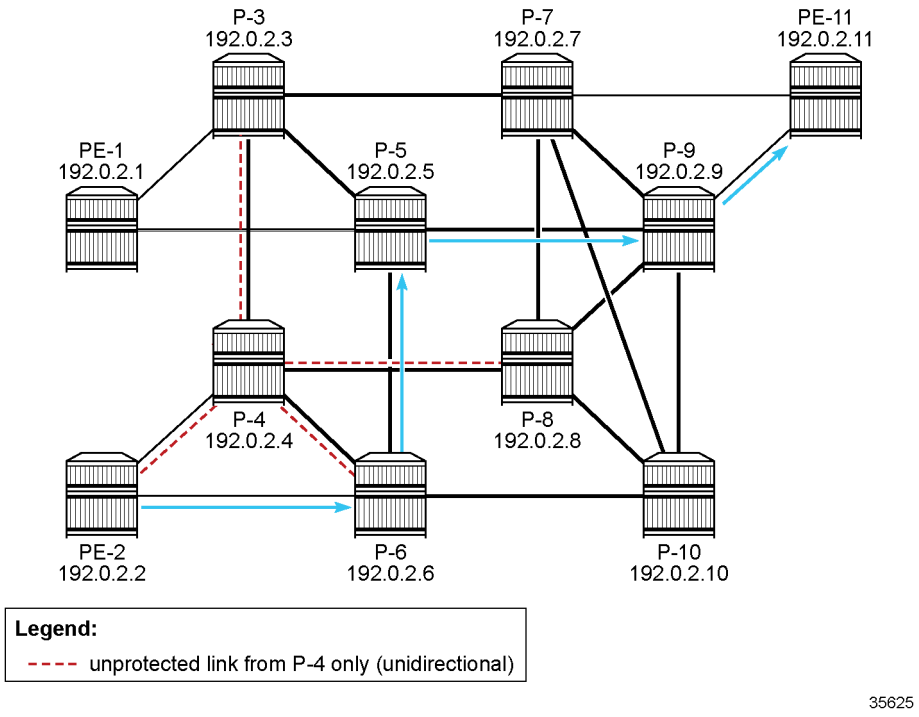
For uncolored SR-MPLS TE policy "LSP_no-exp-path_CSPF_no-LSR_mand", the path must exclude all unprotected links from P-4. The path goes from PE-2 via P-6, P-5, and P-9 to PE-11, but for the same metric, other paths are possible.

```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local segment-list 5 computed-segments segment *
 | as table | filter fields *

+-----------------------------------+-----------------------------------+-----------------
------+-------------+--------------+----------+-----------------------------------+--------
--+-----------------+-----------------------------------+---------------+-----------------
----+
|          Network-instance         |         Policy policy-name        | Policy protocol-
origin | Segment-list | Segment-index | Hop-type |            Ip-address             | Is-
loose | Unnumbered-if-id |             Router-id             |    Sid-type    | Sid-value
 mpls-label |
+===================================+===================================+=================
======+=============+==============+==========+===================================+========
==+=================+===================================+===============+=================
====+
| default                           | LSP_no-expl-path_CSPF_no-LSR_mand   | local
      |           5 |            1 | ipv4     | 192.168.26.2                      | false
    |               | 192.0.2.6                         | adjacency-sid  |
 525001 |
| default                           | LSP_no-expl-path_CSPF_no-LSR_mand   | local
      |           5 |            2 | ipv4     | 192.168.56.1                      | false
    |               | 192.0.2.5                         | adjacency-sid  |
 525003 |
| default                           | LSP_no-expl-path_CSPF_no-LSR_mand   | local
      |           5 |            3 | ipv4     | 192.168.59.2                      | false
```

```
    |                 | 192.0.2.9                          | adjacency-sid  |
 525003 |
| default                              | LSP_no-expl-path_CSPF_no-LSR_mand   | local
      |           5 |             4 | ipv4     | 192.168.119.2                        | false
    |                 | 192.0.2.11                         | adjacency-sid  |
 525001 |
+-------------------------------------+-------------------------------------+-----------------
------+-------------+--------------+----------+-------------------------------------+--------
--+-----------------+-------------------------------------+---------------+-----------------
----+
```

Figure 47: Path from PE-2 to PE-11 including only protected links shows the path that excludes the unprotected links from P-4.

