7450 Ethernet Service Switch
7750 Service Router
7950 Extensible Routing System
Virtualized Service Router

Release 24.3.R1

MPLS 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 Getting started

1.1 About this guide

This guide describes the services and protocol support provided by the router and presents examples to configure and implement MPLS, RSVP, and LDP protocols.

This guide is organized into functional chapters and provides concepts and descriptions of the implementation flow, as well as Command Line Interface (CLI) syntax and command usage.

Note: Unless otherwise indicated, this guide uses classic CLI command syntax and configuration examples.

The topics and commands described in this document apply to the:

- 7450 ESS
- 7750 SR
- 7950 XRS
- Virtualized Service Router

For a list of unsupported features by platform and chassis, see the *SR OS R24.x.Rx Software Release Notes*, part number 3HE 20152 000*x* TQZZA.

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

Note:
The SR OS CLI trees and command descriptions can be found in the following guides:

- *7450 ESS, 7750 SR, 7950 XRS, and VSR Classic CLI Command Reference Guide*
- *7450 ESS, 7750 SR, 7950 XRS, and VSR Clear, Monitor, Show, and Tools CLI Command Reference Guide* (for both MD-CLI and classic CLI)
- *7450 ESS, 7750 SR, 7950 XRS, and VSR MD-CLI Command Reference Guide*

Note:
This guide generically covers Release 24.*x*.R*x* content and may contain some content that will be released in later maintenance loads. Please see the *SR OS R24.x.Rx Software Release Notes*, part number 3HE 20152 000*x* TQZZA, for information about features supported in each load of the Release 24.*x*.R*x* software.

1.2 Nokia router configuration process

Table 1: Configuration process lists the tasks necessary to configure MPLS applications functions.

This guide is presented in an overall logical configuration flow. Each section describes a software area and provides the CLI command usage to configure the functional area.

Table 1: Configuration process

Area	Task	Section
MPLS and RSVP protocol configuration	MPLS Configuration	Common configuration tasks
	Configure RSVP command options	Configuring RSVP parameters
	MPLS configuration management	MPLS configuration management tasks
	RSVP configuration management	RSVP configuration management tasks
Label Distribution Protocol (LDP) configuration	Configure LDP	Configuring LDP with CLI
	LDP configuration management	LDP configuration management tasks

1.3 Conventions

This section describes the general conventions used in this guide.

1.3.1 Precautionary and information messages

The following information symbols are 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.

1.3.2 Options or substeps in procedures and sequential workflows

Options in a procedure or a sequential workflow are indicated by a bulleted list. In the following example, at step 1, the user must perform the described action. At step 2, the user must perform one of the listed options to complete the step.

Example: Options in a procedure

1. User must perform this step.
2. This step offers three options. User must perform one option to complete this step.
   - This is one option.
   - This is another option.
   - This is yet another option.

Substeps in a procedure or a sequential workflow are indicated by letters. In the following example, at step 1, the user must perform the described action. At step 2, the user must perform two substeps (a. and b.) to complete the step.

Example: Substeps in a procedure

1. User must perform this step.
2. User must perform all substeps to complete this action.
   a. This is one substep.
   b. This is another substep.

2 MPLS and RSVP

2.1 MPLS

Multiprotocol Label Switching (MPLS) is a label switching technology that provides the ability to set up connection-oriented paths over a connectionless IP network. MPLS facilitates network traffic flow and provides a mechanism to engineer network traffic patterns independently from routing tables. MPLS sets up a specific path for a sequence of packets. The packets are identified by a label inserted into each packet. MPLS is not enabled by default and must be explicitly enabled.

MPLS is independent of any routing protocol but is considered multiprotocol because it works with Internet Protocol (IP), Asynchronous Transport Mode (ATM), and frame relay network protocols.

2.1.1 MPLS label stack

MPLS requires a set of procedures to enhance network layer packets with label stacks, which turns them into labeled packets. Routers that support MPLS are known as Label Switching Routers (LSRs). To transmit a labeled packet on a particular data link, an LSR must support the encoding technique which, when a label stack and a network layer packet are added, produces a labeled packet.

In MPLS, packets can carry not just one label, but a set of labels in a stack. An LSR can swap the label at the top of the stack, pop the stack, or swap the label and push one or more labels into the stack. The processing of a labeled packet is completely independent of the level of hierarchy. The processing is always based on the top label, without regard for the possibility that some number of other labels may have been above it in the past, or that some number of other labels may be below it at present.

As described in RFC 3032, *MPLS Label Stack Encoding*, the label stack is represented as a sequence of label stack entries. Each label stack entry is represented by 4 octets. Figure 1: Label placement displays the label placement in a packet.

Figure 1: Label placement

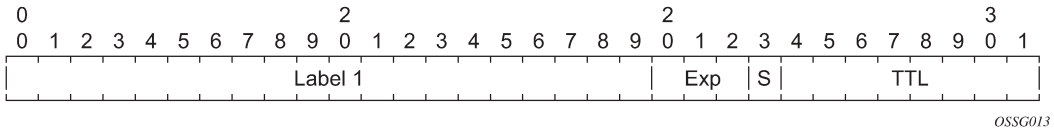


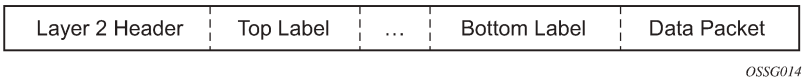
Table 2: Packet/label field description

Field	Description
Label	This 20-bit field carries the actual value (unstructured) of the label.
Exp	This 3-bit field is reserved for experimental use. It is currently used for Class of Service (CoS).

Field	Description
S	This bit is set to 1 for the last entry (bottom) in the label stack, and 0 for all other label stack entries.
TTL	This 8-bit field is used to encode a TTL value.

A stack can carry several labels, organized in a last in/first out order. The top of the label stack appears first in the packet and the bottom of the stack appears last, as shown in Figure 2: Label packet placement.

Figure 2: Label packet placement



The label value at the top of the stack is looked up when a labeled packet is received. A successful lookup reveals:

- the next hop where the packet is to be forwarded
- the operation to be performed on the label stack before forwarding

In addition, the lookup may reveal outgoing data link encapsulation and other information needed to properly forward the packet.

An empty label stack can be thought of as an unlabeled packet. An empty label stack has zero (0) depth. The label at the bottom of the stack is referred to as the Level 1 label. The label above it (if it exists) is the Level 2 label, and so on. The label at the top of the stack is referred to as the Level *m* label.

Labeled packet processing is independent of the level of hierarchy. Processing is always based on the top label in the stack which includes information about the operations to perform on the packet's label stack.

2.1.1.1 Label values

Packets traveling along an LSP (see Label switching routers) are identified by its label, the 20-bit, unsigned integer. The range is 0 through 1,048,575. Label values 0 to 15 are reserved and are defined below as follows:

- A value of 0 represents the IPv4 Explicit NULL label. It indicates that the label stack must be popped, and the packet forwarding must be based on the IPv4 header. SR OS implementation does not support advertising an explicit-null label value, but can properly process in a received packet.
- A value of 1 represents the router alert label. This label value is legal anywhere in the label stack except at the bottom. When a received packet contains this label value at the top of the label stack, it is delivered to a local software module for processing. The actual packet forwarding is determined by the label beneath it in the stack. However, if the packet is further forwarded, the router alert label should be pushed back onto the label stack before forwarding. The use of this label is analogous to the use of the router alert option in IP packets. Because this label cannot occur at the bottom of the stack, it is not associated with a particular network layer protocol.
- A value of 2 represents the IPv6 explicit NULL label. It indicates that the label stack must be popped, and the packet forwarding must be based on the IPv6 header. SR OS implementation does not support advertising an explicit-null label value, but can properly process in a received packet.

- A value of 3 represents the Implicit NULL label. This is a label that a Label Switching Router (LSR) can assign and distribute, but which never actually appears in the encapsulation. When an LSR would otherwise replace the label at the top of the stack with a new label, but the new label is Implicit NULL, the LSR pops the stack instead of doing the replacement. Although this value may never appear in the encapsulation, it needs to be specified in the Label Distribution Protocol (LDP) or RSVP-TE protocol, so a value is reserved.
- A value of 7 represents the Entropy Label Indicator (ELI) which precedes in the label stack the actual Entropy Label (EL) which carries the entropy value of the packet.
- A value of 13 represents the Generic-ACH Label (GAL), an alert mechanism used to carry OAM payload in MPLS-TP LSP.
- Values 5-6, 8-12, and 14-15 are reserved for future use.

The router uses labels for MPLS, RSVP-TE, LDP, BGP Label Unicast, Segment Routing, as well as packet-based services such as VLL and VPLS.

Label values 16 through 1,048,575 are defined as follows:

- label values 16 through 31 are reserved for future use
- label values 32 through 18,431 are available for static LSP, MPLS-TP LSP, and static service label assignments. The upper bound of this range, which is also the lower bound of the dynamic label range, is configurable such that the user can expand or shrink the static or dynamic label range.
- label values 18,432 through 524,287 (1,048,575 in FP4, or later FP generation, profile B) are assigned dynamically by RSVP, LDP, and BGP control planes for both MPLS LSP and service labels.
- label values 524,288 through 1,048,575 are not assigned by SR OS in system profiles other than FP4, or later FP generation, profile B, and therefore no POP or SWAP label operation is possible in that range and for those system profiles. However, a PUSH operation, with a label from the full range 32 through 1,048,575 if signaled by some downstream LSR for LSP or service, is supported.

The user can carve out a range of the dynamic label space dedicated for labels of the following features:

- Segment Routing Global Block (SRGB) and usable by Segment Routing in OSPF and ISIS.
- Reserved Label Block for applications such as SR policy, MPLS forwarding policy, and the assignment of a static label to the SID of a ISIS or OSPF adjacency and adjacency set.

2.1.1.2 Reserved label blocks

Reserved label blocks are used to reserve a set of labels for allocation for various applications. These reserved label blocks are separate from the existing ranges such as the static-labels-range, and are not tied to the bottom of the labels range. For example, a reserved range may be used as a Segment Routing Local Block (SRLB) for local segment identifiers (SIDs). Ranges are reserved from the dynamic label range and up to four reserved label block ranges may be configured on a system.

A range can be configured up to the maximum supported MPLS label value on the system.

Example: Reserved label block configuration (MD-CLI)

```
[ex:/configure router "Base" mpls-labels]
A:admin@node-2# info
    reserved-label-block "test" {
        start-label 18432
        end-label 20000
    }
```

Example: Reserved label block configuration (classic CLI)

```
A:node-2>config>router>mpls-labels# info
----------------------------------------------
            reserved-label-block "test"
                start-label 18432 end-label 20000
            exit
----------------------------------------------
```

2.1.2 MPLS entropy label and hash label

The router supports both the MPLS entropy label, as specified in RFC 6790, and the flow-aware transport (FAT) label (the FAT label is also known as the hash label), as specified in RFC 6391. LSR nodes in a network can load-balance labeled packets in a more granular way than by hashing on the standard label stack by demarking the presence of individual flows on the LSP. The labels also remove the need to have an LSR inspect the payload below the label stack and check for an IPv4 or IPv6 header to determine how to apply load balancing.

The hash label is primarily applicable to Layer 2 services such as VLL and VPLS, while the entropy label (EL) is applicable to more general scenarios where a common way to indicate flows on a wide range of services suitable for load balancing is required.

The application of a hash label or an entropy label is mutually exclusive for a service.

2.1.2.1 Hash label

The hash label is supported on VLL, VPRN, or VPLS services bound to any MPLS type encapsulated SDPs, as well as to a VPRN service using the **auto-bind-tunnel** command with the **resolution-filter** command set to any MPLS tunnel type. When enabled, the ingress datapath is modified such that the result of the hash on the payload packet header is communicated to the egress datapath for use as the value of the label field of the hash label. The egress datapath appends the hash label to the bottom of the stack (BoS) and sets the S-bit to 1. The TTL of the hash label is set to a value of 0. The user enables the signaling of the hash-label capability under a VLL spoke SDP, a VPLS spoke SDP or mesh SDP, or an IES or VPRN spoke SDP interface by adding the signal-capability option. When this capability is enabled, the decision to insert the hash label on the user and control plane packets by the local PE is determined by the outcome of the signaling process and may override the local PE configuration.

2.1.2.2 Entropy label

The MPLS entropy label provides a similar function to the hash label, but is applicable to a wider range of services. The entropy label is appended directly below the tunnel label. As with the hash label, the value of the entropy label is calculated based on a hash of the packet payload header.

The router supports the entropy label for the following services and protocols:

- VPRN
- EVPN VPLS and Epipe
- RFC 8277 MP-BGP tunnels
- RSVP and LDP LSPs used as shortcuts for static, IGP, and BGP route resolution
- VLLs, including BGP VPWS, IES/VPRN, and VPLS spoke-SDP termination, but not including Cpipe

- LDP VPLS and BGP-AD VPLS
- PW ports bound to a specific physical port supporting PW-SAPs used for Epipe VLL, IES, VPRN, and Enhanced Subscriber Management services

The entropy label is supported with the following tunnel types:

- RSVP-TE: configured and auto-LSPs
- LDP
- Segment Routing (shortest path, PCC and PCE-initiated SR-TE and SR-TE auto-LSPs)
- BGP

The entropy label is not supported on P2MP LSPs.

The entropy label indicated (ELI) label (value=7) is a special-purpose label that indicates that the entropy label follows in the stack. It is always placed immediately below the tunnel label to which hashing applies. Inserting the EL adds two labels in the MPLS label stack: the EL and its accompanying ELI.

Three criteria are used to determine if an EL and an ELI are inserted on a labeled packet belonging to a service by an ingress LER:

- Entropy Label Capability (ELC)
- whether a specific tunnel at the ingress LER supports EL
- whether the use of EL has been configured for the service

The following sections provide more detailed information about these three criteria.

ELC

ELC is the ability of the egress LER to receive and process the EL. The ingress LER associates the ELC with the LSP tunnel to be used to transport the service. ELC signaling is supported for RSVP and LDP and causes the router to signal ELC to upstream peers.

ELC is configured on these services by using the following commands.

```
configure router ldp entropy-label-capability
configure router rsvp entropy-label-capability
```

ELC signaling is not supported for BGP or SR tunnels. For these services, configure the ingress LER (or LSR at a stitching point to a BGP or SR segment) with ELC for this tunnel type using **override-tunnel-elc** command for BGP or for the IGP if using SR.

Whether a specific tunnel at the ingress LER supports EL

Support for EL on a specific tunnel is configurable to prevent exceeding the maximum supported label stack depth because of the additional EL and ELI label (see Impact of EL and ELI on MTU and label stack depth for more information). For RSVP and SR-TE LSPs, it is configured using the **entropy-label** command under the LSP, LSP template, or MPLS contexts.

Whether the use of EL has been configured for the service

See the *7450 ESS, 7750 SR, 7950 XRS, and VSR Layer 2 Services and EVPN Guide*, *7450 ESS, 7750 SR, 7950 XRS, and VSR Layer 3 Services Guide: IES and VPRN*, and the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide* for more information about entropy label configuration on services.

Each of these conditions must be true before the ingress LER inserts the EL and ELI into the label stack.

An LSR for RSVP and LDP tunnels passes the ELC from the downstream LSP segment to upstream peers. However, releases of SR OS that do not support EL functionality do not pass the ELC to their peers.

2.1.2.3 Inserting and processing the entropy label at LERs and LSRs

This section describes entropy label processing. Details specific to particular services or other tunnel types are described in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Layer 2 Services and EVPN Guide*, *7450 ESS, 7750 SR, 7950 XRS, and VSR Layer 3 Services Guide: IES and VPRN*, and the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide*.

2.1.2.3.1 Ingress LER

The SR OS router follows the procedures at the ingress LER as specified in Section 4.2 of RFC 6790. In general, the router inserts an EL in a packet if the egress LER for the LSP tunnel has signaled support for ELs, the EL is configured for the service that the packet belongs to, and the EL is not disabled for an RSVP LSP. If there are multiple LSPs in a hierarchy (for example, LDP over RSVP), the router only inserts a single EL and ELI pair under the innermost LSP label closest to the service payload that has advertised EL capability. The router does not insert an EL in a packet belonging to a service for which the hash label has been configured, even if the far end for the LSP tunnel has advertised ELC. The system instead inserts a hash label, as specified by the hash label feature.

If the downstream LSR or LER has signaled implicit or explicit NULL label for a tunnel that is ELC, the router still inserts the EL when required by the service. This ensures consistent behavior as well as ensuring that entropy as determined by the ingress LER is maintained where a tunnel with an implicit NULL label is stitched at a downstream LSR.

2.1.2.3.2 LSR

If an LSR is configured for load balancing and an EL is found in the label stack, the LSR takes the EL into account in the hashing algorithm as follows:

- label-only only uses the EL as input to the hash routine. The rest of the label stack is ignored.
- label-ip only uses the EL and the IP packet as input to the hash routine. The rest of the label stack is ignored.

An EL and its associated ELI are not exposed when a tunnel label is swapped at an LSR acting as an LSP stitching point. Therefore, the EL and ELI are forwarded as any other packet on the LSP.

2.1.2.3.3 Egress LER

If an EL is detected in the label stack at an egress LER for a tunnel where the tunnel label that the EL is associated with is popped, then the EL is also popped and the packet is processed as normal. This occurs whether the system has signaled ELC.

If an ELI is popped that has the BoS bit set, then the system discards the packet and raises a trap.

2.1.2.4 Mapping entropy label capability at LSP stitching points

A router acting as a stitching point between two LSPs maps the ELC received in signaling for a downstream segment to the upstream segment for the level in the LSP hierarchy being stitched.

If an LSR is stitching an RSVP or LDP segment to a downstream segment of a tunnel type that does not support ELC signaling (for example, BGP) and the **override-tunnel-elc** command is configured at the LSR for the **to** command's downstream segment, the system signals ELC on the upstream LSP segment. The **override-tunnel-elc** command must be configured to reflect whether all possible downstream LERs are entropy-label-capable; otherwise, packets with an EL are discarded by a downstream LER that is not entropy-label-capable.

The mapping of ELC across LDP-BGP stitching points is not supported. If a downstream tunnel endpoint signals ELC, this signal is not automatically propagated upstream. The EL and ELI are not inserted on these LSPs by the ingress LER.

2.1.2.5 Entropy label on OAM packets

Service OAM packets or OAM packets within the context of a shortcut (for example, ICMP Ping or traceroute packets), also include an EL and ELI if ELC is signaled for the corresponding tunnel and the **entropy-label** command is enabled for the service. The EL and ELI is inserted at the same level in the label stack as it is in user data packets, which is under the innermost LSP label closest to the service payload that has advertised ELC. The EL and ELI therefore always reside at a different level in the label stack than the special-purpose labels related to the service payload (such as the Router Alert label). OAM packets at the LSP level, such as LSP ping and LSP trace, do not have the EL and ELI inserted.

2.1.2.6 Impact of EL and ELI on MTU and label stack depth

If EL insertion is configured for a VPLS or VLL service, the MTU of the SDP binding is automatically reduced to account for the overhead of the EL and ELI labels. The MTU is reduced whether the LSP tunnel used by the service is entropy-label-capable.

The EL requires the insertion of two additional labels in the label stack. In some cases, the insertion of EL and ELI may result in an unsupported label stack depth or large changes in the label stack depth during the lifetime of an LSP. For RSVP LSPs, use the following commands to provide local control at the head-end of an LSP over whether the entropy label is inserted on an LSP irrespective of the entropy label capability signaled from the egress LER, and control over how the additional label stack depth is accounted for.

```
configure router mpls entropy-label
configure router mpls lsp entropy-label
```

This control allows a user to avoid entropy label insertion where there is a risk of the label stack becoming too deep.

2.1.3 Label switching routers

LSRs perform the label switching function. LSRs perform different functions based on its position in an LSP. Routers in an LSP do one of the following:

- The router at the beginning of an LSP is the ingress label edge router (ILER). The ingress router can encapsulate packets with an MPLS header and forward it to the next router along the path. An LSP can only have one ingress router.
- A Label Switching Router (LSR) can be any intermediate router in the LSP between the ingress and egress routers. An LSR swaps the incoming label with the outgoing MPLS label and forwards the MPLS packets it receives to the next router in the MPLS path (LSP). An LSP can have 0 to 253 transit routers.
- The router at the end of an LSP is the egress label edge router (eLER). The egress router strips the MPLS encapsulation which changes it from an MPLS packet to a data packet, and then forwards the packet to its final destination using information in the forwarding table. Each LSP can have only one egress router. The ingress and egress routers in an LSP cannot be the same router.

A router in your network can act as an ingress, egress, or transit router for one or more LSPs, depending on your network design.

An LSP is confined to one IGP area for LSPs using constrained-path. They cannot cross an autonomous system (AS) boundary.

Static LSPs can cross AS boundaries. The intermediate hops are manually configured so the LSP has no dependence on the IGP topology or a local forwarding table.

2.1.3.1 LSP types

The following are LSP types:

- **static LSPs**

  A static LSP specifies a static path. All routers that the LSP traverses must be configured manually with labels. No signaling such as RSVP or LDP is required.

- **signaled LSPs**

  LSPs are set up using a signaling protocol such as RSVP-TE or LDP. The signaling protocol allows labels to be assigned from an ingress router to the egress router. Signaling is triggered by the ingress routers. Configuration is required only on the ingress router and is not required on intermediate routers. Signaling also facilitates path selection.

  There are two signaled LSP types:

  – **explicit-path LSPs**

    MPLS uses RSVP-TE to set up explicit path LSPs. The hops within the LSP are configured manually. The intermediate hops must be configured as either strict or loose meaning that the LSP must take either a direct path from the previous hop router to this router (strict) or can traverse through other routers (loose). You can control how the path is set up. They are similar to static LSPs but require less configuration. See RSVP.

  – **constrained-path LSPs**

    The intermediate hops of the LSP are dynamically assigned. A constrained path LSP relies on the Constrained Shortest Path First (CSPF) routing algorithm to find a path which satisfies the constraints for the LSP. In turn, CSPF relies on the topology database provided by the extended IGP such as OSPF or IS-IS.

    After the path is found by CSPF, RSVP uses the path to request the LSP set up. CSPF calculates the shortest path based on the constraints provided such as bandwidth, class of service, and specified hops.

If fast reroute is configured, the ingress router signals the routers downstream. Each downstream router sets up a detour for the LSP. If a downstream router does not support fast reroute, the request is ignored and the router continues to support the LSP. This can cause some of the detours to fail, but otherwise the LSP is not impacted.

The hop limit command option specifies the maximum number of hops that an LSP can traverse, including the ingress and egress routers. An LSP is not set up if the hop limit is exceeded. The hop count is set to 255 by default for the primary and secondary paths. It is set to 16 by default for a bypass or detour LSP path.

2.1.4 Bidirectional forwarding detection for MPLS LSPs

BFD for MPLS LSPs monitors the LSP between its LERs, regardless of how many LSRs the LSP may traverse. Therefore, it enables local faults on individual LSPs to be detected, whether they also affect forwarding for other LSPs or IP packet flows. This makes BFD for MPLS LSPs ideal for monitoring LSPs carrying specific high-value services, where detecting forwarding failures in the minimal amount of time is critical. The system raises an SNMP trap, and indicates the BFD session state in show and tools dump commands if an LSP BFD session goes down. It can also optionally determine the availability of the tunnel in TTM for use by applications, or trigger a switchover of the LSP from the currently active path to a backup path.

The system supports LSP BFD on RSVP LSPs. See Label Distribution Protocol for information about using LSP BFD on LDP LSPs and the *7750 SR and 7950 XRS Segment Routing and PCE User Guide* for information about Seamless BFD on SR-TE LSPs. BFD packets are encapsulated in an MPLS label stack corresponding to the FEC that the BFD session is associated with, as described in Section 7 of RFC 5884, *Bidirectional Forwarding Detection (BFD) for MPLS Label Switched Paths (LSPs).*

Because RSVP LSPs are unidirectional, a routed return path is used for the BFD control packets from the egress LER toward the ingress LER.

2.1.4.1 Bootstrapping and maintaining the BFD session

A BFD session on an LSP is bootstrapped using LSP ping. LSP ping is used to exchange the local and remote discriminator values to use for the BFD session for a particular MPLS LSP or FEC.

SR OS supports the sending of periodic LSP ping messages on an LSP for which LSP BFD has been enabled, as specified in RFC 5884. The ping messages are sent, along with the bootstrap TLV, at a configurable interval for LSPs on which the following command has been configured:

- **MD-CLI**

```
configure router mpls lsp bfd bfd-liveness true
```

- **classic CLI**

```
configure router mpls lsp bfd bfd-enable
```

The default interval is 60 seconds, with a maximum interval of 300 seconds. The LSP ping Echo Request message uses the system IP address as the default source address. An alternative source address consisting of any routable address that is local to the node may be configured, and is used if the local system IP address is not routable from the far-end node.

Note: SR OS does not take any action if a remote system fails to respond to a periodic LSP ping message. However, when the **show test-oam lsp-bfd** command is executed, it displays a return code of zero and a replying node address of 0.0.0.0 if the periodic LSP ping times out.

Use the following command to configure the periodic LSP ping interval.

```
configure router mpls lsp bfd lsp-ping-interval
```

LSP BFD sessions are recreated after a High-Availability (HA) switchover between active and standby CPMs. However, some disruption may occur to LSP ping because of LSP BFD.

At the tail end of an LSP, sessions are recreated on the standby CPM following an HA switchover. The following current information is lost from an active display of the following command.

```
tools dump test-oam lsp-bfd tail
```

- handle
- seqNum
- rc
- rsc

Any new, incoming bootstrap requests are dropped until LSP BFD becomes active. When LSP BFD becomes active, new bootstrap requests are considered.

2.1.4.2 LSP BFD configuration

About this task

Use the following content to configure LSP BFD.

Procedure

Step 1. Configure a BFD template.

Step 2. Enable LSP BFD on the tail node and configure the maximum number of LSP BFD sessions at the tail node.

Note: The default number of LSP BFD sessions is zero.

Step 3. Apply a BFD template to the LSP or LSP path.

Step 4. Enable BFD on the LSP or LSP path.

LSP BFD uses BFD templates to set generic BFD session command options.
Network processor BFD is not supported for LSPs. The minimum supported BFD receive or transmit timer interval for RSVP LSPs is 100 milliseconds. Therefore, an error is generated if a user tries to bind a BFD template with the following command or any unsupported transmit or receive interval value to an LSP.

- **MD-CLI**

```
configure bfd bfd-template type cpm-np
```

- **classic CLI**

```
configure router bfd bfd-template type cpm-np
```

An error is also generated when the user attempts to commit changes to a BFD template that is already bound to an LSP if the new values are invalid for LSP BFD.

BFD templates may be used by different BFD applications (for example, LSPs or pseudowires). If the BFD timer values are changed in a template, the BFD sessions on LSPs or spoke SDPs to which that template is bound tries to renegotiate their timers to the new values.

Example

The following example displays the configuration of a BFD template.

- **MD-CLI**

```
[ex:/configure bfd]
A:admin@node-2# info
    bfd-template "test" {
        echo-receive 1000
        multiplier 10
        receive-interval 1000
    }
```

- **classic CLI**
  In the classic CLI, the BFD template uses a **begin** and **commit** model. To edit any value within the BFD template, a **begin** command must be executed before the template context has been entered. However, a value is stored temporarily in the template-module until the **commit** command is issued. Values are actually used after the commit is issue.

```
A:node-2>config>router>bfd# info
----------------------------------------------
            bfd-template "test"
                receive-interval 1000
                multiplier 10
                echo-receive 1000
            exit
----------------------------------------------
```

2.1.4.3 Enabling and implementing limits for LSP BFD on a node

A user can enable support for LSP BFD and allow an upper limit to the number of supported sessions at the tail end node for LSPs. This is useful because BFD resources are shared among applications using BFD, so a user may want to set an upper limit to ensure that a specified number of BFD sessions are reserved for other applications. This is important at the tail end of LSPs where no per-LSP configuration context exists.

Use the following command to enable LSP BFD at the tail end of LSPs on the system and limit the maximum number of LSP BFD sessions established at the tail end of LSPs.

```
configure router lsp-bfd bfd-sessions
```

This command also enables the maximum number of LSP BFD sessions that can be established at the tail end of LSPs to be limited. The default is disabled. A user can specify the maximum number of LSP BFD sessions that the system allows to be established at the tail end of LSPs.

Use the following commands to control the multiplier and minimum receive and transmit intervals at the tail end of LSP BFD sessions.

```
configure router lsp-bfd tail-end multiplier
configure router lsp-bfd tail-end receive-interval
configure router lsp-bfd tail-end transmit-interval
```

Note: To use LSP BFD control packet timer values of less than one second for RSVP LSPs terminating on a node, the **tail-end receive-interval** and **tail-end transmit-interval** must be set to a value that is lower or equal to that at the LSP head end.

2.1.4.4 BFD configuration on RSVP-TE LSPs

LSP BFD is applicable to configured RSVP LSPs as well as mesh-p2p and one-hop-p2p auto-LSPs.

LSP BFD is configured on an RSVP-TE LSP, or on the primary or secondary path of an RSVP-TE LSP, under the **bfd** context at the LSP head end.

A BFD template must always be configured first. BFD is then enabled using the following command.

- **MD-CLI**

```
configure router mpls lsp bfd bfd-liveness true
```

- **classic CLI**

```
configure router mpls lsp bfd bfd-enable
```

When BFD is configured at the LSP level, BFD packets follow the currently active path of the LSP.

The BFD **bfd-template** command provides the control packet timer values for the BFD session to use at the LSP head end. Because there is no LSP configuration at the tail end of an RSVP LSP, the BFD state machine at the tail end initially uses system-wide default command options (the timer values are: min-tx: 1sec, min-rx: 1sec). The head end then attempts to adjust the control packet timer values when it transitions to the INIT state.

The BFD **wait-for-up-timer** command allows RSVP LSPs BFD sessions to come up during MBB and switchover events when the current active path is not BFD degraded (that is, BFD is not down). It is only applicable in cases where the BFD **failure-action failover-or-down** command is also configured (see Using LSP BFD for LSP path protection) and applies to the following:

- a path undergoing MBB when BFD is up on the original path
- the initial administrative enable of an LSP
- signaling retry of non-standby secondary paths

The **wait-for-up-timer** command is configured under the contexts that follow. The value that the system uses is the one configured under the same context in which BFD has been enabled.

Use the commands in following context to configure BFD on RSVP LSPs or Seamless BFD on SR-TE LSPs.

```
configure router mpls lsp bfd
```

Use the commands in the following context to configure BFD at the primary-path level.

```
configure router mpls lsp primary bfd
```

Use the commands in the following context to configure BFD on both standby and non-standby secondary paths.

```
configure router mpls lsp secondary bfd
```

BFD sessions are not established on these paths unless they are made active, unless **failure-action failover-or-down** is configured. See Using LSP BFD for LSP path protection. If **failure-action failover-or-down** is configured then the top three best-preference primary and standby paths (primary and up to two standby paths, or three standby paths if no primary is present) are programmed in the IOM, and BFD sessions are established on all of them.

It is not possible to configure LSP BFD on a secondary path or on P2MP LSPs.

LSP BFD at the LSP level and the path level is mutually exclusive. That is, if LSP BFD is already configured for the LSP then its configuration for the path is blocked. Likewise, it cannot be configured on the LSP if it is already configured at the path level.

LSP BFD is supported on auto-LSPs. The following examples show the configuration of LSP BFD on mesh P2P and one hop P2P auto-LSPs using the LSP template.

Example: LSP BFD on mesh point-to-point (MD-CLI)

```
[ex:/configure router "Base" mpls]
A:admin@node-2# info
    lsp-template "test1" {
        type p2p-rsvp-mesh
        bfd {
            bfd-liveness true
            bfd-template "test"
        }
    }
```

Example: LSP BFD on mesh point-to-point (classic CLI)

```
A:node-2>config>router>mpls# info
----------------------------------------------
...
            lsp-template "test1" mesh-p2p
                shutdown
                path-computation-method local-cspf
                bfd
                    bfd-template "test"
                    bfd-enable
                exit
            exit
----------------------------------------------
```

Example: LSP BFD on one-hop point-to-point (MD-CLI)

```
[ex:/configure router "Base" mpls]
A:admin@node-2# info
...
    lsp-template "test2" {
        type p2p-rsvp-one-hop
        bfd {
```

```
            bfd-liveness true
            bfd-template "test"
        }
    }
```

Example: LSP BFD on one-hop point-to-point (classic CLI)

```
A:node-2>config>router>mpls# info
----------------------------------------------
...
            lsp-template "test2" one-hop-p2p
                shutdown
                path-computation-method local-cspf
                hop-limit 2
                bfd
                    bfd-template "test"
                    bfd-enable
                exit
            exit
----------------------------------------------
```

2.1.4.5 Using LSP BFD for LSP path protection

SR OS can determine the forwarding state of an LSP from the LSP BFD session, allowing users of the LSP to determine whether their transport is operational. If BFD is down on an LSP path, then the path is considered to be BFD degraded by the system.

Use the commands in the following contexts to configure the action the system takes if BFD fails for an RSVP LSP or LDP prefix list.

```
configure router mpls lsp bfd failure-action
configure router mpls lsp-template bfd failure-action
configure router ldp lsp-bfd failure-action
```

There are three possible failure actions:

Note: For the LDP context, only the **failure-action down** command option applies.

- **failure-action down**

  The LSP is marked as unusable in TTM when BFD on the LSP goes down. This is applicable to RSVP and LDP LSPs.

- **failure-action failover**

  When LSP BFD goes down on the currently active path, then the LSP switches from the primary path to the secondary path, or from the currently active secondary path to the next-best preference secondary path. This is applicable to RSVP LSPs.

- **failure-action failover-or-down**

  Similar to **failure-action failover**, when LSP BFD goes down on the currently active path, then the LSP switches from the primary path to the secondary path, or from the currently active secondary path to the next best preference secondary path. However, **failure-action failover-or-down** also supports the ability to run BFD sessions simultaneously on the primary and up to two other secondary or standby paths. The system does not switch to a standby path for which the BFD session is down. If all BFD sessions for the LSP are down, then the LSP is marked as unusable in TTM. This is applicable to RSVP

LSPs and SR-TE LSPs. See the *7750 SR and 7950 XRS Segment Routing and PCE User Guide* for further details of its use for SR-TE LSPs.

In all cases, an SNMP trap is raised indicating that BFD has gone down on the LSP.

Note: Nokia recommends that BFD control packet timers are configured to a value that is large enough to allow for transient datapath disruptions that may occur when the underlying transport network recovers following a failure.

2.1.4.5.1 Failure-action down

Use the following commands to configure point-to-point RSVP (including mesh point-to-point and one-hop point-to-point auto-LSPs), and LDP LSPs.

```
configure router mpls lsp bfd failure-action down
configure router mpls lsp-template bfd failure-action down
configure router ldp lsp-bfd failure-action down
```

For RSVP LSPs, it is only supported at the LSP level and not at the primary or secondary path levels. When configured, an LSP is made unavailable as a transport if BFD on the LSP goes down.

If BFD is disabled, MPLS installs the LSP as "usable" in the TTM. The **failure-action** configuration is ignored.

If BFD is enabled and **failure-action** is disabled, MPLS installs the LSP as "usable" in the TTM regardless of the BFD session state. BFD generates BFD Up and BFD Down traps.

If BFD is enabled and **failure-action down** is configured:

- BFD traps are still generated when the BFD state machine transitions.
- If the BFD session is up for the active path of the LSP, the LSP is installed as "usable" in the TTM. If the BFD session is down for the active path, the LSP is installed as "not-usable" in the TTM.
- When an LSP is first activated, and its LSP BFD session first starts to come up, the LSP is installed as "not-usable" in the TTM to any user until the BFD session transitions to the up state, despite the FEC for the corresponding LSP being installed by the TTM. Users include all protocols, including those in RTM. A tunnel that is marked as down in the TTM is not available to RTM, and all routes using it are withdrawn. SDP auto-bind does not make use of an LSP until it is installed as "usable".
- If the BFD session is up on the active path and the LSP is installed as "usable" in the TTM, and if the LSP switches from its current active path to a new path, the system triggers a new BFD bootstrap using LSP ping for the new path, and waits for a maximum of 10 s for the BFD session to come up on the new path before switching traffic to it. If the BFD session does not come up on the new path after 10 s, the system switches to the new path anyway and install the LSP as "not-usable" in the TTM. This is the only scenario where a switch of the active path can be delayed because of the BFD transition state.
- If the BFD session is down on the active path and the LSP was already installed as "not-usable" in the TTM, then the system immediately switches to the new path without waiting for BFD to become operationally up.
- If BFD is disabled, MPLS installs the LSP as "usable" in the TTM. The **failure-action** configuration is ignored. LSP ping and LSP trace are still able to test an LSP when BFD is disabled.

Note: BFD session state is never used to trigger a switch of the active path when **failure-action down** is configured.

2.1.4.5.2 Failure-action failover

Use the following commands to configure a failure-action of failover. The following commands are supported for point-to-point RSVP LSPs (except mesh point-to-point and one-hop point-to-point auto-LSPs because these do not have a secondary path).

```
configure router mpls lsp bfd failure-action failover
configure router mpls lsp-template bfd failure-action failover
```

When failure action failover is configured, the system triggers a failover from the currently active path to the secondary path, the next-best preference secondary path, or the secondary-standby path of an LSP when an LSP BFD session configured at the LSP level transitions from an up state to a down state. Unlike **failure-action failover-or-down**, this failure action does not affect how LSP paths are programmed in the datapath and only runs LSP BFD on the active path.

The LSP is always marked as usable in the TTM, regardless of the BFD session state and BFD traps that are generated when the BFD state machine transitions. If BFD is enabled and failure-action failover is configured, the following conditions apply:

- It is possible to bring the LSP up regardless of the current BFD session state.
- If the BFD session transitions from up to down, the current path immediately switches to the next-best preference standby path.
- If MBB is triggered, then this occurs immediately on the primary path, regardless the BFD session state.
- If the user is concerned about detecting datapath failures that may not be detected by the control plane, Nokia recommends that the revert timer be set to its maximum value.
- LSP BFD only runs on the currently active path. It cannot determine if any non-active paths (for example, a secondary path or primary path during reversion) that the system switches to is up and forwarding. The system relies on the normal control plane mechanisms.

Table 3: Changes to the failure action while BFD is down describes how the system behaves if a user changes the failure-action while BFD is down. The LSP remains on the current path unless (or until) the control plane takes action or the revert timer expires.

Table 3: Changes to the failure action while BFD is down

Action combination (old action/new action)	Tunnel flag in TTM
None/Down	as unusable
None/Failover	as usable
Down/None	as usable
Down/Failover	as usable
Failover/None	as usable
Failover/Down	as unusable

2.1.4.5.3 LSP active path failover triggers

The active path of an LSP is switched to an alternative path in the following cases:

- the active path goes into degraded state because of FRR or soft preemption
- the active path is degraded because the BFD session is going from up to down; only applicable if the failure action is set to **failover** or **failover-or-down** for the MPLS LSP or LSP template) in the following contexts

```
configure router mpls lsp bfd failure-action
configure router mpls lsp-template bfd failure-action
```

- reverting from a secondary or standby path to the primary path (with or without a reverter time configured)
- switching between secondary or standby paths because of path preference
- switching between secondary or standby paths when using the following commands

```
tools perform router mpls switch-path
tools perform router mpls force-switch-path
```

- switching because of an MBB on the active path where the old and new path have the same configuration for enabling BFD
- switching from the primary path to secondary or standby paths using the following command

```
tools perform router mpls manual-switch-path
```

Table 4: Path switchover triggers based on BFD failure action configuration describes path switchover events depending on the failure action configuration.

Table 4: Path switchover triggers based on BFD failure action configuration

BFD failure-action configuration	Old active path		New active path	Switchover to new path
	bfd-enable configuration at LSP or path	BFD session state	bfd-enable configuration at LSP or path	
no failure action fail action is **failover**	Any	Any	Any	Switch immediately without checking the BFD session state on new path.
failure action is **down**	BFD enabled	BFD session up	BFD enabled	Wait for a maximum of 10 seconds for the BFD session to come up on the new path before switching. If the BFD session does not come up on the new path after 10 seconds, switch anyway.

BFD failure-action configuration	Old active path		New active path	Switchover to new path
	bfd-enable configuration at LSP or path	BFD session state	bfd-enable configuration at LSP or path	
			BFD disabled	Switch immediately without checking the BFD session state on new path.
		BFD session down	BFD enabled	Switch immediately without checking the BFD session state on new path.
			BFD disabled	Switch immediately without checking the BFD session state on new path.
	BFD disabled	—	BFD enabled	Wait for a maximum of 10 seconds for the BFD session to come up on the new path before switching. If the BFD session does not come up on the new path after 10 seconds, switch anyway.
			BFD disabled	Switch immediately without checking the BFD session state on new path.

For the **failure-action failover-or-down** command, a path is in the degraded state if it has BFD enabled and the BFD session is not up. Switching between primary, standby, and secondary paths of the LSP follows rules of the best path selection algorithm, for example, a non-degraded path is better than a degraded path and a degraded primary is better than a degraded standby or secondary path. Because the BFD degraded state affects LSP active path selection, waiting for BFD to come up on new path is already accounted for and these cases have been excluded from Table 5: MBB path switching with failure-action failover-or-down.

Switching to an MBB path requires waiting for the BFD session to come up on the new MBB path. These cases are described in Table 5: MBB path switching with failure-action failover-or-down. This applies to MBB on both active and inactive paths to reduce the toggling of a BFD degraded state on the path.

Table 5: MBB path switching with failure-action failover-or-down

BFD failure-action configuration	Old path		New MBB path	Switching to new path
	bfd-enable configuration at LSP or path	**BFD session state**	**bfd-enable configuration at LSP or path**	
failure action is **failover-or-down**	BFD enabled	BFD session up	BFD enabled	Wait for a maximum of "*w*" seconds for the BFD session to come up on the new path before switching. If the BFD session does not come up on the new path after "*w*" seconds, switch anyway. Where *w* is the BFD **wait-for-up-timer** from the context where BFD is enabled.
			BFD disabled	This case is not applicable because the MBB path has same BFD configuration as existing path.
	BFD enabled	BFD session down	BFD enabled	Switch immediately without checking the BFD session state on new path.
			BFD disabled	This case is not applicable because the MBB path has same BFD configuration as existing path.
	BFD disabled	—	BFD enabled	This case is not applicable because the MBB path has the same BFD configuration as existing path.
			BFD disabled	Switch immediately without checking the BFD session state on new path.

2.1.4.6 MPLS/RSVP on broadcast interface

The MPLS/RSVP on Broadcast Interface feature allows MPLS and RSVP to distinguish neighbors from one another when the outgoing interface is a broadcast interface connecting to multiple neighbors over a broadcast domain. More specifically, in the case where a BFD session toward a specific neighbor on the broadcast domain goes down, the consecutive actions (for example, FRR switchover) only concerns the

LSPs of the affected neighbor. Previously, the actions would have been taken on the LSPs of all neighbors over the outgoing interface.

2.1.5 MPLS facility bypass method of MPLS FRR

The MPLS facility bypass method of MPLS Fast Reroute (FRR) functionality is extended to the ingress node.

The behavior of an LSP at an ingress LER with both fast reroute and a standby LSP path configured is as follows:

- **when a downstream detour becomes active at a point of local repair (PLR)**

  The ingress LER switches to the standby LSP path. If the primary LSP path is repaired subsequently at the PLR, the LSP switches back to the primary path. If the standby goes down, the LSP is switched back to the primary, even though it is still on the detour at the PLR. If the primary goes down at the ingress while the LSP is on the standby, the detour at the ingress is cleaned up and for one-to-one detours a "path tear" is sent for the detour path. In other words, the detour at the ingress does not protect the standby. If and when the primary LSP is again successfully re-signaled, the ingress detour state machine is restarted.

- **when the primary fails at the ingress**

  The LSP switches to the detour path. If a standby is available, the LSP switches to standby after the expiration of the hold timer configured for the MPLS router in the following command.

  ```
  configure router mpls hold-timer
  ```

  If the **hold-timer** is disabled, then a switchover to standby would occur immediately. On the successful global revert of the primary path, the LSP would switch back to the primary path.

Note: Admin groups are not taken into account when creating detours for LSPs.

2.1.6 Manual bypass LSP

SR OS implements dynamic bypass tunnels as defined in RFC 4090, *Fast Reroute Extensions to RSVP-TE for LSP Tunnels*. When an LSP is signaled and the local protection flag is set in the session_attribute object or the FRR object in the path message indicates that facility backup is needed, the PLR establishes a bypass tunnel to provide node and link protection. The bypass tunnel is selected if a bypass LSP that merges in a downstream node with the protected LSP exists, and if this LSP satisfies the constraints in the FRR object.

With the manual bypass feature, an LSP can be preconfigured from a PLR that is used exclusively for bypass protection. When a Path message for a new LSP requests bypass protection, the node first checks if a manual bypass tunnel satisfying the path constraints exists. If one is found, it is selected. If no manual bypass tunnel is found, the router dynamically signals a bypass LSP in the default behavior. Users can disable the dynamic bypass creation on a per node basis using the CLI.

A maximum of 1000 associations of primary LSP paths can be made with a single manual bypass by default. Increase or decrease the number of associations with the following command.

```
configure router mpls max-bypass-associations
```

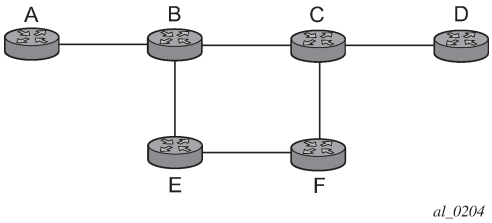
If dynamic bypass creation is disabled on the node, it is recommended to configure additional manual bypass LSPs to handle the required number of associations.

See Configuring manual bypass tunnels for configuration information.

2.1.6.1 PLR bypass LSP selection rules

The PLR uses rules to select a bypass LSP among multiple manual and dynamic bypass LSPs at the time of establishment of the primary LSP path or when searching for a bypass for a protected LSP which does not have an association with a bypass tunnel: Figure 3: Bypass tunnel nodes shows an example of bypass tunnel nodes.