Figure 47: Path from PE-2 to PE-11 including only protected links



For uncolored SR-MPLS TE policy "LSP_no-exp-path_CSPF_no-LSR_none", the path should only use unprotected links, but only the adjacencies from P-4 are unprotected, so CSPF cannot find an end-to-end path. The uncolored SR-MPLS TE policy remains operationally down, as follows:

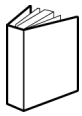
```
--{ + running }--[  ]--
A:admin@PE-2# info from state / network-instance default traffic-engineering-policies policy-
database sr-uncolored policy * protocol-origin local | as table | filter fields endpoint
 policy-type tunnel-id metric segment-list-count oper-state

+-------------------------------------+-------------------------------------+--------------
---+-------------------------------------+------------------+------------+------------+-----
--------------+------------+
|          Network-instance           |             Policy-name             | Protocol-
origin |               Endpoint              |    Policy-type    | Tunnel-id  |   Metric   |
 Segment-list-count | Oper-state |
```

```
+=====================================+=====================================+==============
===+=====================================+==================+============+============+=====
==============+============+
| default                             | LSP_no-expl-path_CSPF_LSR             | local
   | 192.0.2.11                          | sr-mpls-uncolored |          1 |        215 |
            1 | up         |
| default                             | LSP_no-expl-path_CSPF_no-LSR          | local
   | 192.0.2.11                          | sr-mpls-uncolored |          2 |        215 |
            1 | up         |
| default                             | LSP_no-expl-path_CSPF_no-LSR_mand     | local
   | 192.0.2.11                          | sr-mpls-uncolored |         10 |        220 |
            1 | up         |
| default                             | LSP_no-expl-path_CSPF_no-LSR_none     | local
   | 192.0.2.11                          | sr-mpls-uncolored |         11 |   16777215 |
            1 | down       |
| default                             | LSP_no-expl-path_CSPF_no-LSR_pref     | local
   | 192.0.2.11                          | sr-mpls-uncolored |         12 |        215 |
            1 | up         |
| default                             | LSP_no-expl-path_no-dynamic           | local
   | 192.0.2.11                          | sr-mpls-uncolored |          3 |        215 |
            1 | up         |
| default                             | LSP_w-loose-hops_CSPF_LSR             | local
   | 192.0.2.11                          | sr-mpls-uncolored |          4 |        230 |
            1 | up         |
| default                             | LSP_w-loose-hops_CSPF_no-LSR          | local
   | 192.0.2.11                          | sr-mpls-uncolored |          5 |        230 |
            1 | up         |
| default                             | LSP_w-loose-hops_no-dynamic           | local
   | 192.0.2.11                          | sr-mpls-uncolored |          6 |        230 |
            1 | up         |
| default                             | LSP_w-strict-hops_CSPF_LSR            | local
   | 192.0.2.11                          | sr-mpls-uncolored |          7 |        220 |
            1 | up         |
| default                             | LSP_w-strict-hops_CSPF_no-LSR         | local
   | 192.0.2.11                          | sr-mpls-uncolored |          8 |        220 |
            1 | up         |
| default                             | LSP_w-strict-hops_no-dynamic          | local
   | 192.0.2.11                          | sr-mpls-uncolored |          9 |        220 |
            1 | up         |
+-------------------------------------+-------------------------------------+--------------
---+-------------------------------------+------------------+------------+------------+-----
--------------+------------+
```

16.4 Conclusion

Within a single-level IS-IS network, uncolored SR-MPLS TE policy path compution using local CSPF on the head-end router results in an end-to-end path using IPv4 adjacencies.

Customer document and product support



Customer documentation

Customer documentation welcome page

Technical support

Product support portal

Documentation feedback

Customer documentation feedback