Figure 3: Bypass tunnel nodes



The rules are:

1. The MPLS task in the PLR node checks if an existing manual bypass satisfies the constraints. If the path message for the primary LSP path indicated node protection is needed, which is the default LSP FRR setting at the head end node, MPLS task searches for a node-protect bypass LSP. If the path message for the primary LSP path indicated link protection is needed, then it searches for a link-protect bypass LSP.
2. If multiple manual bypass LSPs satisfying the path constraints exist, it prefers a manual-bypass terminating closer to the PLR over a manual bypass terminating further away. If multiple manual bypass LSPs satisfying the path constraints terminate on the same downstream node, it selects one with the lowest IGP path cost or if in a tie, picks the first one available.
3. If none satisfies the constraints and dynamic bypass tunnels have not been disabled on PLR node, then the MPLS task in the PLR checks if any of the already established dynamic bypasses of the requested type satisfy the constraints.
4. If none do, then the MPLS task asks CSPF to check if a new dynamic bypass of the requested type, node-protect or link-protect, can be established.
5. If the path message for the primary LSP path indicated node protection is needed, and no manual bypass was found after Step 1, or no dynamic bypass LSP was found after one attempt of performing Step 3, the MPLS task repeats Steps 1 to 3 looking for a suitable link-protect bypass LSP. If none are found, the primary LSP has no protection and the PLR node must clear the "local protection available" flag in the IPv4 address sub-object of the RRO starting in the next Resv refresh message it sends upstream. Node protection continues to be attempted using a background re-evaluation process.
6. If the path message for the primary LSP path indicated link protection is needed, and no manual bypass was found after Step 1, or no dynamic bypass LSP was found after performing Step 3, the primary LSP has no protection and the PLR node must clear the "local protection available" flag in the IPv4 address sub-object of the RRO starting in the next RESV refresh message it sends upstream. The PLR does not search for a node-protect' bypass LSP in this case.

7. If the PLR node successfully makes an association, it must set the "local protection available" flag in the IPv4 address sub-object of the RRO starting in the next RESV refresh message it sends upstream.
8. For all primary LSP that requested FRR protection but are not currently associated with a bypass tunnel, the PLR node on reception of RESV refresh on the primary LSP path repeats Steps 1 to 7.

If the user disables dynamic-bypass tunnels on a node while dynamic bypass tunnels were activated and were passing traffic, traffic loss occurs on the protected LSP. Furthermore, if no manual bypass exist that satisfy the constraints of the protected LSP, the LSP remains without protection.

If the user configures a bypass tunnel on node B and dynamic bypass tunnels have been disabled, LSPs which have been previously signaled and which were not associated with any manual bypass tunnel, for example, none existed, are associated with the manual bypass tunnel if suitable. The node checks for the availability of a suitable bypass tunnel for each of the outstanding LSPs every time a RESV message is received for these LSPs.

If the user configures a bypass tunnel on node B and dynamic bypass tunnels have not been disabled, LSPs which have been previously signaled over dynamic bypass tunnels are not automatically switched into the manual bypass tunnel even if the manual bypass is a more optimized path. The user must perform a make before break at the head end of these LSPs.

If the manual bypass goes into the down state in node B and dynamic bypass tunnels have been disabled, node B (PLR) clears the "protection available" flag in the RRO IPv4 sub-object in the next RESV refresh message for each affected LSP. It then tries to associate each of these LSPs with one of the manual bypass tunnels that are still up. If it finds one, it makes the association and sets again the "protection available" flag in the next RESV refresh message for each of these LSPs. If it could not find one, it keeps checking for one every time a RESV message is received for each of the remaining LSPs. When the manual bypass tunnel is back UP, the LSPs which did not find a match are associated back to this tunnel and the protection available flag is set starting in the next RESV refresh message.

If the manual bypass goes into the down state in node B and dynamic bypass tunnels have not been disabled, node B signals automatically a dynamic bypass to protect the LSPs if a suitable one does not exist. Similarly, if an LSP is signaled while the manual bypass is in the down state, the node only signals a dynamic bypass tunnel if the user has not disabled dynamic tunnels. When the manual bypass tunnel is back into the UP state, the node does not switch the protected LSPs from the dynamic bypass tunnel into the manual bypass tunnel.

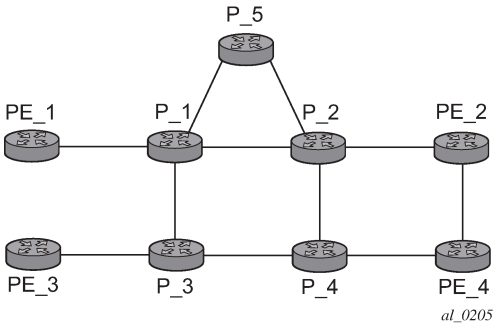
2.1.6.2 FRR facility background evaluation task

The MPLS Fast Re-Route (FRR) feature implements a background task to evaluate Path State Block (PSB) associations with bypass LSP. The following is the task evaluation behavior:

- For PSBs that have facility FRR enabled but no bypass association, the task triggers a FRR protection request.
- For PSBs that have requested node-protect bypass LSP but are currently associated with a link-protect bypass LSP, the task triggers a node-protect FRR request.
- For PSBs that have LSP statistics enabled but the statistic index allocation failed, the task re-attempts index allocation.

The MPLS FRR background task enables PLRs to be aware of the missing node protection and allows them to probe regularly for a node-bypass. Figure 4: FRR node-protection example shows an example of FRR node protection.

Figure 4: FRR node-protection example



The following describes an LSP scenario where:

- LSP 1: from PE_1 to PE_2, with CSPF, FRR facility node-protect enabled
- P_1 protects P_2 with bypass-nodes P_1 -P_3 - P_4 - PE_4 -PE_2
- If P_4 fails, P_1 tries to establish the bypass-node three times
- When the bypass-node creation fails, P_1 protects link P_1-P_2
- P_1 protects the link to P_2 through P_1 - P_5 - P_2
- P_4 returns online

LSP 1 has requested node protection, but because there is no available path, it can only obtain link protection. Therefore, every 60 seconds the PSB background task triggers the PLR for LSP 1 to search for a new path that can provide node protection. When P_4 is back online and such a path is available, a new bypass tunnel is signaled and LSP 1 gets associated with this new bypass tunnel.

2.1.7 Uniform FRR failover time

The failover time during FRR consists of a detection time and a switchover time. The detection time corresponds to the time it takes for the RSVP control plane protocol to detect that a network IP interface is down or that a neighbor/next-hop over a network IP interface is down. The control plane can be informed of an interface down event when the event is caused by a failure in a lower layer such in the physical layer. The control plane can also detect the failure of a neighbor/next-hop on its own by running a protocol such as Hello, keepalive, or BFD.

The switchover time is measured from the time the control plane detects the failure of the interface or neighbor/next-hop to the time the XCMs or IOMs completes the reprogramming of all the impacted ILM or service records in the datapath. This includes the time it takes for the control plane to send a down notification to all XCMs or IOMs to request a switch to the backup NHLFE.

Uniform Fast-Reroute (FRR) failover enables the switchover of MPLS and service packets from the outgoing interface of the primary LSP path to that of the FRR backup LSP within the same amount of time regardless of the number of LSPs or service records. This is achieved by updating Ingress Label Map (ILM) records and service records to point to the backup Next-Hop Label to Forwarding Entry (NHLFE) in a single operation.

2.1.8 Automatic bandwidth allocation for RSVP LSPs

2.1.8.1 Enabling and disabling auto-bandwidth allocation on an LSP

This section discusses an auto-bandwidth hierarchy configurable in the following context.

```
configure router mpls lsp
```

Adding auto-bandwidth at the LSP level starts the measurement of LSP bandwidth described in Measurement of LSP bandwidth and allows auto-bandwidth adjustments to take place based on the triggers described in Periodic automatic bandwidth adjustment.

When an LSP is first established, the bandwidth reserved along its primary path is controlled by the following command, whether the LSP has auto-bandwidth enabled or not.

```
configure router mpls lsp primary bandwidth
```

The bandwidth reserved along a secondary path is controlled by the following command.

```
configure router mpls lsp secondary bandwidth
```

When **auto-bandwidth** is enabled and a trigger occurs, the system attempts to change the bandwidth of the LSP to a value between **min-bandwidth** and **max-bandwidth**, which are configurable values in the following context.

```
configure router mpls lsp auto-bandwidth
```

The **min-bandwidth** option is the minimum bandwidth that **auto-bandwidth** can signal for the LSP, and the **max-bandwidth** option is the maximum bandwidth that can be signaled. The user can set the **min-bandwidth** to the same value as the primary path bandwidth but the system does not enforce this restriction. The system allows:

- no **min-bandwidth** to be configured. In this case, the implicit minimum is 0 Mb/s.
- no **max-bandwidth** to be configured, as long as overflow-triggered auto-bandwidth is not configured. In this case, the implicit maximum is infinite (effectively 100 Gb/s).
- the configured primary path bandwidth to be outside the range of **min-bandwidth** to **max-bandwidth**
- the auto-bandwidth configuration can be changed at any time on an operational LSP; in most cases, the changes have no immediate impact, but subsequent sections describe some exceptions.

All of the auto-bandwidth adjustments discussed are performed using MBB procedures.

Auto-bandwidth can be added to an operational LSP at any time (without the need to administratively disable the LSP or path), but no bandwidth change occurs until a future trigger event. Auto-bandwidth may also be removed from an operational LSP at any time and this causes an immediate MBB bandwidth change to be attempted using the configured primary path bandwidth.

A change to the configured bandwidth of an auto-bandwidth LSP has no immediate effect. The change only occurs if the LSP or path goes down (because of a failure or an administrative action) and comes back up, or if auto-bandwidth is removed from the LSP. The user can force an auto-bandwidth LSP to be resized immediately to an arbitrary bandwidth using the appropriate tools commands.

2.1.8.2 Auto-bandwidth on LSPs with secondary or secondary standby paths

Auto-bandwidth is supported for LSPs that have secondary or secondary standby paths. A secondary path is only initialized at its configured bandwidth when it is established, and the bandwidth is adjusted only when the secondary path becomes active.

Auto-bandwidth on LSPs with standby paths use the following terminology.

Current bandwidth	the last known reserved bandwidth for the LSP; may be the value of a different path from the currently active path
Operational bandwidth	the last known reserved bandwidth for a specified path, as recorded in the MIB
Configured bandwidth	the bandwidth explicitly configured for the LSP path by the user in CLI
Active path	the path (primary or secondary) the LSP currently uses to forward traffic
Signaled bandwidth	the new bandwidth value signaled during an MBB

A secondary or standby secondary path is initially signaled with its configured bandwidth. Setup for the secondary path is triggered only when the active path goes down or becomes degraded (for example, because of FRR or preemption). An auto-bandwidth triggered bandwidth adjustment (auto bandwidth MBB) only takes place on the active path. For example, if an auto-bandwidth adjustment occurs on the primary path, which is currently active, no adjustment is made at that time to the secondary path because that path is not active.

When the active path changes, the current bandwidth is updated to the operational bandwidth of the newly active path. While the auto-bandwidth MBB on the active path is in progress, a statistics sample could be triggered, and this would be collected in the background. Auto-bandwidth computations use the current bandwidth of the newly active path. In case the statistics sample collection results in a bandwidth adjustment, the in-progress auto-bandwidth MBB is restarted. If after five attempts, the auto-bandwidth MBB fails, the current bandwidth and secondary operational bandwidth remain unchanged.

For a secondary or standby secondary path, if the active path for an LSP changes (without the LSP going down), an auto-bandwidth MBB is triggered for the new active path. The bandwidth used to signal the MBB is the operational bandwidth of the previous active path. If the MBB fails, it retries with a maximum of five attempts. The reserved bandwidth of the newly active path is therefore its configured bandwidth until the MBB succeeds.

For a secondary path where the active path goes down, the LSP goes down temporarily until the secondary path is setup. If the LSP goes down, all statistics and counters are cleared, so the previous path operational bandwidth is lost. That is, the operational BW of a path is not persistent across LSP down events. In this case, there is no immediate bandwidth adjustment on the secondary path.

The following algorithm is used to determine the signaled bandwidth on a newly active path:

- For a path that is operationally down, signaled bandwidth = configured bandwidth.
- For the active path, if an auto-bandwidth MBB adjustment is in progress, signaled bandwidth = previous path operational bandwidth for the first five attempts. For the remaining attempts, the signaled bandwidth = operational BW.
- For an MBB on the active path (other than an auto-BW MBB), MBB signaled BW = operational BW.
- For an MBB on the inactive path, MBB signaled bandwidth = configured BW.

If the primary path is not the currently active path and it has not gone down, then any MBB uses the configured bandwidth for the primary path. However, if the configured bandwidth is changed for a path that is currently not active, then a config change MBB is not triggered.

If the standby is SRLG enabled, and the active path is the standby, and the primary comes up, this immediately triggers a delayed retry MBB on the standby. If the delayed retry MBB fails, immediate reversion to the primary occurs regardless of the retry timer.

When the system reverts from a secondary standby or secondary path to the primary path, a Delayed Retry MBB is attempted to bring the bandwidth of the standby path back to its configured bandwidth. Delayed Retry MBB is attempted one time, and if it fails, the standby is torn down. A Delayed Retry MBB has highest priority among all MBBs, so it takes precedence over any other MBB in progress on the standby path (for example, config change or preemption).

The system carries over the last signaled bandwidth of the LSP over multiple failovers. For example, if an LSP is configured with auto-bandwidth for some time, and adjusts its currently reserved bandwidth for the primary, and Monitor mode is then enabled, bandwidth adjustment on the primary ceases, but the bandwidth remains reserved at the last adjusted value. Next, the LSP fails over to a secondary or secondary standby. The secondary inherits the last reserved bandwidth of the primary, but then disables further adjustment as long as monitoring mode is enabled.

The system's ability to carry-over the last signaled BW across failovers has the following limitations:

- **case 1**

  If the LSP fails over from path1 to path2 and the auto-bandwidth MBB on path2 is successful, the last signaled bandwidth is carried over when the LSP reverts back to path1 or fails over to a new path3. This may trigger an auto-bandwidth MBB on the new active path to adjust its bandwidth to last signaled BW.

- **case 2**

  If the LSP fails over from path1 to path2 and the auto-bandwidth MBB on path2 is still in progress and the LSP reverts back to path1 or fails over to a new path3, the last signaled BW is carried over to the new active path (path1 or path3) and this may result in an auto-bandwidth MBB on that path.

- **case 3**

  If the LSP fails over from path1 to path2 and the auto-bandwidth MBB on path2 fails (after 5 retry attempts), the last signaled bandwidth from when path1 was active is lost. Therefore, when the LSP reverts back to path1 or fails over to a new path3, the original signaled bandwidth from path1 is not carried over. However the signaled bandwidth of path2 is carried over to the new active path (path1 or path3) and may trigger an AutoBW on that path.

2.1.8.3 Measurement of LSP bandwidth

A user must configure the LSP for egress statistics collection at the ingress LER to allow for automatic adjustment of RSVP LSP bandwidth based on measured traffic rate into the tunnel. The following example displays the configuration of egress statistics collection at the ingress LER.

Example: Egress statistics collection at the ingress LER (MD-CLI)

```
[ex:/configure router "Base" mpls lsp "test3"]
A:admin@node-2# info
...
    egress-statistics {
        admin-state enable
        collect-stats true
        accounting-policy 99
```

```
    }
```

Example: Egress statistics collection at the ingress LER (classic CLI)

```
A:node-2>config>router>mpls>lsp$ info
----------------------------------------------
                egress-statistics
                    collect-stats
                    accounting-policy 99
                    no shutdown
                exit
                no shutdown
----------------------------------------------
```

All LSPs configured for accounting, including any configured for auto-bandwidth based on traffic measurements, must reference the same accounting policy. The following example displays the configuration of an accounting-policy.

Example: Accounting policy configuration (MD-CLI)

```
[ex:/configure log]
A:admin@node-2# info
    accounting-policy 99 {
        collection-interval 5
        record combined-mpls-lsp-egress
    }
```

Example: Accounting policy configuration (classic CLI)

```
A:node-2>config>log# info
----------------------------------------------
        accounting-policy 99
            shutdown
            record combined-mpls-lsp-egress
            collection-interval 5
        exit
```

The **combined-mpls-lsp-egress** record name in the following context records egress packet, byte counts, and bandwidth measurements (expressed in packets per second and Mb/s).

```
configure log accounting-policy record
```

When egress statistics are enabled the CPM collects stats from all XCMs or IOMs involved in forwarding traffic belonging to the LSP (whether the traffic is currently leaving the ingress LER via the primary LSP path, a secondary LSP path, an FRR detour path, or an FRR bypass path). The egress statistics have counts for the number of packets and bytes forwarded per LSP on a per-forwarding class, per-priority (in-profile vs. out-of-profile) basis. The ingress LER calculates a traffic rate for the LSP as follows:

Average data rate of LSP[x] during interval[i] = F(x,i) - F(x,i-1)/sample interval

where

F(x,i) is the total number of bytes belongings to LSP[x], regardless of forwarding-class or priority, at time[i]

sample interval = time[i] - time[i-1], time[i+1] - time[i], and so on.

The sample interval is the product of the sample multiplier and the collection interval specified in the auto-bandwidth accounting policy. A sample multiplier for all LSPs may be configured using the following command.

```
configure router mpls auto-bandwidth-multipliers sample-multiplier
```

This preceding sample-multiplier value can be overridden on a per-LSP basis in the following context.

```
configure router mpls lsp auto-bandwidth multiplier
```

The default value of sample multiplier (the value that would result from the **auto-bandwidth-multipliers** command being disabled) is 1, which means the default sample interval is 300 seconds.

Over a longer period of time called the adjust interval the router keeps track of the maximum average data rate recorded during any constituent sample interval. The adjust interval is the product of adjust multiplier and the collection interval specified in the auto-bandwidth accounting policy. A default adjust multiplier for all LSPs may be configured using the following command.

```
configure router mpls auto-bandwidth-multipliers adjust-multiplier
```

The preceding adjust-multiplier value can be overridden on a per-LSP basis using the following context.

```
configure router mpls lsp auto-bandwidth multipliers
```

The default value of the **adjust-multiplier** command option (the value that would result from the **auto-bandwidth-multiplier** command being disabled) is 288. This means the default adjust interval is 86400 seconds or 24 hours. The system enforces the restriction that the **adjust-multiplier** is equal to or greater than **sample-multiplier**. Nokia recommends that the **adjust-multiplier** be an integer multiple of the **sample-multiplier**.

The collection interval in the auto-bandwidth accounting policy can be changed at any time, without disabling any of the LSPs that rely on that policy for statistics collection.

The sample multiplier in either of the following contexts can be changed at any time.

```
configure router mpls auto-bandwidth-multipliers
configure router mpls lsp auto-bandwidth multipliers
```

This change has no effect until the beginning of the next sample interval. In this case the adjust interval does not change and information about the current adjust interval (such as the remaining adjust multiplier, the maximum average data rate) is not lost when the sample multiplier change takes effect.

The system allows the adjust multiplier (at the **mpls** level or the **lsp auto-bandwidth** level) to be changed at any time as well but in this case the new value shall have no effect until the beginning of the next adjust interval.

Byte counts collected for LSP statistics include Layer 2 encapsulation (Ethernet headers and trailers) and therefore average data rates measured by this feature include Layer 2 overhead as well.

2.1.8.4 Passive monitoring of LSP bandwidth

The system offers the option to not take any action to adjust the bandwidth reservation, regardless of how different the measured bandwidth is from the current reservation. Enable passive monitoring with the following command.

```
configure router mpls lsp-template auto-bandwidth monitor-bandwidth
```

Use the following command to view the maximum average data rate in the current adjust interval and the remaining time in the current adjust interval.

```
show router mpls lsp detail
```

2.1.8.5 Periodic automatic bandwidth adjustment

Automatic bandwidth allocation is supported on any RSVP LSP that has MBB enabled in the following context.

```
configure router mpls lsp adaptive
```

If the following command is enabled, the LSP is not resignaled to adjust its bandwidth to the calculated values.

```
configure router mpls lsp auto-bandwidth monitor-bandwidth
```

If an eligible RSVP LSP is configured for auto-bandwidth using the following command, the ingress LER decides for every adjust interval whether to attempt an auto-bandwidth adjustment.

```
configure router mpls lsp auto-bandwidth
```

The following options are defined.

Current bandwidth

the currently reserved bandwidth of the LSP; this is the operational bandwidth that is already maintained in the MIB

Measured bandwidth

the maximum average data rate in the current adjust interval

Signaled bandwidth

the bandwidth that is provided to the CSPF algorithm and signaled in the SENDER_TSPEC and FLOWSPEC objects when an auto-bandwidth adjustment is attempted

Minimum bandwidth

the configured minimum bandwidth of the LSP

Maximum bandwidth

the configured maximum bandwidth of the LSP

Bandwidth percentage up

the minimum difference between measured bandwidth and current bandwidth, expressed as a percentage of current bandwidth, for increasing the bandwidth of the LSP

Bandwidth up

the minimum difference between measured bandwidth and current bandwidth, expressed as an absolute bandwidth relative to current bandwidth, for increasing the bandwidth of the LSP. This is optional; if not defined the value is 0.

Bandwidth percentage down

the minimum difference between current bandwidth and measured bandwidth, expressed as a percentage of current bandwidth, for decreasing the bandwidth of the LSP

Bandwidth down

the minimum difference between current bandwidth and measured bandwidth, expressed as an absolute bandwidth relative to current bandwidth, for decreasing the bandwidth of the LSP. This is optional; if not defined the value is 0.

At the end of every adjust interval the system decides if an auto-bandwidth adjustment should be attempted. The heuristics are as follows:

- If the measured bandwidth exceeds the current bandwidth by more than the percentage threshold and also by more than the absolute threshold then the bandwidth is re-signaled to the measured bandwidth (subject to minimum and maximum constraints).
- If the measured bandwidth is less than the current bandwidth by more than the percentage threshold and also by more than the absolute threshold then the bandwidth is re-signaled to the measured bandwidth (subject to minimum and maximum constraints).
- If the current bandwidth is greater than the maximum bandwidth then the LSP bandwidth is re-signaled to the maximum bandwidth, even if the thresholds have not been triggered.
- If the current bandwidth is less than the minimum bandwidth then the LSP bandwidth is re-signaled to minimum bandwidth, even if the thresholds have not been triggered.

Changes to the minimum bandwidth, maximum bandwidth, and any of the threshold values (up, up%, down, down%) are permitted at any time on an operational LSP, but the changes have no effect until the next auto-bandwidth trigger (for example, adjust interval expiry).

If the measured bandwidth exceeds the current bandwidth by more than the percentage threshold and also by more than the absolute threshold then the bandwidth is re-signaled to the measured bandwidth (subject to minimum and maximum constraints).

The adjust interval and maximum average data rate are reset whether the adjustment succeeds or fails. If the bandwidth adjustment fails (for example, CSPF cannot find a path), the existing LSP is maintained with its existing bandwidth reservation. The system does not retry the bandwidth adjustment (for example, per the configuration of the LSP retry timer and retry limit).

2.1.8.6 Overflow-triggered auto-bandwidth adjustment

For cases where the measured bandwidth of an LSP has increased significantly since the start of the current adjust interval, it may be desirable for the system to preemptively adjust the bandwidth of the LSP and not wait until the end of the adjust interval.

The following options are defined.

Current bandwidth

the currently reserved bandwidth of the LSP

Sampled bandwidth

the average data rate of the sample interval that just ended

Measured bandwidth

the maximum average data rate in the current adjust interval

Signaled bandwidth

the bandwidth that is provided to the CSPF algorithm and signaled in the SENDER_TSPEC and FLOWSPEC objects when an auto-bandwidth adjustment is attempted

Maximum bandwidth

the configured maximum bandwidth of the LSP

Percentage threshold

the minimum difference between the sampled bandwidth and the current bandwidth, expressed as a percentage of the current bandwidth, for counting an overflow event

Minimum threshold

the minimum difference between the sampled bandwidth and the current bandwidth, expressed as an absolute bandwidth relative to current bandwidth, for counting an overflow event. This is optional; if not defined the value is 0.

When a sample interval ends it is counted as an overflow if:

- The sampled bandwidth exceeds the current bandwidth by more than the percentage threshold and by more than the absolute bandwidth threshold (if defined).
- When the number of overflow samples reaches a configured limit, an immediate attempt is made to adjust the bandwidth to the measured bandwidth (subject to the min and max constraints).

If the bandwidth adjustment is successful, then the adjust-interval, maximum average data rate, and overflow count are all reset. If the bandwidth adjustment fails, then the overflow count is reset but the adjust-interval and maximum average data rate continue with current values. It is possible that the overflow count reach the configured limit again before the end of adjust-interval is reached and this triggers again an immediate auto-bandwidth adjustment attempt.

The overflow configuration command fails if the max-bandwidth of the LSP has not been defined.

The threshold limit can be changed on an operational auto-bandwidth LSP at any time and the change should take effect at the end of the current sample interval (for example, if the user decreases the overflow limit to a value lower than the current overflow count, then auto-bandwidth adjustment takes place as soon as the sample interval ends). The threshold values can also be changed at any time (for example, percentage threshold and minimum threshold), but the new values do not take effect until the end of the current sample interval.

2.1.8.7 Manually-triggered auto-bandwidth adjustment

Use the following command to trigger auto-bandwidth adjustment to attempt an immediate auto-bandwidth adjustment for either one specific LSP or all active LSPs.

```
tools perform router mpls adjust-autobandwidth [lsp lsp-name [force [bandwidth mbps]]]
```

If the LSP is not specified, the system assumes the command applies to all LSPs. If an LSP name is provided, the command applies to that specific LSP only and the **force** command option (with or without a bandwidth) can be used.

If **force** is not specified (or the command is not LSP-specific), the measured bandwidth is compared to the current bandwidth and bandwidth adjustment may or may not occur.

If **force** is specified and a bandwidth is not provided, the threshold checking is bypassed but the minimum and maximum bandwidth constraints are still enforced.

If **force** is specified with a bandwidth (in Mb/s), the signaled bandwidth is set to this bandwidth. There is no requirement that the bandwidth entered as part of the command fall within the range of the **min-bandwidth** rate to **max-bandwidth** rate.

The adjust interval, maximum average data rate, and overflow count are not reset by the manual **auto-bandwidth** command, whether the bandwidth adjustment succeeds or fails. The overflow count is reset only if the manual automatic bandwidth adjustment is successful.

2.1.8.8 Operational bandwidth carryover between active paths

SR OS supports carrying over of the operational bandwidth (for example, the last successfully signaled bandwidth) of an LSP path to the next active path following a switchover. The new active path can be a secondary or a primary path. The bandwidth is not lost even when the previously active path fails. The last successfully signaled bandwidth is known as the last adjusted bandwidth.

Use the following command to configure operational bandwidth carryover.

```
configure router mpls lsp auto-bandwidth use-last-adj-bw
```

When enabled, secondary paths are initially signaled with the last adjusted bandwidth of the primary, and not the configured bandwidth. If signaling a secondary at this bandwidth fails after a number of retries, then the path fails instead of falling back to using the configured bandwidth. Use the following command to configure the number of retries for secondary paths at the last adjusted bandwidth.

```
configure router mpls lsp auto-bandwidth use-last-adj-bw secondary-retry-limit
```

Disabling the primary or any configuration that changes events causing a switch to a secondary uses the last adjusted bandwidth. The user can toggle the **use-last-adj-bw** command at any time; this does not require administratively disabling auto-bandwidth, however, the new value is not used until the next path switchover.

Note: The last adjusted bandwidth value is reset when MPLS, the LSP, or auto-bandwidth are disabled.

If the revert timer is enabled, the primary is resignaled before the revert timer expires with its configured bandwidth. An auto-bandwidth MBB using the last adjusted bandwidth of the secondary occurs immediately on switching back when the revert timer expires. If the system switches to a new path while an auto-bandwidth MBB is in progress on the previously active path, then the bandwidth used to signal the new path is the new value that was being attempted on the old path (instead of the last adjusted bandwidth). This means that the new path establishes with the most up to date bandwidth for the LSP (provided sufficient network resources are available) instead of a potentially out of date bandwidth.

2.1.9 MPLS LSP history

The router can store the 100 most recent events for each configured point-to-point RSVP LSP. This is independent of any other system log functionality.

Use the commands in the following context to enable the ability to store LSP state history.

```
configure router mpls lsp-history
```

When enabled, the router stores up to 100 of the most recent significant events for each LSP as a sliding window of events. When new events occur on an LSP and the record of 100 is fully consumed, new events are added and the oldest events are removed. The recording of LSP events is paused when the context is administratively disabled. The stored history for the LSPs is deleted when the context is deleted, and the memory allocated to store these events becomes available.

The history for a named RSVP LSP can be displayed for all LSPs, or for a single named LSP. Use the following command to display a specific RSVP LSP or all LSPs.

```
tools dump router mpls lsp-history [lsp-name]
```

If the LSP name is not specified, the output displays the LSP history for all RSVP LSPs, in sequence.

The history for a single named RSVP LSP or all LSPs can be cleared. Use the following command to clear the history for a specific named RSVP LSP or all LSPs.

```
clear router mpls lsp-history [lsp-name]
```

2.1.10 LSP failure codes

The table below lists the MPLS LSP path failure codes and their meanings. The failure codes are indicated in the FailureCode output field in the TiMetra MPLS MIB and for specific CLI commands. Use the following commands to display the FailureCode output field.

```
show router mpls lsp path detail
tools dump router mpls lsp-history
```

Table 6: LSP failure codes

LSP Failure Code (Value)	Meaning
noError (0)	Indicates no errors for this LSP.
admissionControlError (1)	An RSVP admission control failure occurred at some point along the path of an LSP. This is recorded as a result of a PathErr message.
noRouteToDestination (2)	No route could be found toward the requested destination.
trafficControlSystemError (3)	An error in the traffic control system because of an unsupported traffic parameter, for example, a bad FLOWSPEC, TSPEC, or ADSPEC value.
routingError (4)	Indicates a problem with the route defined for the LSP, for example, the ERO is truncated.

LSP Failure Code (Value)	Meaning
noResourcesAvailable (5)	Insufficient system or protocol resources are available to complete the request, for example, out of memory or out of resources such as NHLFE indexes or labels. This error code is also used for RSVP packet decode failures, such as. bad object length or unknown sub-object.
badNode (6)	Indicates a bad node in the path hop list at head end or ERO at transit.
routingLoop (7)	A routing loop was detected for the LSP path.
labelAllocationError (8)	Unable to allocate a label for the LSP path.
badL3PID (9)	The router has received a PathErr with the error code "Routing problem" and the error value "Unsupported L3PID." Indicates that a downstream LSR does not support the protocol type “L3PID”.
tunnelLocallyRepaired (10)	A PLR has triggered a local repair at some point along the path of the LSP.
unknownObjectClass (11)	A downstream LSR rejected an RSVP message because it contained an Unknown object class – Error code 13 defined in RFC 2205, *Resource Re SerVation Protocol (RSVP) - Version 1 Functional Specification*.
unknownCType (12)	A downstream LSR rejected an RSVP message because of an Unknown object C-type – Error code 14 defined in RFC 2205.
noEgressMplsInterface (13)	An egress MPLS interface could not be found for the LSP path.
noEgressRsvpInterface (14)	An egress RSVP interface could not be found for the LSP path.
looseHopsInFRRLsp (15)	The path calculated for the FRR enabled LSP contains loose hops.
unknown (16)	Indicates an error not covered by one of the other known errors for this LSP.
retryExceeded (17)	The retry limit for the LSP path has been exceeded.
noCspfRouteOwner (18)	No IGP instance was found that has a route to the LSP destination.
noCspfRouteToDestination (19)	CSPF was unable to find a route to the requested destination that satisfies all of the constraints.

LSP Failure Code (Value)	Meaning
hopLimitExceeded (20)	The hop limit for the LSP path has been exceeded.
looseHopsInManualBypassLsp (21)	A manual bypass LSP contains loose hops.
emptyPathInManualBypassLsp (22)	A manual bypass LSP uses an empty path.
lspFlowControlled (23)	The router initiated flow control for path messages for paths that have not yet been established.
srlgSecondaryNotDisjoint (24)	The secondary or standby path is not an SRLG disjoint from the primary path.
srlgPrimaryCspfDisabled (25)	An SRLG disjoint path could not be found for the secondary because CSPF is disabled on the primary.
srlgPrimaryPathDown (26)	An SRLG disjoint path could not be found for the secondary because the primary is down.
localLinkMaintenance (27)	A TE link (RSVP interface) local to this LSR or on a remote LSR used by the LSP is in TE graceful shutdown. The link that has been gracefully shutdown is also identified.
unexpectedCtObject (28)	A downstream LSR does not recognize something about the content of the DiffServ class type object.
unsupportedCt (29)	A downstream LSR does not support the signaled DiffServ class type.
invalidCt (30)	Indicates the signaled DiffServ class type is invalid, for example it is 0.
invCtAndSetupPri (31)	The combination of signaled DiffServ class type and setup priority does not map to a valid DiffServ TE class.
invCtAndHoldPri (32)	The combination of signaled DiffServ class type and hold priority does not map to a valid DiffServ TE class.
invCtAndSetupAndHoldPri (33)	The combination of signaled DiffServ class type and setup priority and hold priority does not map to a valid DiffServ TE class.
localNodeMaintenance (34)	The local LSR or a remote LSR used by the LSP is in TE graceful shutdown because of maintenance. The LSR that is shut down is also identified.
softPreemption (35)	The LSP path is under soft pre-emption.
p2mpNotSupported (36)	An LSR does not support P2MP LSPs.

LSP Failure Code (Value)	Meaning
badXro (37)	An LSR for the LSP encountered a badly formed exclude route object, for example, a sub-object is missing or unrecognized.
localNodeInXro (38)	The Exclude Route object includes the local node.
routeBlockedByXro (39)	The Exclude Route object prevents the LSP path from being established at all.
xroTooComplex (40)	The Exclude Route object contains too many entries or is too complex to calculate a path. If an SR OS router receives an XRO with more than five sub-objects then it is rejected.
rsvpNotSupported (41)	Maps to SubErrorCode 8 for ErrorCode 24 (Routing error) from RFC 3209. An LSR sends ErrorCode= 24, SubErrorCode=8 when it receives PATH for P2MP LSP but P2MP is not supported on that router.
conflictingAdminGroups (42)	The specified admin groups contradict each other, for example, the same group is both included and excluded.
nodeInIgpOverload (43)	An LSR along the path of the LSP has advertised the IS-IS overload state.
srTunnelDown(44)	An SR tunnel is admin or operationally down.
fibAddFailed(45)	An LSP path could not be added to the FIB, for example, if IOM programming fails for an SR-TE tunnel.
labelStackExceeded(46)	The label stack depth for an SR-TE LSP exceeds the maximum SR labels.
pccDown(47)	The PCC or the PCEP channel to the PCC is down.
pccError(48)	An error has been received from the PCC related to this LSP. Such errors relate to processing requests, message objects, or TLVs.
pceDown(49)	The PCE or PCEP channel is down.
pceError(50)	An error has been received from the PCE related to this LSP. Such errors relate to processing requests, message objects, or TLVs.
pceUpdateWithEmptyEro (51)	MPLS received an update from PCE with an empty ERO.
pceInitLspDisabled (52)	The related context for this LSP type is disabled.

LSP Failure Code (Value)	Meaning

	• **MD-CLI**
	`configure router mpls pce-init-lsp`
	• **classic CLI**
	`configure router mpls pce-initiated-lsp`

adminDown (53)	A related MPLS path is disabled.
sidHopsInRsvpLsp (54)	SID hops in the path for RSVP-TE LSP.
ipv6HopsInRsvpLsp (55)	IPv6 hops in the path for RSVP-TE LSP.
ipv4HopsInIpv6Lsp (56)	IPv4 hops in the path for SR-TE LSP with IPv6 ‘to’ address.
ipv6HopsInIpv4Lsp(57)	IPv6 hops in the path for SR-TE LSP with IPv4 ‘to’ address.
sidHopsInIpv6Lsp (58)	SID hops in the path for SR-TE LSP with IPv4 ‘to’ address.
srlgPathWithSidHops (59)	LSP path is SRLG enabled but has SID hops in the path.
mplsV4Down (60)	MPLS IPv4 operational state is down.
mplsV6Down (61)	MPLS IPv6 operational state is down.
lspAdminDown (62)	LSP is admin down.
pathAdminDown (63)	Path or LSP path is admin down.
templateAdminDown (64)	LSP template is admin down.
pceAssocConflict (65)	PCE association is conflicting.
pathRetried (66)	LSP path was brought down and retried.
clearCommand (67)	LSP path was brought down because of a **clear** command.
nonActiveSecondary (68)	The secondary path is down because the LSP has an alternate active path.
autoBandwidthAdjustment (69)	For an auto-bandwidth LSP, operational bandwidth for a non-active LSP path does not match the bandwidth configured for that path and the bandwidth was not adjusted using MBB. The path is brought down and retried to adjust its bandwidth back to configured bandwidth.

LSP Failure Code (Value)	Meaning
pathDegraded (71)	Non-active path was brought down because it was in a degraded state, for example, FRR active or soft-preempted, and the MBB could not be used to resignal the path.
lspSelfPingTimeout (72)	LSP self-ping timed out.
rsvpError (73)	RSVP signaling errors, such as, ResvTear received or egress neighbor down.
p2mpInstanceAdminDown (74)	P2MP instance is admin down.

2.1.11 Labeled traffic statistics

SR OS provides a wide range of capabilities for collecting statistics of labeled traffic. This section provides an overview of these capabilities.

2.1.11.1 Interface statistics

By default, the system continuously collects statistics (packet and octet counts) of MPLS traffic on ingress and egress of MPLS interfaces. Use the following command to view these statistics.

```
show router mpls interface statistics
```

The implicit null on ingress is not regarded as labeled traffic and octet counts include Layer 2 headers and trailers.

In addition, the system can provide auxiliary statistics (packet and octet counts) for a specific type of labeled traffic on ingress and egress of MPLS interfaces. Use the following command to access auxiliary statistics and display the types of labeled traffic that should be counted.

```
configure router mpls aux-stats
```

The **sr** command option refers to any type of MPLS-SR traffic (such as SR-OSPF, SR-ISIS, SR-TE). After being enabled and configured, auxiliary statistics can be viewed, monitored, and cleared. The two types of statistics (global or default MPLS statistics and auxiliary statistics) are independent; clearing one counter does not affect the values of the other counter.

For both types of statistics, implicit null on ingress is not regarded as labeled traffic and octet counts include Layer 2 headers and trailers.

Segment routing traffic statistics have a dependency with the ability to account for dark bandwidth in IGP-TE advertisements.

2.1.11.2 Traffic statistics for stacked tunnels

The nature of MPLS allows for LSPs, owned by a specific protocol, to be tunneled into an LSP that is owned by another protocol. Typical examples of this capability are LDP over RSVP-TE, SR over RSVP-TE, and LDP over SR-TE. Also, in a variety of constructs (SR-TE LSPs, SR policies) SR OS uses hierarchical

NHLFEs where a single (top) NHLFE that models the forwarding actions toward the next hop, can be referenced by one or more (inner) NHLFEs that model the forwarding actions for the rest of the end-to-end path.

SR OS enables collecting the traffic statistics from the majority of all supported types of tunnels. In cases where statistics collection is enabled on multiple labels of the stack, SR OS provides the capability to collect traffic statistics on two labels of the MPLS stack. Any label needs to be processed (as part of ILM or NHLFE processing) for statistics to be collected. For example, a node acting as an LSR for an RSVP-TE LSP (that transports an LDP LSP) can collect statistics for the RSVP-TE LSP but does not collect stats for the LDP LSP. A node acting as an LER for that same RSVP-TE LSP is, however, able to collect statistics for the LDP LSP.

Use the following command to control statistics collection on one or two labels.

```
configure system ip mpls label-stack-statistics-count
```

This command does not enable statistics collection. It only performs controls on a specific number of labels, and out of those that have statistics collection enabled, statistics collection is effectively performed.

If the MPLS label stack represents more than two stacked tunnels, the system collects statistics on the outermost (top) label for which statistics collection is enabled (if above value is 1 or 2), and collects statistics on the innermost (bottom) label for which statistics collection is enabled (if above value is 2).

2.1.11.3 Traffic statistics details and scale

For RSVP-TE and LDP, statistics are provided per forwarding class and as **in-profile** or **out-of-profile**. For all other labeled constructs, statistics are provided regardless of the forwarding class and the QoS profile. Altogether, labeled constructs share 128k statistic indexes (on ingress and on egress independently). Statistics with FC and QoS profile consume 16 indexes.

2.1.11.4 RSVP-TE and MPLS-TP traffic statistics

See RSVP-TE LSP statistics and P2MP RSVP-TE LSP statistics for information about RSVP-TE and MPLS-TP traffic statistics.

2.1.12 Monitoring MPLS resource consumption

SR OS supports the display of MPLS system resources on an egress-operation basis for NHLFEs, labels, and LTNs. Users can access resource consumption information directly using a **tools** or **state** command, or remotely through SNMP and NETCONF.

Use the following command to display all MPLS resource usage information.

```
tools dump mpls-resources
```

Use commands in the following MD-CLI context to display YANG state information for MPLS resources.

```
state system mpls-resource-usage
```

Output example: Global MPLS resource usage

```
Global MPLS Resource Usage
-------------------------+------------+-------------+-------------+
                         |   Total    | Allocated   |    Free     |
-------------------------+------------+-------------+-------------+
 mpls  NHLFE             |    262125  |         1   |    262124   |
    RSVP                 |            |         1   |             |
    LDP                  |            |         0   |             |
    BGP                  |            |         0   |             |
    MPLS-TP              |            |         0   |             |
    SR                   |            |         0   |             |
    BIER                 |            |         0   |             |
    TREE-SID             |            |         0   |             |
 mpls labels             |    524256  |         0   |    524256   |
    RSVP                 |            |         0   |             |
    LDP                  |            |         0   |             |
    BGP                  |            |         0   |             |
    MPLS-TP              |            |         0   |             |
    STATIC-SVC           |            |         0   |             |
    SR                   |            |         0   |             |
    BIER                 |            |         0   |             |
    RESERVED-BLK         |            |         0   |             |
 mpls  LTN (FTN)         |    131071  |         0   |    131071   |

    RSVP                 |            |         0   |             |
    LDP                  |            |         0   |             |
    BGP                  |            |         0   |             |
    MPLS-TP              |            |         0   |             |
    SR                   |            |         0   |             |
    BIER                 |            |         0   |             |
    TREE-SID             |            |         0   |             |
```

Example: YANG state MPLS resource usage

```
[/state system mpls-resource-usage]
A:admin@node-2# info
    nhlfe {
        total 262125
        allocated 1
        free 262124
        by-owner rsvp {
            allocated 1
        }
        by-owner ldp {
            allocated 0
        }
        by-owner bgp {
            allocated 0
        }
        by-owner mpls-tp {
            allocated 0
        }
        by-owner static-service {
            allocated 0
        }
        by-owner sr-mpls {
            allocated 0
        }
        by-owner bier {
            allocated 0
        }
        by-owner tree-sid {
```

```
            allocated 0
        }
        by-owner reserved-blk {
            allocated 0
        }
    }
    ltn {
        total 131071
        allocated 0
        free 131071
        by-owner rsvp {
            allocated 0
        }
        by-owner ldp {
            allocated 0
        }
        by-owner bgp {
            allocated 0
        }
        by-owner mpls-tp {
            allocated 0
        }
        by-owner static-service {
            allocated 0
        }
        by-owner sr-mpls {
            allocated 0
        }
        by-owner bier {
            allocated 0
        }
        by-owner tree-sid {
            allocated 0
        }
        by-owner reserved-blk {
            allocated 0
        }
    }
    label {
        total 524256
        allocated 0
        free 524256
        by-owner rsvp {
            allocated 0
        }
        by-owner ldp {
            allocated 0
        }
        by-owner bgp {
            allocated 0
        }
        by-owner mpls-tp {
            allocated 0
        }
        by-owner static-service {
            allocated 0
        }
        by-owner sr-mpls {
            allocated 0
        }
        by-owner bier {
            allocated 0
        }
        by-owner tree-sid {
```

```
            allocated 0
        }
        by-owner reserved-blk {
            allocated 0
        }
    }
```

2.2 RSVP

The Resource Reservation Protocol (RSVP) is a network control protocol used by a host to request specific qualities of service from the network for particular application data streams or flows. RSVP is also used by routers to deliver quality of service (QoS) requests to all nodes along the paths of the flows and to establish and maintain state to provide the requested service. RSVP requests generally result in resources reserved in each node along the datapath. MPLS leverages this RSVP mechanism to set up traffic engineered LSPs. RSVP is not enabled by default and must be explicitly enabled.

RSVP requests resources for simplex flows. It requests resources only in one direction (unidirectional). Therefore, RSVP treats a sender as logically distinct from a receiver, although the same application process may function as both a sender and a receiver at the same time. Duplex flows require two LSPs, to carry traffic in each direction.

RSVP is not a routing protocol. RSVP operates with unicast and multicast routing protocols. Routing protocols determine where packets are forwarded. RSVP consults local routing tables to relay RSVP messages.

RSVP uses two message types to set up LSPs, PATH and RESV. Figure 5: Establishing LSPs depicts the process to establish an LSP.

1. The sender (the ingress LER (ILER)), sends PATH messages toward the receiver, (the egress LER (eLER)) to indicate the FEC for which label bindings are required. PATH messages are used to signal and request label bindings required to establish the LSP from ingress to egress. Each router along the path observes the traffic type.

   PATH messages facilitate the routers along the path to make the necessary bandwidth reservations and distribute the label binding to the router upstream.
2. The eLER sends label binding information in the RESV messages in response to PATH messages received.
3. The LSP is considered operational when the ILER receives the label binding information.

Figure 5: Establishing LSPs

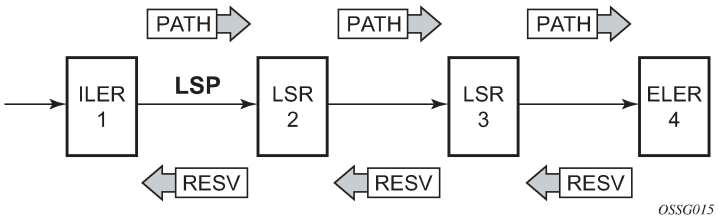


Figure 6: LSP using RSVP path setup

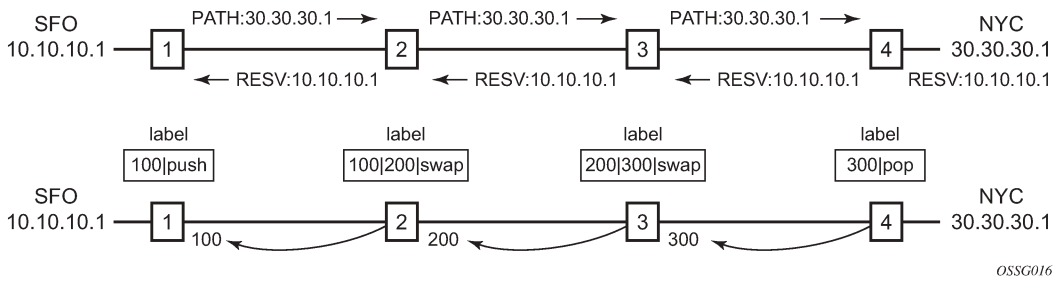


Figure 6: LSP using RSVP path setup displays an example of an LSP path set up using RSVP. The ingress label edge router (ILER 1) transmits an RSVP path message (path: 30.30.30.1) downstream to the egress label edge router (eLER 4). The path message contains a label request object that requests intermediate LSRs and the eLER to provide a label binding for this path.

In addition to the label request object, an RSVP PATH message can also contain other optional objects:

- **explicit route object (ERO)**

  When the ERO is present, the RSVP path message is forced to follow the path specified by the ERO (independent of the IGP shortest path).

- **record route object (RRO)**

  This object allows the ILER to receive a listing of the LSRs that the LSP tunnel actually traverses.

- **session attribute object**

  A session attribute object controls the path set up priority, holding priority, and local-rerouting features.

Upon receiving a path message containing a label request object, the eLER transmits a RESV message that contains a label object. The label object contains the label binding that the downstream LSR communicates to its upstream neighbor. The RESV message is sent upstream toward the ILER, in a direction opposite to that followed by the path message. Each LSR that processes the RESV message carrying a label object uses the received label for outgoing traffic associated with the specific LSP. When the RESV message arrives at the ingress LSR, the LSP is established.

2.2.1 Using RSVP for MPLS

Hosts and routers that support both MPLS and RSVP can associate labels with RSVP flows. When MPLS and RSVP are combined, the definition of a flow can be made more flexible. After an LSP is established, the traffic through the path is defined by the label applied at the ingress node of the LSP. The mapping of label to traffic can be accomplished using a variety of criteria. The set of packets that are assigned the same label value by a specific node are considered to belong to the same FEC which defines the RSVP flow.

For use with MPLS, RSVP already has the resource reservation component built-in which makes it ideal to reserve resources for LSPs.

2.2.1.1 RSVP traffic engineering extensions for MPLS

RSVP has been extended for MPLS to support automatic signaling of LSPs. To enhance the scalability, latency, and reliability of RSVP signaling, several extensions have been defined. Refresh messages are still transmitted but the volume of traffic, the amount of CPU utilization, and response latency are reduced while reliability is supported. None of these extensions result in backward compatibility problems with traditional RSVP implementations.

2.2.1.2 Hello protocol

The Hello protocol detects the loss of a neighbor node or the reset of a neighbor's RSVP state information. In standard RSVP, neighbor monitoring occurs as part of RSVP's soft-state model. The reservation state is maintained as cached information that is first installed and then periodically refreshed by the ingress and egress LSRs. If the state is not refreshed within a specified time interval, the LSR discards the state because it assumes that either the neighbor node has been lost or its RSVP state information has been reset.

The Hello protocol extension is composed of a Hello message, a hello request object and a hello ACK object. Hello processing between two neighbors supports independent selection of failure detection intervals. Each neighbor can automatically issue hello request objects. Each hello request object is answered by a hello ACK object.

2.2.1.3 MD5 authentication of RSVP interface

When the following command is enabled on an RSVP interface, authentication of RSVP messages operates in both directions of the interface.

```
configure router rsvp interface authentication-key
```

A router maintains a security association using one authentication key for each interface to an RSVP neighbor.

An RSVP neighbor transmits an authenticating digest of the RSVP message that is computed using the shared authentication key and a keyed-hash algorithm. The message digest is included in an INTEGRITY object, which also contains a flags field, a key identifier field, and a sequence number field. An RSVP neighbor uses the key together with the authentication algorithm to process received RSVP messages. The RSVP MD5 authentication complies to the procedures for RSVP message generation in RFC 2747, *RSVP Cryptographic Authentication*.

When a Point of Local Repair (PLR) activates a bypass LSP toward a Merge Point (MP), by default, the INTEGRITY object corresponding to the bypass LSP interface is not added to a transmitted RSVP message except for packets of routed RSVP messages (Resv, Srefresh. and ACK) and only when the packet is intended for a bypass LSP endpoint (PLR or MP) that is a directly connected neighbor.

When the following command is enabled, the INTEGRITY object of the interface corresponding to the bypass LSP is added to a transmitted RSVP message whether the bypass LSP endpoint (PLR or MP) is a directly connected RSVP neighbor.

```
configure router rsvp authentication-over-bypass
```

The INTEGRITY object is included with the following RSVP messages: Path, PathTear, PathErr, Resv, ResvTear, ResvErr, Srefresh, and ACK.

In all cases, an RSVP message received from a PLR or an MP (sender address in the SenderTemplate or FilterSpec is different from an Extended Tunnel ID in a Session Object), and which includes the INTEGRITY object, is authenticated against the bypass LSP interface. An RSVP message received from a PLR or MP without the INTEGRITY object is also accepted.

The MD5 implementation does not support the authentication challenge procedures in RFC 2747.

2.2.1.4 Configuring authentication using keychains

The use of authentication mechanism is recommended to protect against malicious attack on the communications between routing protocol neighbors. These attacks could aim to either disrupt communications or to inject incorrect routing information into the systems routing table. The use of authentication keys can help to protect the routing protocols from these types of attacks.

Within RSVP, authentication must be explicitly configured through the use of the authentication keychain mechanism. This mechanism allows for the configuration of authentication keys and allows the keys to be changed without affecting the state of the protocol adjacencies.

To configure the use of an authentication keychain within RSVP, use the following steps:

1. Configure an authentication keychain under the following context. The configured keychain must include at least on valid key entry, using a valid authentication algorithm for the RSVP protocol.
   - **MD-CLI**

     ```
     configure system security keychains
     ```

   - **classic CLI**

     ```
     configure system security keychain
     ```

2. Use the following command to associate the configured authentication keychain with RSVP at the interface level of the CLI.
   - **MD-CLI**

     ```
     configure router rsvp interface authentication-keychain
     ```

   - **classic CLI**

     ```
     configure router rsvp interface auth-keychain
     ```

   For a key entry to be valid, it must include a valid key, the current system clock value must be within the begin and end time of the key entry, and the algorithm specified in the key entry must be supported by the RSVP protocol.

   The RSVP protocol supports the following algorithms:

   - cleartext password
   - HMAC-MD5
   - HMC-SHA-1

   Error handling:

- If a keychain exists but there are no active key entries with an authentication type that is valid for the associated protocol then inbound protocol packets are not authenticated and discarded, and no outbound protocol packets should be sent.
- If keychain exists but the last key entry has expired, a log entry is raised indicating that all keychain entries have expired. The RSVP protocol requires that the protocol not revert to an unauthenticated state and requires that the old key is not to be used, therefore, when the last key has expired, all traffic is discarded.

2.2.2 Reservation styles

LSPs can be signaled with explicit reservation styles. A reservation style is a set of control options that specify a number of supported command options. The style information is part of the LSP configuration. SR OS supports two reservation styles:

- **fixed filter (ff)**

  The fixed filter (ff) reservation style specifies an explicit list of senders and a distinct reservation for each of them. Each sender has a dedicated reservation that is not shared with other senders. Each sender is identified by an IP address and a local identification number, the LSP ID. Because each sender has its own reservation, a unique label and a separate LSP can be constructed for each sender-receiver pair. For traditional RSVP applications, the FF reservation style is ideal for a video distribution application in which each channel (or source) requires a separate pipe for each of the individual video streams.

- **shared explicit (se)**

  The shared explicit (se) reservation style creates a single reservation over a link that is shared by an explicit list of senders. Because each sender is explicitly listed in the RESV message, different labels can be assigned to different sender-receiver pairs, thereby creating separate LSPs.

  If FRR option is enabled for the LSP and selects the facility FRR method at the head-end node, only the SE reservation style is allowed. Furthermore, if a PLR node receives a path message with fast-reroute requested with facility method and the FF reservation style, it rejects the reservation. The one-to-one detour method supports both FF and SE styles.

2.2.2.1 RSVP message pacing

When a flood of signaling messages arrive because of topology changes in the network, signaling messages can be dropped which results in longer set up times for LSPs. RSVP message pacing controls the transmission rate for RSVP messages, allowing the messages to be sent in timed intervals. Pacing reduces the number of dropped messages that can occur from bursts of signaling messages in large networks.

2.2.3 RSVP overhead refresh reduction

The RSVP refresh reduction feature consists of the following capabilities implemented in accordance to RFC 2961, *RSVP Refresh Overhead Reduction Extensions*:

- **RSVP message bundling**

  This capability is intended to reduce overall message handling load. The system supports receipt and processing of bundled message only, but no transmission of bundled messages.

- **reliable message delivery**

  This capability consists of sending a message-id and returning a message-ack for each RSVP message. It can be used to detect message loss and support reliable RSVP message delivery on a per hop basis. It also helps reduce the refresh rate because the delivery becomes more reliable.

- **summary refresh**

  This capability consists of refreshing multiples states with a single message-id list and sending negative ACKs (NACKs) for a message_id which could not be matched. The summary refresh capability reduce the amount of messaging exchanged and the corresponding message processing between peers. It does not however reduce the amount of soft state to be stored in the node.

These capabilities can be enabled on a per-RSVP-interface basis are referred to collectively as "refresh overhead reduction extensions". When the refresh-reduction is enabled on an RSVP interface, the node indicates this to its peer by setting a refresh-reduction-capable bit in the flags field of the common RSVP header. If both peers of an RSVP interface set this bit, all the above three capabilities can be used. Furthermore, the node monitors the settings of this bit in received RSVP messages from the peer on the interface. As soon as this bit is cleared, the node stops sending summary refresh messages. If a peer did not set the refresh-reduction-capable bit, a node does not attempt to send summary refresh messages.

The RSVP Overhead Refresh Reduction is supported with both RSVP P2P LSP path and the S2L path of an RSVP P2MP LSP instance over the same RSVP interface.

2.2.4 RSVP Graceful Restart helper

Use the following command to enable RSVP Graceful Restart helper:

- **MD-CLI**

```
configure router rsvp interface graceful-restart-helper-mode
```

- **classic CLI**

```
configure router rsvp interface gr-helper
```

The RSVP-TE Graceful Restart helper mode allows the SR OS based system (the helper node) to provide another router that has requested it (the restarting node) a grace period, during which the system continues to use RSVP sessions to neighbors requesting the grace period. This is typically used when another router is rebooting its control plane but its forwarding plane is expected to continue to forward traffic based on the previously available Path and Resv states.

The user can enable Graceful Restart helper on each RSVP interface separately. When the GR helper feature is enabled on an RSVP interface, the node starts inserting a new Restart_Cap Object in the Hello packets to its neighbor. The restarting node does the same and indicates to the helper node the required Restart Time and Recovery Time.

The Graceful Restart helper consists of a couple of phases. When it loses hello communication with its neighbor, the helper node enters the Restart phase. During this phase, it preserves the state of all RSVP sessions to its neighbor and waits for a new Hello message.

When the Hello message is received indicating the restarting node preserved state, the helper node enters the recovery phase in which it starts refreshing all the sessions that were preserved. The restarting node activates all the stale sessions that are refreshed by the helper node. Any Path state that did not get a Resv message from the restarting node after the Recovery Phase time is over is considered to have expired and is deleted by the helper node causing the correct Path Tear generation downstream.

The duration of the restart phase (recovery phase) is equal to the minimum of the neighbor's advertised Restart Time (Recovery Time) in its last Hello message and the locally configured value of the **max-restart max-recovery** command options under the following context:

- **MD-CLI**

```
configure router rsvp graceful-restart
```

- **classic CLI**

```
configure router rsvp gr-helper-time
```

When GR helper is enabled on an RSVP interface, its procedures apply to the state of both P2P and P2MP RSVP LSP to a neighbor over this interface.

2.2.5 Enhancements to RSVP control plane congestion control

The RSVP control plane makes use of a global flow control mechanism to adjust the rate of Path messages for unmapped LSP paths sent to the network under congestion conditions. When a Path message for establishing a new LSP path or retrying an LSP path that failed is sent out, the control plane keeps track of the rate of successful establishment of these paths and adjusts the number of Path messages it sends per second to reflect the success ratio.

In addition, an option to enable an exponential back-off retry-timer is available. When an LSP path establishment attempt fails, the path is put into retry procedures and a new attempt is performed at the expiry of the user-configurable retry-timer. By default, the retry time is constant. The exponential back-off timer procedures doubles the value of the user configurable retry-timer value at every failure of the attempt to adjust to the potential network congestion that caused the failure. An LSP establishment fails if no Resv message was received and the Path message retry-timer expired, or a PathErr message was received before the timer expired.

Three enhancements to this flow-control mechanism to improve congestion handling in the rest of the network are supported.

The first enhancement is the change to the LSP path retry procedure. If the establishment attempt failed because of a Path message timeout and no Resv was received, the next attempt is performed at the expiry of a new LSP path initial retry-timer instead of the existing retry-timer. While the LSP path initial retry-timer is still running, a refresh of the Path message using the same path and the same LSP-id is performed according to the configuration of the refresh-timer. After the LSP path initial retry-timer expires, the ingress LER then puts this path on the regular retry-timer to schedule the next path signaling using a new computed path by CSPF and a new LSP-id.

The benefits of this enhancement is that the user can now control the number of refreshes of the pending PATH state that can be performed before starting a new retry-cycle with a new LSP-id. This is all done without affecting the ability to react faster to failures of the LSP path, which continues to be governed by the existing retry-timer. By configuring the LSP path initial retry-timer to values that are larger than the retry-timer, the ingress LER decreases the probability of overwhelming a congested LSR with new state while the previous states installed by the same LSP are lingering and is only removed after the refresh timeout period expires.

The second enhancement consists of applying a jitter +/- 25% to the value of the retry-timer similar to how it is currently done for the refresh timer. This further decreases the probability that ingress LER nodes synchronize their sending of Path messages during the retry-procedure in response to a congestion event in the network.

The third enhances the RSVP flow control mechanism by taking into account new options: outstanding CSPF requests, Resv timeouts and Path timeouts.

2.2.6 RSVP-TE LSP statistics

SR OS provides the following statistics:

- per forwarding class forwarded in-profile packet count
- per forwarding class forwarded in-profile byte count
- per forwarding class forwarded out-of-profile packet count
- per forwarding class forwarded out-of-profile byte count

The counters are available for RSVP LSPs, including template-based (mesh or one-hop, see Automatic creation of RSVP-TE LSP mesh), and for MPLS-TP LSPs at the egress datapath of an ingress LER and the ingress datapath of an egress LER. No LSR statistics are provided.

2.2.6.1 Rate statistics

SR OS also provides traffic rate statistics. For RSVP-TE LSPs, including template-based LSPs and MPLS-TP LSPs, the user performs one of the following options to enable that capability:

- configures an accounting policy that uses the following command with the **combined-mpls-lsp-egress** record name

```
configure log accounting-policy record
```

- assigns that accounting policy to a specific LSP (or template)
- enables stats collection

The frequency at which the rate is determined is defined using the **collection-interval** command in the accounting policy. The minimum interval is 5 minutes.

Rate statistics are provided in packets per second and Mb/s. Rate statistics are provided as an aggregate across all paths of the LSP, which have a statistical index assigned, and for all forwarding classes in or out-of-profile.

Rate statistics are only available on the egress of the ingress LER. At least two samples are needed to determine a rate.

2.2.7 P2MP RSVP-TE LSP statistics

This feature provides the following counters for a RSVP P2MP LSP instance:

- per forwarding class forwarded in-profile packet count
- per forwarding class forwarded in-profile byte count
- per forwarding class forwarded out of profile packet count
- per forwarding class forwarded out of profile byte count

The above counters are provided for the following LSR roles:

- At the ingress LER, a set of per-P2MP LSP instance counters for packets forwarded to the P2MP LSP instance without counting the replications is provided. In other words, a packet replicated over multiple branches of the same P2MP LSP instance counts once as long as at least one LSP branch forwarded it.
- At BUD LSR and egress LER, per ILM statistics are provided. These counters include all packets received on the ILM, whether they match a Layer 2/Layer 3 MFIB record or not. ILM stats work the same way as for a P2P LSP. In other words, they count all packets received on the primary ILM, including packets received over the bypass LSP.

  When MBB is occurring for an S2L path of an RSVP P2MP LSP, paths of the new and old S2L both receive packets on the egress LER. Both packets are forwarded to the fabric and outgoing PIM/IGMP interfaces until the older path is torn down by the ingress LER. In this case, packet duplication should be counted.
- No branch LSR statistics are provided.
- The P2MP LSP statistics share the same pool of counters and stat indexes the P2P LSP share on the node. Each P2P/P2MP RSVP LSP or LDP FEC consumes one statistics index for egress stats and one stat index for ingress statistics.
- The user can retrieve the above counters in four different ways:
  - In the CLI display of the output of the show command applied to a specific instance, or a specific template instance, of an RSVP P2MP.
  - In the CLI display of the output of the monitor command applied to a specific instance, or a specific template instance, of an RSVP P2MP.
  - Via an SNMP interface by querying the MIB.
  - Via an accounting file if statistics collection with the default or user specified accounting policy is enabled for the MPLS LSP stats configuration contexts.
- OAM packets that are forwarded using the LSP encapsulation, for example, P2MP LSP Ping and P2MP LSP Trace, are also included in the above counters.

The user can determine if packets are dropped for a specific branch of a P2MP RSVP LSP by comparing the egress counters at the ingress LER with the ILM counters at the egress LER or BUD LSR.

Octet counters are for the entire frame and so include the label stack and the Layer 2 header and padding similar to the existing P2P RSVP LSP and LDP FEC counters. As such, ingress and egress octet counters for an LSP may slightly differ if the type of interface or encapsulation is different (POS, Ethernet NULL, Ethernet Dot1.Q).

2.2.7.1 Configuring RSVP P2MP LSP egress statistics

At ingress LER, the configuration of the egress statistics is under the MPLS P2MP LSP context when carrying multicast packets over a RSVP P2MP LSP in the base routing instance. This is the same configuration as the one already supported with P2P RSVP LSP.

Example: Egress statistics configuration (MD-CLI)

```
[ex:/configure router "Base" mpls]
A:admin@node-2# info
...
    lsp "test7" {
        type p2mp-rsvp
        egress-statistics {
```

```
            admin-state enable
            collect-stats true
            accounting-policy 99
        }
    }
```

Example: Egress statistics configuration (classic CLI)

```
A:node-2>config>router>mpls# info
----------------------------------------------
...
            lsp "test7" p2mp-lsp
                shutdown
                egress-statistics
                    collect-stats
                    accounting-policy 99
                    no shutdown
                exit
            exit
```

If there are no statistic indexes available when the user administratively enables the egress statistics node, the command fails.

The configuration is in the P2MP LSP template when the RSVP P2MP LSP is used as an I-PMSI or S-PMSI in multicast VPN or in VPLS/B-VPLS.

Example: P2MP LSP template configuration (MD-CLI)

```
[ex:/configure router "Base" mpls]
A:admin@node-2# info
...
    lsp-template "test8" {
        type p2mp-rsvp
        egress-statistics {
            collect-stats true
            accounting-policy 99
        }
    }
```

Example: P2MP LSP template configuration (classic CLI)

```
A:node-2>config>router>mpls# info
----------------------------------------------
...
            lsp-template "test8" p2mp
                shutdown
                egress-statistics
                    collect-stats
                    accounting-policy 99
                exit
            exit
```

If there are no statistic indexes available at the time, an instance of the P2MP LSP template is signaled, no stats are allocated to the instance, but the LSP is brought up. In this case, an operational state of out-of-resources is shown for the egress statistics in the show command output of the P2MP LSP S2L path.

2.2.7.2 Configuring RSVP P2MP LSP ingress statistics

When the ingress LER signals the path of the S2L sub-LSP, it includes the name of the LSP and that of the path in the Session Name field of the Session Attribute object in the Path message. The encoding is as follows:

Session Name: *lsp-name::path-name*, where the *lsp-name* component is encoded as follows.

1. P2MP LSP via user configuration for Layer 3 multicast in global routing instance: "LspNameFromConfig"
2. P2MP LSP as I-PMSI or S-PMSI in Layer 3 mVPN: templateName-SvcId-mTTmIndex
3. P2MP LSP as I-PMSI in VPLS/B-VPLS: templateName-SvcId-mTTmIndex

The ingress statistics configuration allows the user to match either on the exact name of the P2MP LSP as configured at the ingress LER or on a context which matches on the template name and the service ID as configured at the ingress LER.

Example: RSVP P2MP LSP ingress statistics configuration (MD-CLI)

```
[ex:/configure router "Base" mpls ingress-statistics]
A:admin@node-2# info
    lsp sender 192.0.0.2 lsp-name "test9" {
        admin-state enable
        collect-stats true
        accounting-policy 88
    }
    p2mp-template-lsp sender 192.0.0.2 rsvp-session-name "test9" {
        admin-state enable
        collect-stats true
        accounting-policy 88
        max-stats 1000
    }
```

Example: RSVP P2MP LSP ingress statistics configuration (classic CLI)

```
A:node-2>config>router>mpls>ingr-stats# info
----------------------------------------------
                lsp "test9" sender 192.0.0.2
                    collect-stats
                    accounting-policy 88
                    no shutdown
                exit
                p2mp-template-lsp rsvp-session-name "test9" sender 192.0.0.2
                    collect-stats
                    accounting-policy 88
                    max-stats 1000
                    no shutdown
                exit
----------------------------------------------
```

When the matching is performed on a context, the user must enter the RSVP session name string in the format *templateName-svcId* to include the LSP template name as well as the mVPN VPLS/B-VPLS service ID as configured at the ingress LER. In this case, one or more P2MP LSP instances signaled by the same ingress LER could be associated with the ingress statistics configuration. In this case, the user is provided with the **max-stats** command to limit the maximum number of stat indexes which can be assigned to this context. If the context matches more than this value, the additional request for stat indexes from this context is rejected.

Use the following rules when configuring an ingress statistics context based on template matching:

- In the classic CLI, allocated **max-stats** can be increased but not decreased unless the entire ingress statistics context matching a template name is deleted.
- In the classic CLI, to delete ingress statistics context matching a template name, a shutdown is required.
- In the classic CLI, an accounting policy cannot be configured or de-configured until the ingress statistics context matching a template name is disabled.
- After deleting an accounting policy from an ingress statistics context matching a template name, the policy is not removed from the log until the ingress statistics context is enabled.

If there are no statistic indexes available at the time the session of the P2MP LSP matching a template context is signaled and the session state installed by the egress LER, no stats are allocated to the session.

Furthermore, the assignment of stat indexes to the LSP names that match the context is not deterministic. The latter is because a stat index is assigned and released following the dynamics of the LSP creation or deletion by the ingress LER. For example, a multicast stream crosses the rate threshold and is moved to a newly signaled S-PMSI dedicated to this stream. Later on, the same steam crosses the threshold downwards and is moved back to the shared I-PMSI and the P2MP LSP corresponding to the S-PMSI is deleted by the ingress LER.

2.2.8 Configuring implicit null

The implicit null label option allows a router egress LER to receive MPLS packets from the previous hop without the outer LSP label. The operation of the previous hop is referred to as penultimate hop popping (PHP).

This option is signaled by the egress LER to the previous hop during the LSP signaling with RSVP control protocol. In addition, the egress LER can be configured to receive MPLS packet with the implicit null label on a static LSP.

Use the following command to configure the router to signal the implicit null label value over all RSVP interfaces and for all RSVP LSPs for which this node is the egress LER.

```
configure router rsvp implicit-null-label
```

In the classic CLI, the user must administratively disable RSVP before being able to change the implicit null configuration.

Use the following commands to override the RSVP level configuration for a specific RSVP interface with the following command:

- **MD-CLI**

  ```
  configure router rsvp interface implicit-null-label [true|false]
  ```

- **classic CLI**

  ```
  configure router rsvp interface implicit-null-label {enable|disable}
  ```

All LSPs for which this node is the egress LER and for which the path message is received from the previous hop node over this RSVP interface signal the implicit null label. This means that if the egress LER is also the merge-point (MP) node, then the incoming interface for the path refresh message over the bypass dictates if the packet uses the implicit null label or not; the same applies to a 1-to-1 detour LSP.

By default, an RSVP interface inherits the RSVP level configuration. In the classic CLI, the user must administratively disable the RSVP interface before being able to change the implicit null configuration option.

Note: In the classic CLI, the RSVP interface must be disabled regardless of whether the new value for the interface is the same or different than the one it is currently using.

The egress LER does not signal the implicit null label value on P2MP RSVP LSPs. However, the PHP node can honor a Resv message with the label value set to the implicit null value when the egress LER is a third party implementation.

The **implicit-null-label** option is also supported on a static label LSP. A user can push or swap an implicit null label on the MPLS packet using the **implicit-null-label** option and configuring next hop in the following contexts:

```
configure router mpls static-lsp push
configure router mpls interface label-map swap
```

2.2.9 Using unnumbered point-to-point interface in RSVP

This feature introduces the use of unnumbered IP interface as a Traffic Engineering (TE) link for the signaling of RSVP P2P LSP and P2MP LSP.

An unnumbered IP interface is identified uniquely on a router in the network by the tuple {router-id, ifIndex}. Each side of the link assigns a system-wide unique interface index to the unnumbered interface. ISIS, OSPF, RSVP, and OAM modules use this tuple to advertise the link information, signal LSP paths over this unnumbered interface, or send and respond to an MPLS echo request message over an unnumbered interface.

The interface borrowed IP address is used exclusively as the source address for IP packets that are originated from the interface and needs to be configured to an address different from system interface for the FRR bypass LSP to come up at the ingress LER.

Use the following command to configure a borrowed IP address for an unnumbered interface. The default value is set to the system interface address:

- **MD-CLI**

```
configure router interface ipv4 unnumbered ip-address
```

- **classic CLI**

```
configure router interface unnumbered
```

The support of unnumbered TE link in IS-IS consists of adding a new sub-TLV of the extended IS reachability TLV, which encodes the Link Local and Link Remote Identifiers as defined in RFC 5307.

The support of unnumbered TE link in OSPF consists of adding a new sub-TLV, which encodes the same Link Local and Link Remote Identifiers in the Link TLV of the TE area opaque LSA and sends the local Identifier in the Link Local Identifier TLV in the TE link local opaque LSA as per RFC 4203.

The support of unnumbered TE link in RSVP implements the signaling of unnumbered interfaces in ERO/RRO as per RFC 3477 and the support of IF_ID RSVP_HOP object with a new Ctype as per Section 8.1.1 of RFC 3473. The IPv4 Next/Previous Hop Address field is set to the borrowed IP interface address.

The unnumbered IP is advertised by IS-IS TE and OSPF TE, and CSPF can include them in the computation of a path for a P2P LSP or for the S2L of a P2MP LSP. This feature does not, however, support defining an unnumbered interface a hop in the path definition of an LSP.

A router creates an RSVP neighbor over an unnumbered interface using the tuple {router-id, ifIndex}. The router-id of the router that advertised a specific unnumbered interface index is obtained from the TE database. As a result, if TE is disabled in IS-IS or OSPF, a non-CSPF LSP with the next-hop for its path is over an unnumbered interface does not come up at the ingress LER because the router-id of the neighbor that has the next-hop of the path message cannot be looked up. In this case, the LSP path remains in the operationally down state with a reason noRouteToDestination. If a PATH message was received at the LSR in which TE was disabled and the next-hop for the LSP path is over an unnumbered interface, a PathErr message is sent back to the ingress LER with the "Routing Problem" error code of 24 and an error value of 5 "No route available toward destination".

All MPLS features available for numbered IP interfaces are supported, with the exception of the following:

- configuring a router ID with a value other than system
- signaling of an LSP path with an ERO based a loose or strict hop using an unnumbered TE link in the path hop definition
- signaling of one-to-one detour LSP over unnumbered interface
- unnumbered RSVP interface registration with BFD
- RSVP Hello and all Hello-related capabilities such as Graceful Restart helper
- the user SRLG database feature; the following command allows the user to manually enter the SRLG membership of any link in the network in a local database at the ingress LER.

  ```
  configure router mpls user-srlg-db
  ```

  The user cannot enter an unnumbered interface into this database; and therefore, all unnumbered interfaces are considered as having no SRLG membership if the user enabled **user-srlg-db**.

This feature also extends the support of LSP ping, P2MP LSP ping, LSP trace, and P2MP LSP trace to P2P and P2MP LSPs that have unnumbered TE links in their path.

2.2.9.1 Operation of RSVP FRR facility backup over unnumbered interface

When the Point-of-Local Repair (PLR) node activates the bypass LSP by sending a PATH message to refresh the path state of protected LSP at the Merge-Point (MP) node, it must use an IPv4 tunnel sender address in the sender template object that is different than the one used by the ingress LER in the PATH message. These are the procedures specified in RFC 4090 that are followed in the SR OS implementation.

The router uses the address of the outgoing interface of the bypass LSP as the IPv4 tunnel sender address in the sender template object. This address is different from the system interface address used in the sender template of the protected LSP by the ingress LER and so, there are no conflicts when the ingress LER acts as a PLR.

When the PLR is the ingress LER node and the outgoing interface of the bypass LSP is unnumbered, it is required that the user assigns to the interface a borrowed IP address that is different from the system interface. If not, the bypass LSP does not come up.

In addition, the PLR node includes the IPv4 RSVP_HOP object (C-Type=1) or the IF_ID RSVP_HOP object (C-Type=3) in the PATH message if the outgoing interface of the bypass LSP is numbered or unnumbered respectively.

When the MP node receives the PATH message over the bypass LSP, it creates the merge-point context for the protected LSP and associate it with the existing state if any of the following is satisfied:

- Change in C-Type of the RSVP_HOP object
- C-Type is IF_ID RSVP_HOP and did not change but IF_ID TLV is different
- Change in IPv4 Next or Previous Hop Address in RSVP_HOP object regardless of the C-Type value.

These procedures at the PLR and MP nodes are followed in both the link-protect and the node-protect FRR. If the MP node is running a pre-Release 11.0 implementation, it rejects the new IF_ID C-Type and drops the PATH over bypass. This results in the protected LSP state expiring at the MP node, which tears down the path. This is the case in general when node-protect FRR is enabled and the MP node does not support unnumbered RSVP interface.

2.3 MPLS transport profile

Note:

- Users require a valid Application Specific License Manager (ASLM) license to use MPLS transport profile (MPLS-TP) features.
- This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

MPLS can be used to provide a network layer to support packet transport services. In some operational environments, it is desirable that the operation and maintenance of such an MPLS based packet transport network follow operational models typical in traditional optical transport networks (for example, SONET/SDH), while providing additional OAM, survivability and other maintenance functions targeted at that environment.

MPLS-TP defines a profile of MPLS targeted at transport applications. This profile defines the specific MPLS characteristics and extensions required to meet transport requirements, while retaining compliance to the standard IETF MPLS architecture and label switching paradigm. The basic requirements are architecture for MPLS-TP are described by the IETF in RFC 5654, RFC 5921, and RFC 5960, to meet two objectives:

- To enable MPLS to be deployed in a transport network and operated in a similar manner to existing transport technologies.
- To enable MPLS to support packet transport services with a similar degree of predictability to that found in existing transport networks.

To meet these objectives, MPLS-TP has a number of high level characteristics:

- It does not modify the MPLS forwarding architecture, which is based on existing pseudowire and LSP constructs. Point-to-point LSPs may be unidirectional or bidirectional. Bidirectional LSPs must be congruent (that is, co-routed and follow the same path in each direction). The system supports bidirectional co-routed MPLS-TP LSPs.
- There is no LSP merging.
- OAM, protection, and forwarding of data packets can operate without IP forwarding support. When static provisioning is used, there is no dependency on dynamic routing or signaling.
- LSP and pseudowire monitoring is only achieved through the use of OAM and does not rely on control plane or routing functions to determine the health of a path. For example, LDP hello failures do not trigger protection.

- MPLS-TP can operate in the absence of an IP control plane and IP forwarding of OAM traffic. MPLS-TP is only supported on static LSPs and PWs.

The system supports MPLS-TP on LSPs and PWs with static labels. MPLS-TP is not supported on dynamically signaled LSPs and PWs. MPLS-TP is supported for Epipe and Cpipe VLLs, and Epipe spoke SDP termination on IES, VPRN and VPLS. Static PWs may use SDPs that use either static MPLS-TP LSPs or RSVP-TE LSPs.

The following MPLS-TP OAM and protection mechanisms, defined by the IETF, are supported:

- MPLS-TP Generic Associated Channel for LSPs and PWs (RFC 5586)
- MPLS-TP Identifiers (RFC 6370)
- Proactive CC, CV, and RDI using BFD for LSPs (RFC 6428)
- On-Demand CV for LSPs and PWs using LSP Ping and LSP Trace (RFC 6426)
- 1-for-1 Linear protection for LSPs (RFC 6378)
- Static PW Status Signaling (RFC 6478)

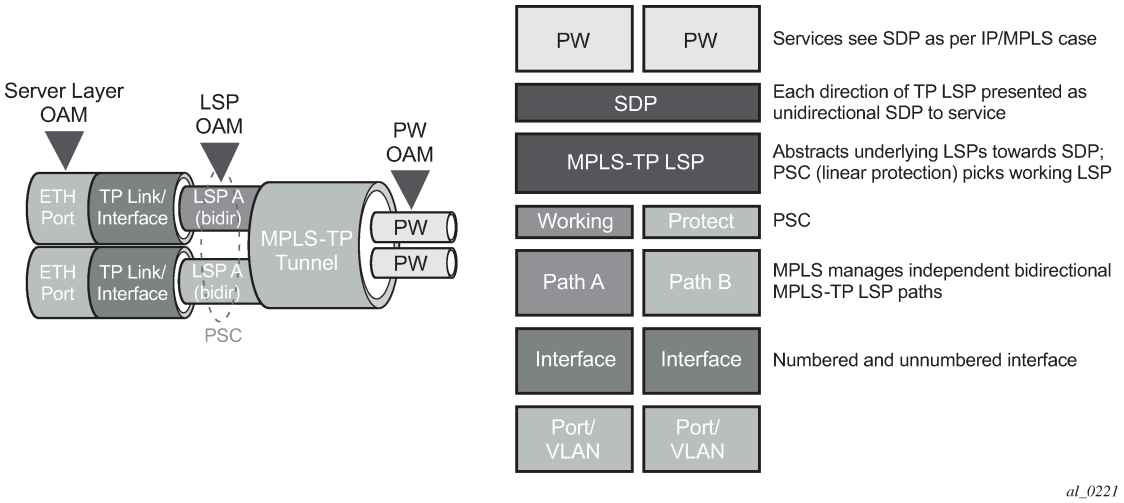
The system can play the role of an LER and an LSR for static MPLS-TP LSPs, and a PE/T-PE and an S-PE for static MPLS-TP PWs. It can also act as a S-PE for MPLS-TP segments between an MPLS network that strictly follows the transport profile, and an MPLS network that supports both MPLS-TP and dynamic IP/MPLS.

2.3.1 MPLS-TP model

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

Figure 7: MPLS-TP model shows a high level functional model for MPLS-TP in SR OS. LSP A and LSP B are the working and protect LSPs of an LSP tunnel. These are modeled as working and protect paths of an MPLS-TP LSP in SR OS. MPLS-TP OAM runs in-band on each path. 1:1 linear protection coordinates the working and protect paths, using a protection switching coordination protocol (PSC) that runs in-band on each path over a Generic Associated Channel (G-ACh) on each path. Each path can use either an IP numbered, IP unnumbered, or MPLS-TP unnumbered (that is, non-IP) interface.

Figure 7: MPLS-TP model



All MPLS-TP LSPs are bidirectional co-routed, as detailed in RFC 5654. That is, the forward and backward directions follow the same route (in terms of links and nodes) across the network. Both directions are set up, monitored and protected as a single entity. Therefore, both ingress and egress directions of the same LSP segment are associated at the LER and LSR and use the same interface (although this is not enforced by the system).

In the above model, an SDP can use one MPLS-TP LSP. This abstracts the underlying paths toward the overlying services, which are transported on pseudowires. Pseudowires are modeled as spoke SDPs and can also use MPLS-TP OAM. PWs with static labels may use SDPs that, in turn, use either signaled RSVP-TE LSPs or one static MPLS-TP LSP.

2.3.2 MPLS-TP provider edge and gateway

This section describes some example roles for the system in an MPLS-TP network.

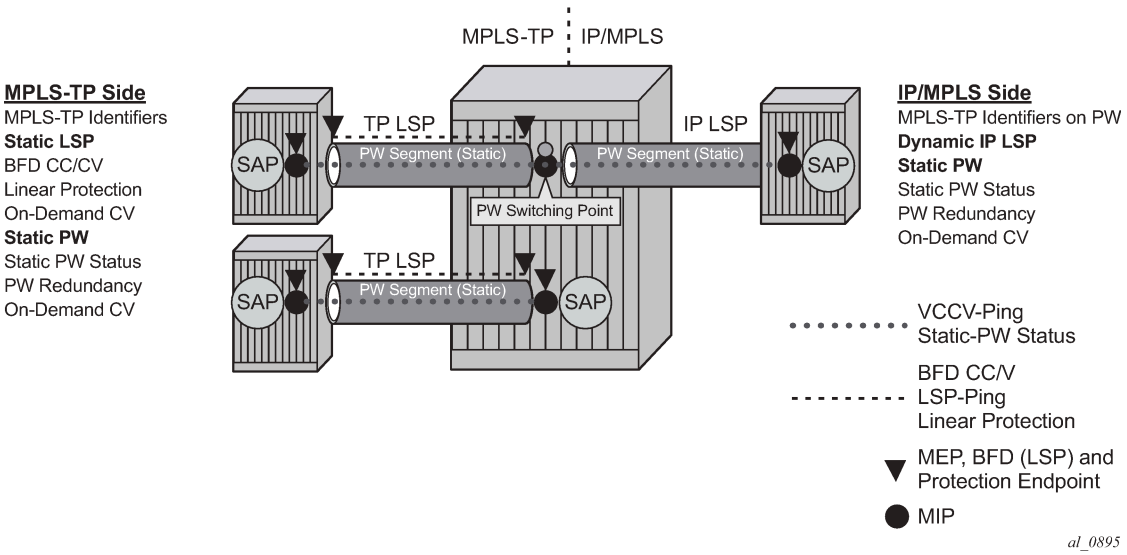
2.3.2.1 VLL services

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

The system may use MPLS-TP LSPs, and PWs, to transport point to point virtual leased line services. The router may play the role of a terminating PE or switching PE for VLLs. Epipe and Cpipe VLL services of type Epipe and Cpipe. The router may play the role of a switching PE.

Figure 8: MPLS-TP provider edge and gateway, VLL services illustrates the use of the system as a T-PE for services in an MPLS-TP domain, and as a S-PE for services between an MPLS-TP domain and an IP/MPLS domain. Static PWs with MPLS-TP identifiers, originating in the MPLS-TP network, are transported over static MPLS-TP LSPs. These either terminate on a local SAP on the system, or are switched to another PW segment across the IP/MPLS network. The PW segment in the IP/MPLS network may have static labels or be signaled using T-LDP.

Figure 8: MPLS-TP provider edge and gateway, VLL services



2.3.2.2 Spoke SDP termination

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

Figure 9: MPLS-TP provider edge and gateway, spoke SDP termination on VPLS and Figure 10: MPLS-TP provider edge and gateway, spoke SDP termination on IES/VPRN illustrate the model for spoke SDP termination on VPLS, IES, and VPRN services, respectively. Similar to the VLL case, the static MPLS-TP PW may terminate on an interface belonging to the service on the router at the border between the MPLS-TP and IP/MPLS networks, or be switched to another PW segment to be terminated on a remote PE.

Figure 9: MPLS-TP provider edge and gateway, spoke SDP termination on VPLS

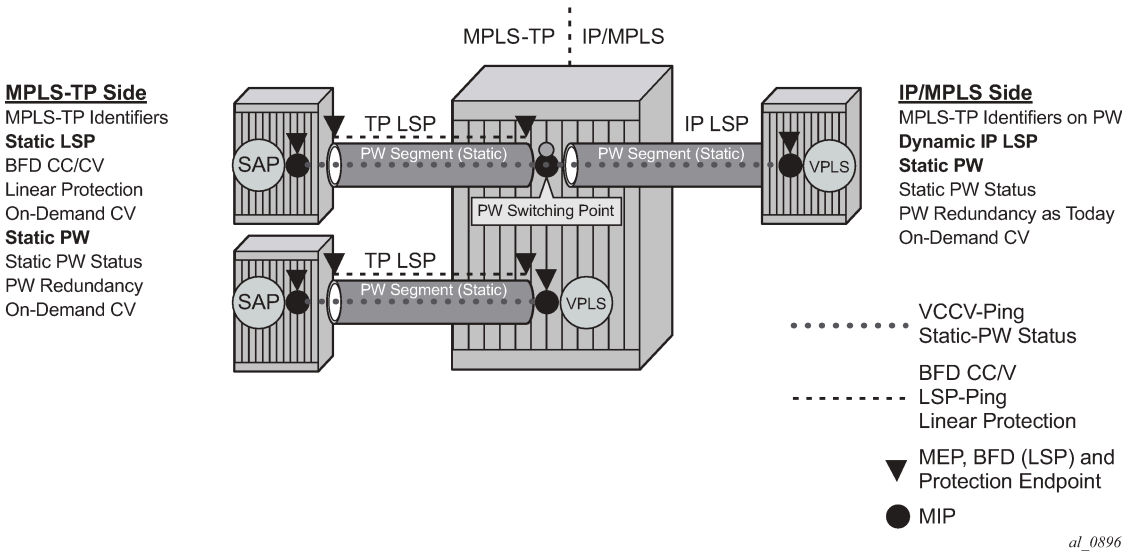
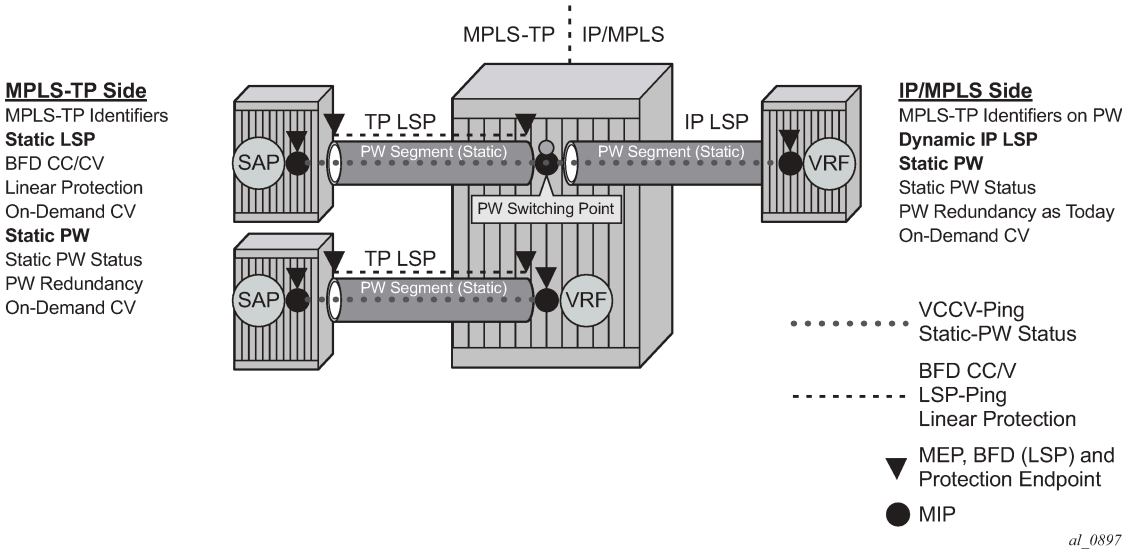


Figure 10: MPLS-TP provider edge and gateway, spoke SDP termination on IES/VPRN

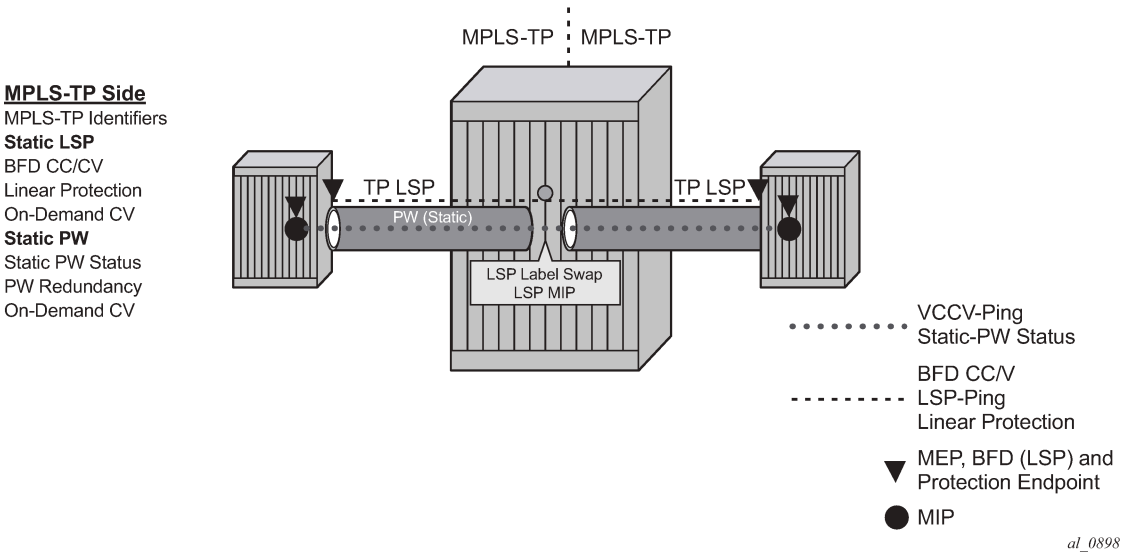


2.3.3 MPLS-TP LSR

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

The SR OS MPLS-TP LSR model is illustrated in Figure 11: MPLS-TP LSR. The system is able to swap a statically configured LSP label on an ingress path to a statically configured LSP label on an egress path. Bidirectional co-routed MPLS TP LSPs are supported by configuring the forward and reverse paths of the LSP to use the same ports on ingress and egress.

Figure 11: MPLS-TP LSR



2.3.4 Detailed descriptions of MPLS-TP

2.3.4.1 MPLS-TP LSPs

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

SR OS supports the configuration of MPLS-TP tunnels, which comprise a working and, optionally, a protect LSP. In SR OS, a tunnel is referred to as an LSP, while an MPLS-TP LSP is referred to as a path. It is then possible to bind an MPLS-TP tunnel to an SDP.

MPLS-TP LSPs (that is, paths) with static labels are supported. MPLS-TP is not supported for signaled LSPs.

Both bidirectional associated (where the forward and reverse directions of a bidirectional LSP are associated at a specific LER, but may take different routes through the intervening network) and bidirectional co-routed (where the forward and reverse directions of the LSP are associated at each LSR, and take the same route through the network) are possible in MPLS-TP. However, only bidirectional co-routed LSPs are supported.

It is possible to configure MPLS-TP identifiers associated with the LSP, and MPLS-TP OAM command options on each LSP of a tunnel. MPLS-TP protection is configured for a tunnel at the level of the protect path level. Both protection and OAM configuration is managed via templates, to simplify provisioning for large numbers of tunnels.

The router may play the role of either an LER or an LSR.

2.3.4.2 MPLS-TP on pseudowires

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

MPLS-TP is supported on PWs with static labels. The provisioning model supports RFC 6370-style PW path identifiers for MPLS-TP PWs.

MPLS-TP PWs reuse the static PW provisioning model of previous SR OS releases. Including the use of the PW-switching key work to distinguish an S-PE. Therefore, the primary distinguishing feature for an MPLS-TP PW is the ability to configure MPLS-TP PW path identifiers, and to support MPLS-TP OAM and static PW status signaling.

The system can perform the role of a T-PE or an S-PE for a PW with MPLS-TP.

A spoke SDP with static PW labels and MPLS-TP identifiers and OAM capabilities can use an SDP that uses either an MPLS-TP tunnel, or that uses regular RSVP-TE LSPs. The control word is supported for all MPLS-TP PWs.

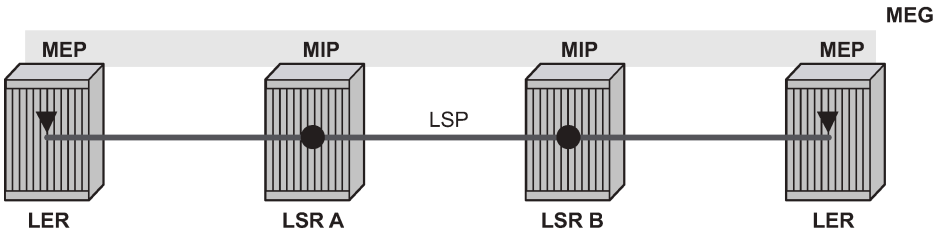
2.3.5 MPLS-TP maintenance identifiers

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

MPLS-TP is designed for use both with and without a control plane. MPLS-TP therefore specifies a set of identifiers that can be used for objects in either environment. This includes a path and maintenance identifier architecture composed of Node, Interface, PW and LSP identifiers, Maintenance Entity Groups (MEGs), Maintenance End Points (MEPs) and Maintenance Intermediate Points (MIPs). These identifiers are specified in RFC 6370.

MPLS-TP OAM and protection switching operates within a framework that is designed to be similar to existing transport network maintenance architectures. MPLS-TP introduces concept of maintenance domains to be managed and monitored. In these, Maintenance Entity Group End Points (MEPs) are edges of a maintenance domain. OAM of a maintenance level must not leak beyond corresponding MEP and so MEPs typically reside at the end points of LSPs and PWs. Maintenance Intermediate Points (MIPS) define intermediate nodes to be monitored. Maintenance Entity Groups (MEGs) comprise all the MEPs and MIPs on an LSP or PW.

Figure 12: MPLS-TP maintenance architecture



Both IP-compatible and ICC (ITU-T carrier code) based identifiers for the above objects are specified in the IETF, but only the IP-compatible identifiers defined in RFC 6370 are supported.

SR OS supports the configuration of the following node and interface related identifiers:

- **Global_ID**

  This is similar to the global ID that can be configured for dynamic MS-PWs. However, in MPLS-TP this should be set to the AS number of the node. If not explicitly configured, then it assumes the default value of 0. In SR OS, the source global ID for an MPLS-TP tunnel is taken to be the global ID configured at the LER. The destination global ID is optional in the tunnel configuration. If it is not configured, then it is taken as the same as the source global ID.

- **Node_ID**

  This is a 32-bit value assigned by the operator within the scope of the global ID. The system supports the configuration of an IPv4 formatted address <a.b.c.d> or an unsigned 32-bit integer for the MPLS-TP node ID at each node. The node ID must be unique within the scope of the global ID, but there is no requirement for it to be a valid routable IP address. Indeed, a node ID can represent a separate IP-compatible addressing space that may be separate from the IP addressing plan of the underlying network. If no node ID is configured, then the node ID is taken to be the system interface IPv4 address of the node. When configuring a tunnel at an LER, either an IPv4 or an unsigned integer node ID can be configured as the source and destination identifiers, but both ends must be of the same type.

- **IF_ID**

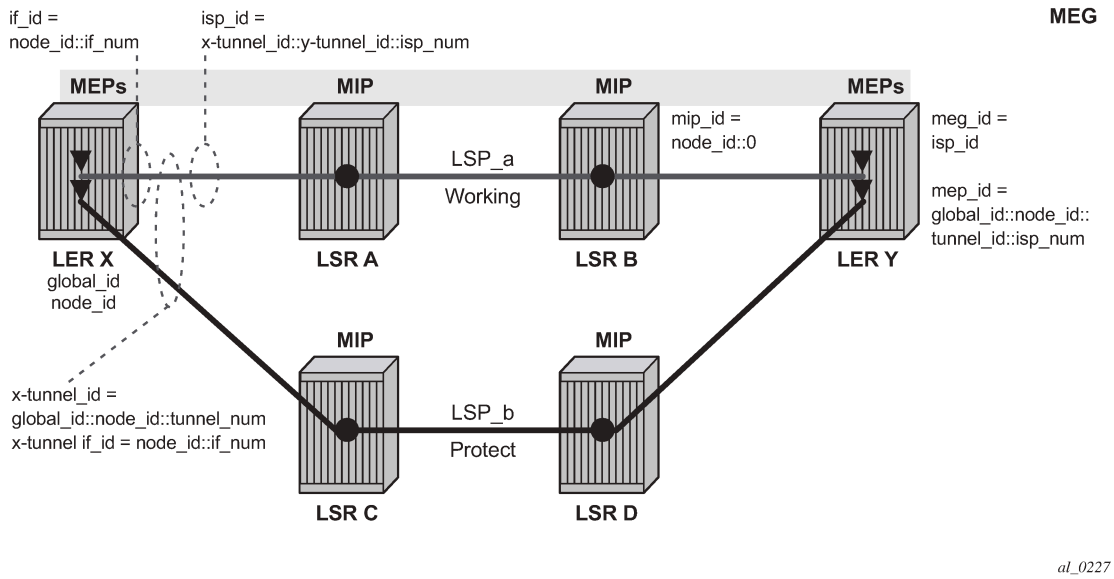
  This is an MPLS-TP section layer identifier at the MPLS interface level. On the router, this is used to provide an identifier for the LSP-trace DSMAP when an IP identifier is not available. The IF_ID is a 64-bit identifier of an MPLS-TP interface on a node that is unique within the scope of a global ID. It is composed of the node ID and the IF_Num. The IF_Num is a node-wide unique identifier for an MPLS-TP interface. On the router, this is primarily used for supporting the DSMAP TLV in LSP trace using MPLS-TP identifiers with unnumbered MPLS-TP interfaces.

Statically configured LSPs are identified using GMPLS-compatible identifiers with the addition of a Tunnel_Num and LSP_Num. As in RSVP-TE, tunnels represent, for example, a set of working and protect LSPs. These are GMPLS-compatible because GMPLS chosen by the IETF as the control plane for MPLS-TP LSPs, although this is not supported in Release 11.0 of the software. PWs are identified using a PW path ID which has the same structure as FEC129 AII Type 2.

SR OS derives the identifiers for MEPs and MIPs on LSPs and PWs based on the configured identifiers for the MPLS-TP Tunnel, LSP or PW path ID, for use in MPLS-TP OAM and protection switching, as per RFC 6370.

The information models for LSPs and PWs are illustrated in Figure 13: MPLS-TP LSP and tunnel information model and Figure 14: MPLS-TP PW information model. The figures use the terminology defined in RFC 6370.

Figure 13: MPLS-TP LSP and tunnel information model

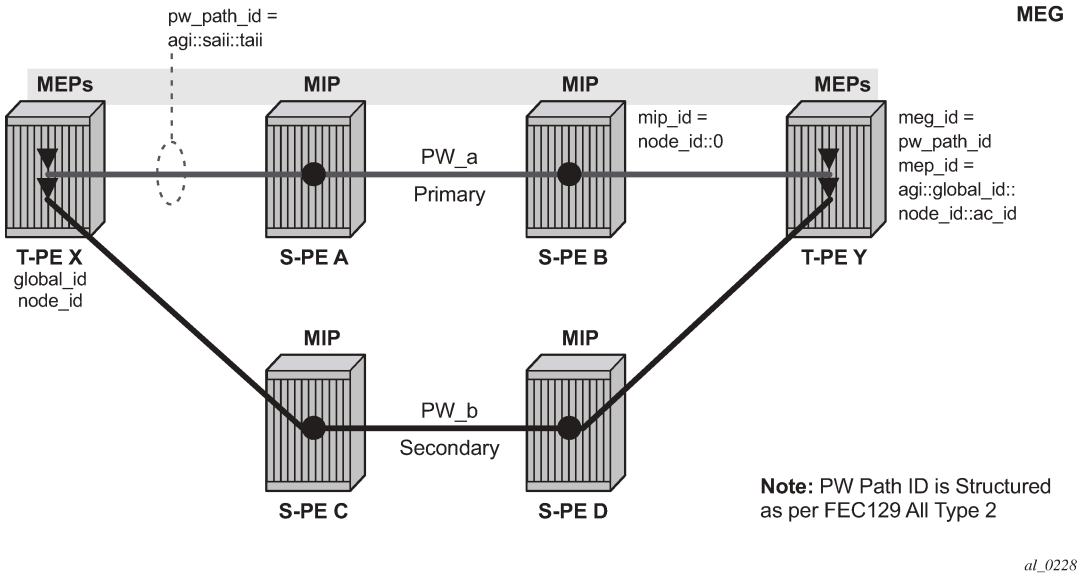


The MPLS-TP Tunnel ID and LSP ID are not to be confused with the RSVP-TE tunnel ID implemented on the router system. Table 7: Mapping from RSVP-TE to MPLS-TP maintenance identifiers shows how these map to the X and Y ends of the tunnel shown in Figure 13: MPLS-TP LSP and tunnel information model for the case of co-routed bidirectional LSPs.

Table 7: Mapping from RSVP-TE to MPLS-TP maintenance identifiers

RSVP-TE identifier	MPLS-TP maintenance identifier
Tunnel Endpoint Address	Node ID (Y)
Tunnel ID (X)	Tunnel Num (X)
Extended Tunnel ID	Node ID (X)
Tunnel Sender Address	Node ID (X)
LSP ID	LSP Num

Figure 14: MPLS-TP PW information model

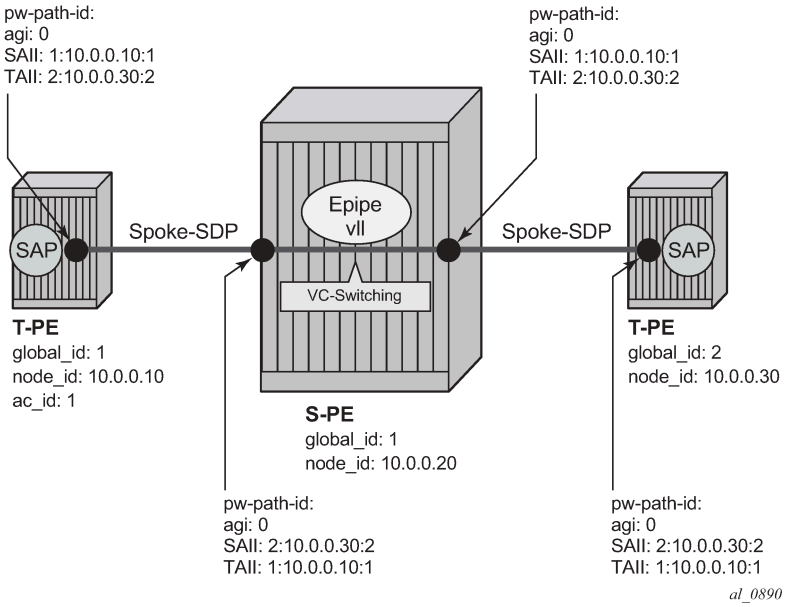


In the PW information model shown in Figure 14: MPLS-TP PW information model, the MS-PW is identified by the PW path ID that is composed of the full AGI:SAII:TAII. The PW path ID is also the MEP ID at the T-PEs, so a user does not have to explicitly configure a MEP ID; it is automatically derived by the system. For MPLS-TP PWs with static labels, although the PW is not signaled end-to-end, the directionality of the SAII and TAII is taken to be the same as for the equivalent label mapping message that is from downstream to upstream. This is to maintain consistency with signaled pseudowires using FEC 129.

On the system, an S-PE for an MS-PW with static labels is configured as a pair of spoke SDPs bound together in an VLL service using the VC-switching command. Therefore, the PW path ID configured at the spoke SDP level at an S-PE must contain the global ID, node ID, and AC ID at the far end T-PEs, not the local S-PE. The ordering of the SAII:TAII in the PW path ID where static PWs are used should be consistent with the direction of signaling of the egress label to a spoke SDP forming that segment, if that label were signaled using T-LDP (in downstream unsolicited mode). VCCV ping checks the PW ID in the VCCV ping echo request message against the configured PW path ID for the egress PW segment.

Figure 15: Example usage of PW identifiers shows an example of how the PW path IDs can be configured for a simple two-segment MS-PW.

Figure 15: Example usage of PW identifiers



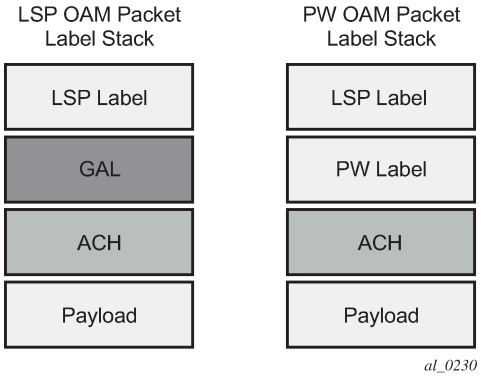
2.3.5.1 Generic associated channel

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

MPLS-TP requires that all OAM traffic be carried in-band on both directions of an LSP or PW. This is to ensure that OAM traffic always shares fate with user data traffic. This is achieved by using an associated control channel on an LSP or PW, similar to that used today on PWs. This creates a channel, which is used for OAM, protection switching protocols (for example, LSP linear protection switching coordination), and other maintenance traffic, and is known as the Generic Associated Channel (G-ACh).

RFC 5586 specifies mechanisms for implementing the G-ACh, relying on the combination of a reserved MPLS label, the Generic-ACH Label (GAL), as an alert mechanism (value equals 13) and Generic Associated Channel Header (G-ACH) for MPLS LSPs, and using the Generic Associated Channel Header, only, for MPLS PWs (although the GAL is allowed on PWs). The purpose of the GAL is to indicate that a G-ACH resides at the bottom of the label stack, and is only visible when the bottom non-reserved label is popped. The G-ACH channel type is used to indicate the packet type carried on the G-ACh. Packets on a G-ACh are targeted to a node containing a MEP by ensuring that the GAL is pushed immediately below the label that is popped at the MEP (for example, LSP endpoint or PW endpoint), so that it can be inspected as soon as the label is popped. A G-ACh packet is targeted to a node containing a MIP by setting the TTL of the LSP or PW label, as applicable, so that it expires at that node, in a similar manner to the SR OS implementation of VCCV for MS-PWs.

Figure 16: Label for LSP and PW G-ACh packets



The system supports the G-ACh on static PWs and static LSPs.

2.3.5.2 MPLS-TP Operations, Administration, and Maintenance (OAM)

This section details the MPLS-TP OAM mechanisms that are supported.

2.3.5.2.1 On-demand CV using LSP-ping

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

MPLS-TP supports mechanisms for on demand CC/CV as well as route tracing for LSPs and PWs. These are required to enable a user to test the initial configuration of a transport path, or to assist with fault isolation and diagnosis. On demand CC/CV and route tracing for MPLS-TP is based on LSP-Ping and is described in RFC 6426. Three possible encapsulations are specified in that RFC:

- IP encapsulation, using the same label stack as RFC 8029, or encapsulated in the IPv4 G-ACh channel with a GAL/ACH
- non-IP encapsulation with GAL/ACH for LSPs and ACH for PWs

In IP-encapsulation, LSP ping packets are sent over the MPLS LSP for which OAM is being performed and contain an IP/UDP packet within them. The On-demand CV echo response message is sent on the reverse path of the LSP, and the reply contains IP or UDP headers followed by the On-demand CV payload.

In non-IP environments, LSP ping can be encapsulated with no IP/UDP headers in a G-ACh and use a source address TLV to identify the source node, using forward and reverse LSP or PW associated channels on the same LSP or PW for the echo request and reply packets. In this case, no IP or UDP headers are included in the LSP ping packets.

The routers support the following encapsulations:

- IP encapsulation with ACH for PWs (as per VCCV type 1)
- IP encapsulation without ACH for LSPs using labeled encapsulation
- non-IP encapsulation with ACH for both PWs and LSPs

LSP ping and VCCV ping for MPLS-TP use two new FEC sub-types in the target FEC stack to identify the static LSP or static PW being checked. These are the static LSP FEC sub-type, which has the same format

as the LSP identifier described above, and the static PW FEC sub-type,. These are used in-place of the currently defined target FEC stack sub-TLVs.

In addition, MPLS-TP uses a source or destination TLV to carry the MPLS-TP global ID and node ID of the target node for the LSP ping packet, and the source node of the LSP ping packet.

LSP ping and VCCV Ping for MPLS-TP can only be launched by the LER or T-PE. The replying node therefore sets the TTL of the LSP label or PW label in the reply packet to 255 to ensure that it reaches the node that launched the LSP ping or VCCV ping request.

RFC 8029 specifies four address types for the downstream mapping TLV for use with IP numbered and unnumbered interfaces, as listed in Table 8: Downstream mapping (RFC 8029).

Table 8: Downstream mapping (RFC 8029)

Type #	Address type	K Octets	Reference
1	IPv4 Numbered	16	RFC 8029
2	IPv4 Unnumbered	16	
3	IPv6 Numbered	40	
4	IPv6 Unnumbered	28	

RFC 6426 adds address type 5 for use with non-IP interfaces, including MPLS-TP interfaces. In addition, this RFC specifies that type 5 must be used when non-IP ACH encapsulation is used for LSP Trace.

It is possible to send and respond to a DSMAP/DDMAP TLV in the LSP trace packet for numbered IP interfaces as per RFC 8029. In this case, the echo request message contains a downstream mapping TLV with address type 1 (IPv4 address) and the IPv4 address in the DDMAP/DSMAP TLV is taken to be the IP address of the IP interface that the LSP uses. The LSP trace packet therefore contains a DSMAP TLV in addition to the MPLS-TP static LSP TLV in the target FEC stack.

DSMAP/DDMAP is not supported for pseudowires.

2.3.5.2.2 Proactive CC, CV, and RDI

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

Proactive Continuity Check (CC) is used to detect a loss of continuity defect (LOC) between two MEPs in a MEG. Proactive Connectivity Verification (CV) is used to detect an unexpected connectivity defect between two MEPs (for example, mis-merging or mis-connection), as well as unexpected connectivity within the MEG with an unexpected MEP. This feature implements both functions using proactive generation of OAM packets by the source MEP that are processed by the peer sink MEP. CC and CV packets are always sent in-band such that they fate share with user traffic, either on an LSP, PW or section and are used to trigger protection switching mechanisms.

Proactive CC/CV based on bidirectional forwarding detection (BFD) for MPLS-TP is described in RFC 6428. BFD packets are sent using configurable timers and encapsulated without UDP or IP headers on a standardized G-ACh channel on an LSP or PW. CC packets simply consist of a BFD control packet, while CV packets also include an identifier for the source MEP in order that the sink MEP can detect if it is receiving packets from an incorrect peer MEP, indicating a mis-connectivity defect. Other defect types (including period mis-configuration defect) should be supported. When a supported defect is detected, an

appropriate alarm is generated (for example, log, SNMP trap) at the receiving MEP and all traffic on the associated transport path (LSP or PW) is blocked. This is achieved using linear protection for CC defects, and by blocking the ingress datapath for CV defects. The system supports both a CC-only mode and a combine CC/CV mode, as defined in RFC 6428.

When an LSP with CV is first configured, the LSP is held in the CV defect state for 3.5 seconds after the first valid CV packet is received.

Figure 17: BFD used for proactive CC on MPLS-TP LSP

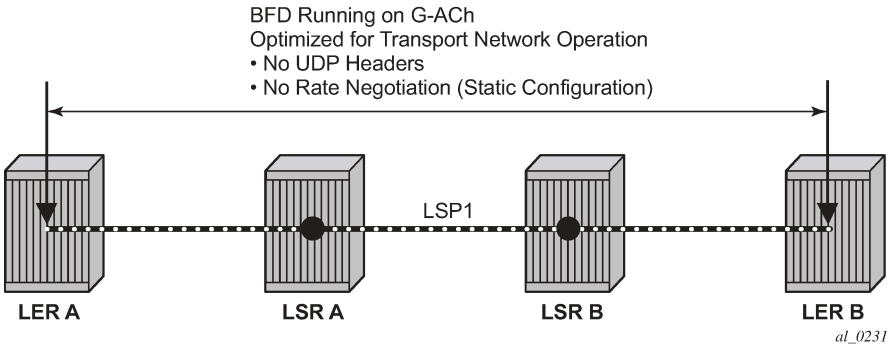
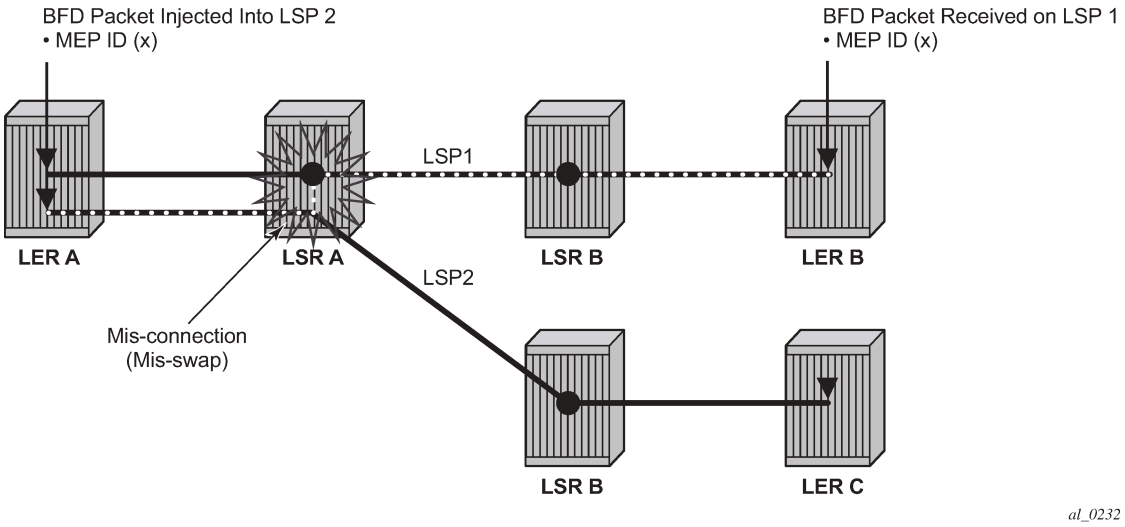


Figure 18: BFD used for proactive CV on MPLS-TP LSP



Linear protection switching of LSPs (see below) is triggered based on a CC or CV defect detected by BFD CC/CV.

RFC 6428 defines two BFD session modes. Coordinated mode is supported.

- **coordinated mode**

  The session state on both directions of the LSP is coordinated and constructed from a single, bidirectional BFD session.

- **independent mode**

  Two independent sessions are bound together at a MEP.

BFD is supported on MPLS-TP LSPs. When BFD_CV detects a misconnectivity on an LSP, the system drops all incoming non-OAM traffic with the LSP label (at the LSP termination point) instead of forwarding it to the associated SAP or PW segment.

The following GACh channel types are supported for the combined CC/CV mode:

- 0x22 for BFD CC with no IP encapsulation
- 0x23 for BFD CV

The G-ACh channel type, 0x07 is used for the CC-only mode.

2.3.5.2.3 BFD-based RDI

RDI provides a mechanism whereby the source MEP can be informed of a downstream failure on an LSP, and can either raise an alarm, or initiate a protection switching operation. In the case of BFD based CC/CV, RDI is communicated using the BFD diagnostic field in BFD CC/CV messages. The following diagnostic codes are supported:

- 1 indicates Control Detection Time Expired.
- 9 indicates mis-connectivity defect.

2.3.5.3 PW control channel status notifications (static pseudowire status signaling)

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

MPLS-TP introduces the ability to support a full range of OAM and protection and redundancy on PWs for which no dynamic T-LDP control plane exists. Static PW status signaling is used to advertise the status of a PW with statically configured labels by encapsulating the PW status TLV in a G-ACh on the PW. This mechanism enables OAM message mapping and PW redundancy for such PWs, as defined in RFC 6478. This mechanism is known as control channel status signaling in SR OS.

PW control channel status notifications use a similar model to T-LDP status signaling. That is, in general, status is always sent to the nearest neighbor T-PE or S-PE and relayed to the next segment by the S-PE. To achieve this, the PW label TTL is set to 1 for the G-ACh packet containing the status message.

Control channel status notifications are disabled by default on a spoke SDP. If they are enabled, then the default refresh interval is set to zero (although this value should be configurable in CLI). That is, when a status bit changes, three control channel status packets are sent consecutively at one-second intervals, and then the transmitter falls silent. If the refresh timer interval is non-zero, then status messages continue to be sent at that interval. The system supports the configuration of a refresh timer of 0, or from 10 to 65535 seconds. The recommended value is 600 seconds.

The system supports the optional acknowledgment of a PW control channel status message.

To constrain the CPU resources consumed processing control channel status messages, the system implements a credit-based mechanism. If a user enables control channel status on a PW[n], then a specific number of credits *c_n* are consumed from a CPM-wide pool of max_credit credits. The number of credits consumed is inversely proportional to the configured refresh timer (the first three messages at 1 second interval do not count against the credit). If the current_credit ≤ 0, then control channel status signaling cannot be configured on a PW (but the PW can still be configured and enabled).

If a PE with a non-zero refresh timer configured does not receive control channel status refresh messages for 3.5 time the specified timer value, then by default it times out and assume a PW status of zero.

A trap is generated if the refresh timer times out.

If PW redundancy is configured, the system always considers the literal value of the PW status; a time-out of the refresh timer does not impact the choice of the active transit object for the VLL service. The result of this is that if the refresh timer times-out, and a specified PW is currently the active PW, then the system does not fail-over to an alternative PW if the status is zero and some lower-layer OAM mechanism; for example, BFD has not brought down the LSP because of a connectivity defect. It is recommended that the PW refresh timer be configured with a much longer interval than any proactive OAM on the LSP tunnel, so that the tunnel can be brought down before the refresh timer expires if there is a CC defect.

A unidirectional continuity fault on a RSVP TE LSP may not result in the LSP being brought down before the received PW status refresh timer expires. Nokia recommends that either bidirectional static MPLS-TP LSPs with BFD CC, or additional protection mechanisms; for example, FRR be used on RSVP-TE LSPs carrying MPLS-TP PWs. This is particularly important in active and standby PW dual homing configurations, where the active and standby forwarding state or operational state of every PW in the redundancy set must be accurately reflected at the redundant PE side of the configuration.

A PW with a refresh timer value of zero is always treated as having not expired.

The system implements a hold-down timer for **control-channel-status** PW status bits to suppress bouncing of the status of a PW. For a specific spoke SDP, if the system receives 10 PW status change events in 10 seconds, the system holds down the spoke SDP on the local node with the last received non-zero PW-status bits for 20 seconds. It updates the local spoke with the most recently received PW status. This hold down timer is not persistent across disabled and enabled events.

2.3.5.4 PW control channel status request mechanism

The system implements an optional PW control channel status request mechanism. This enhances the existing control channel status mechanism so that a peer that has a "stale" PW status for the far end of a PW can request that the peer PE send a static PW status update. Accurate and current information about the far end status of a PW is important for correct operation of PW redundancy. This mechanism ensures a consistent view of the control plane is maintained, as far as possible, between peer nodes. It is not intended to act as a continuity check between peer nodes.

2.3.5.5 Pseudowire redundancy and active or standby dual homing

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

PW redundancy is supported for static MPLS-TP pseudowires. However, instead of using T-LDP status signaling to signal the forwarding state of a PW, control channel status signaling is used.

The following PW redundancy scenarios must be supported:

- MC-LAG and MC-APS with single and multisegment PWs interconnecting the PEs
- MS-PW (S-PE) redundancy between VLL PEs with single-homed CEs
- dual-homing of a VLL service into redundant IES or VPRN PEs, with active or standby PWs
- dual-homing of a VLL service into a VPLS with active/standby PWs

Active or standby dual-homing into routed VPLS is not supported in for MPLS-TP PWs. This is because it relies on PW label withdrawal of the standby PW to take down the VPLS instance, and therefore the associated IP interface. Instead, it is possible to enable BGP multihoming on a routed VPLS that has

MPLS-TP PWs as spoke SDPs, and for the PW status of each spoke SDP to be driven (using control channel status) from the active or standby forwarding state assigned to each PW by BGP.

It is possible to configure inter-chassis backup (ICB) PWs as static MPLS-TP PWs with MPLS-TP identifiers. Only MPLS-TP PWs are supported in the same endpoint. That is, PWs in an endpoint must either be all MPLS-TP, or none of them must be MPLS-TP. This implies that an ICB used in an endpoint for which other PWs are MPLS TP must also be configured as an MPLS-TP PW.

A failover to a standby pseudowire is initiated based on the existing supported methods (for example, failure of the SDP).

2.3.5.6 Lock instruct and loopback for MPLS-TP pseudowires

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

On the 7750 SR and 7450 ESS, the MPLS-TP supports lock instruct and loopback for PWs, including the ability to:

- administratively lock a spoke SDP with MPLS-TP identifiers
- divert traffic to and from an external device connected to a SAP
- create a datapath loopback on the corresponding PW at a downstream S-PE or T-PE that was not originally bound to the spoke SDP being tested
- forward test traffic from an external test generator into an administratively locked PW, while simultaneously blocking the forwarding of user service traffic

MPLS-TP provides the ability to conduct test service throughput for PWs, through the configuration of a loopback on an administratively locked pseudowire. To conduct a service throughput test, an administrative lock is applied at each end of the PW. A test service that contains the SAP connected to the external device is used to inject test traffic into the PW. Lock request messaging is not supported.

A lock can be applied using the CLI or NMS. The forwarding state of the PW can be either active or standby.

After the PW is locked it can be put into loopback mode (for two way tests) so the ingress datapath in the forward direction is cross connected to the egress datapath in the reverse direction of the PW. The loopback can be configured through the CLI or NMS.

The PW loopback is created at the PW level, so everything under the PW label is looped back. This distinguishes a PW loopback from a service loopback, where only the native service packets are looped back.

The following MPLS-TP loopback configuration is supported:

- An MPLS-TP loopback can be created for an Epipe or Cpipe VLL.
- Test traffic can be inserted at an Epipe or Cpipe VLL endpoint or at an Epipe spoke-sdp termination on a VPLS interface.

For more information about configuring lock instruct and loopback for MPLS-TP Pseudowires see, the *7450 ESS, 7750 SR, 7950 XRS, and VSR Services Overview Guide* and the *7450 ESS, 7750 SR, 7950 XRS, and VSR Layer 2 Services and EVPN Guide*.

2.3.5.7 MPLS-TP LSP protection

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

Linear 1-for-1 protection of MPLS-TP LSPs is supported, as defined in the RFC. This applies only to LSPs (not PWs).

This is supported edge-to-edge on an LSP, between two LERs, where normal traffic is transported either on the working LSP or on the protection LSP using a logical selector bridge at the source of the protected LSP.

At the sink LER of the protected LSP, the LSP that carries the normal traffic is selected, and that LSP becomes the working LSP. A protection switching coordination (PSC) protocol coordinates between the source and sink bridge, which LSP is used, as working path and protection path. The PSC protocol is always carried on a G-ACh on the protection LSP.

The system supports single-phased coordination between the LSP endpoints, in which the initiating LER performs the protection switchover to the alternate path and informs the far-end LER of the switch.

Bidirectional protection switching is achieved by the PSC protocol coordinating between the two end points to determine which of the two possible paths (that is the working or protect path), transmits user traffic at any specific time.

It is possible to configure non-revertive or revertive behavior. For non-revertive, the LSP does not switch back to the working path when the PSC switchover requests end, while for revertive configurations, the LSP always returns back to the working path when the switchover requests end.

The following figures illustrate the behavior of linear protection in more detail.

Figure 19: Normal operation

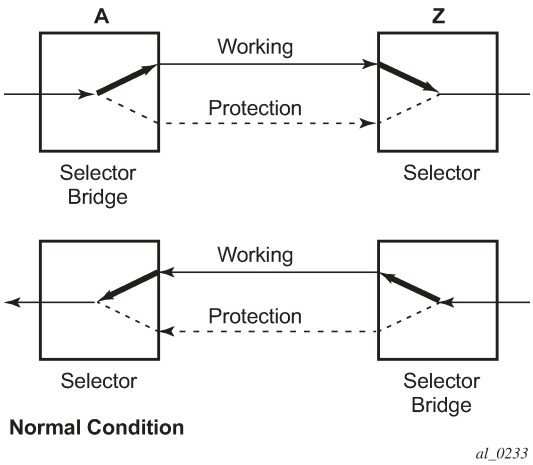
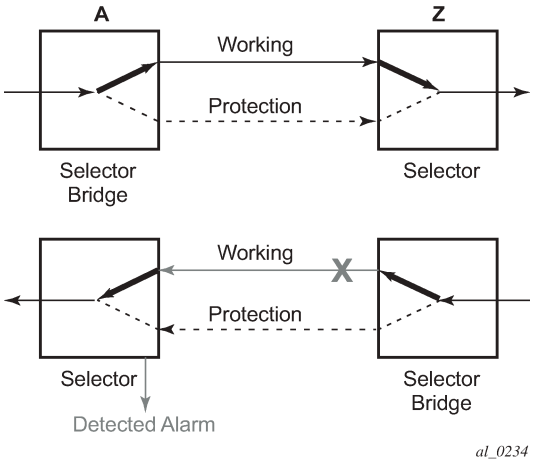


Figure 20: Failed condition



In normal condition, user data packets are sent on the working path on both directions, from A to Z and Z to A.

A defect in the direction of transmission from node Z to node A impacts the working connection Z-to-A, and initiates the detection of a defect at the node A.

Figure 21: Failed condition - switching at A

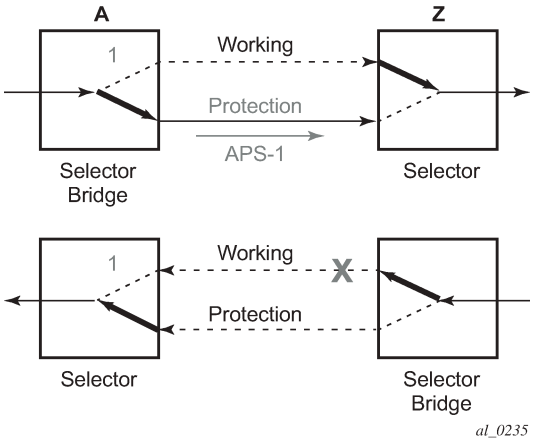
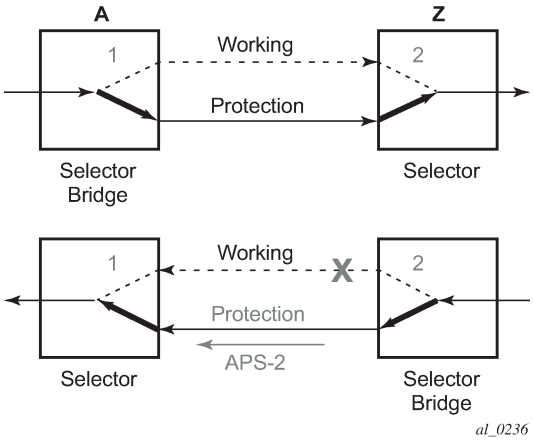


Figure 22: Failed condition - switching at Z



The unidirectional PSC protocol initiates protection switching: the selector bridge at node A is switched to protection connection A-to-Z and the selector at node A switches to protection connection Z to-A. The PSC packet, sent from node A to node Z, requests a protection switch to node Z.

After node Z validates the priority of the protection switch request, the selector at node Z is switched to protection connection A-to-Z and the selector bridge at the node Z is switched to protection connection Z-to-A. The PSC packet, sent from node Z to node A, is used as acknowledge, informing node A about the switching.

If BFD CC or CC/CV OAM packets are used to detect defects on the working and protection paths, they are inserted on both working and protection paths. Packets are sent whether the path is selected as the currently active path. Linear protection switching is also triggered on receipt of an AIS with the LDI bit set.

The following commands are supported:

- Forced Switch
- Manual Switch
- Clear

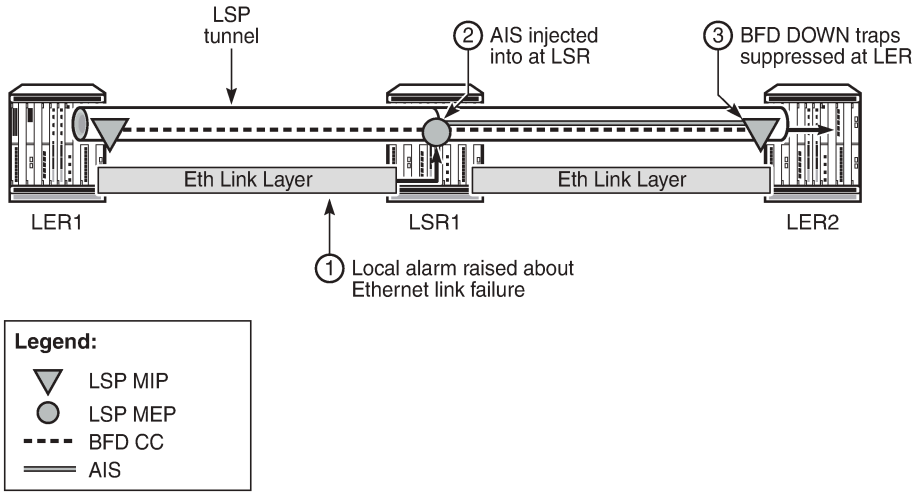
2.3.6 AIS

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

When a MEP at a server layer (such as a link layer with respect to a specified LSP) detects a failure, the server MEP notifies a co-located client layer of the condition. The client layer then generates Alarm Indication Signal (AIS) packets downstream in the client layer. These fault OAM messages are generated by intermediate nodes where a client LSP is switched, as per RFC 6427. This means that AIS packets are only inserted at an LSP MIP. AIS is used by the receiving MEP to suppress client layer traps caused by the upstream server layer failure; for example, if BFD CC is running on the LSP, then AIS suppresses the generation of multiple traps because of loss of CC.

Figure 23: Example of AIS in MPLS-TP illustrates an example of the operation of AIS in MPLS-TP.

Figure 23: Example of AIS in MPLS-TP



In the example, a failure of the Ethernet link layer between PE1 and LSR1 is detected at LSR1, which raises a local trap. LSPs transiting the LSR may be running CC OAM, such as BFD, and have AIS packets injected into them at LSR1. These AIS messages are received by the corresponding downstream MEP and processed. The failure of the Ethernet link between PE1 and LSR1 means that CC OAM on the LSPs is not received by the MEPs at PE2. Normally, this would cause multiple traps to be raised at PE2, but the reception of AIS causes PE2 to suppress the local generation of traps related to the failed LSP.

For traps to be suppressed successfully, the AIS message must arrive and be processed at the far-end PE or LER in sufficient time for the initial alarm to be suppressed. Therefore, the router implements a 2.5 secs hold-down timer for such traps on MPLS-TP LSPs.

Fault management for MPLS-TP, including AIS, is specified in RFC 6427.

The router supports:

- receiving and processing of AIS messages at LSP MEPs (at the LER)
- generation of AIS messages at LSP MIPs (at the LSR) in response to a failure of the ingress link
- suppression of SNMP traps indicating changes in the state of a BFD session, which result from the failure of the LSP datapath upstream of a receiving LER; these traps would otherwise be sent to the 5620 SAM
- suppression of any BFD state machine Up and Down changes that occur while AIS is being received; there is no buffering or storage of state machine changes that occur during this period. This suppression only applies to Up and Down state change traps; other traps that would be expected are observed as normal.
- inclusion of the Link Down Indication (LDI) in an AIS message. This triggers a switchover of LSP linear protection if used on the LSP.
- insertion of AIS in the downstream direction of the transit path if a unidirectional fault is detected at an LSR. This suppresses CC traps at the downstream LER. However, the BFD session still goes down, causing RDI to be sent upstream in BFD, which causes an alarm at the upstream LER.

2.3.7 Configuring MPLS-TP

This section describes the steps required to configure MPLS-TP.

2.3.7.1 Configuration overview

The following actions must be performed to configure MPLS-TP LSPs or PWs.

Note: The **configure router mpls mpls-tp** context only applies to the classic CLI.

At the router LER and LSR:

1. In the classic CLI, configure MPLS-TP containing nodal MPLS-TP identifiers.

   ```
   configure router mpls mpls-tp
   ```

2. Configure a sufficient range of reserved labels for static LSPs and PWs.

   ```
   configure router mpls-labels static-label-range
   ```

3. In the classic CLI, configure a range of reserved tunnel identifiers for MPLS-TP LSPs.

   ```
   configure router mpls mpls-tp tp-tunnel-id-range
   ```

4. Optionally, configure MPLS-TP interfaces, which are interfaces that do not use IP addressing or ARP for next hop resolution. These can only be used by MPLS-TP LSPs. For information, see Interface configuration for MPLS-TP.

At the router LER:

1. In the classic CLI, configure OAM templates; these contain generic command options for MPLS-TP proactive OAM.

   ```
   configure router mpls mpls-tp oam-template
   ```

2. Configure BFD templates using commands in the following context. These contain generic command options for BFD used for MPLS-TP LSPs.
   - **MD-CLI**

     ```
     configure bfd bfd-template
     ```

   - **classic CLI**

     ```
     configure router bfd bfd-template
     ```

3. In the classic CLI, configure protection templates in the following context; these contain generic command options for MPLS-TP one-for-one linear protection.

   ```
   configure router mpls mpls-tp protection-template
   ```

4. In the classic CLI, configure MPLS-TP LSPs.

```
configure router mpls lsp mpls-tp
```

5. Configure pseudowires using MPLS-TP as spoke SDPs with static PW labels. For more information, see MPLS-TP on pseudowires.

At an LSR:

In the classic CLI, use the following command to configure an LSP transit path.

```
configure router mpls mpls-tp transit-path
```

2.3.7.2 Node-wide MPLS-TP configuration

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

If a user disables MPLS, normally the entire MPLS configuration is deleted. However, in the case of MPLS-TP a check that there is no other MPLS-TP configuration; for example, services or tunnels using MPLS-TP on the node, is performed.

In the classic CLI, use the following command to configure MPLS-TP.

```
configure router mpls mpls-tp
```

MPLS-TP LSPs may be configured if the MPLS-TP context is administratively disabled, but they remain down until the MPLS-TP context is configured as administratively up. No programming of the datapath for an MPLS-TP path occurs until the following are all true:

- MPLS-TP context is administratively enabled
- MPLS-TP LSP context is administratively enabled
- MPLS-TP path context is administratively enabled

Administratively disabling MPLS-TP, therefore, brings down all MPLS-TP LSPs on the system.

The MPLS-TP context cannot be deleted if MPLS-TP LSPs or SDPs exist on the system.

2.3.7.3 Node-wide MPLS-TP identifier configuration

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

In the classic CLI, the following example displays the configuration of the MPLS-TP identifiers.

Output example: classic CLI

```
A:node-2>config>router>mpls# info
----------------------------------------------
...
            mpls-tp
                global-id 500
                node-id 0.0.0.4
```

```
                no shutdown
```

The default value for the **global-id** is 0. This is used if the global ID is not explicitly configured. If a user expects that inter domain LSPs are configured, Nokia recommends setting the global ID to the local ASN of the node configured under the **configure system** context. If two-byte ASNs are used, the most significant two bytes of the global ID are padded with zeros.

The default value of the node ID is the system interface IPv4 address. The MPLS-TP context cannot be administratively enabled unless at least a system interface IPv4 address is configured because MPLS requires that this value is configured.

These values are used unless overridden at the LSP or PW end-points, and apply only to static MPLS-TP LSPs and PWs.

In the classic CLI, the following command must be in an administratively disabled state to change the MPLS-TP values.

```
configure router mpls mpls-tp
```

This brings down all of the MPLS-TP LSPs on the node. New values are propagated to the system when the preceding command is administratively enabled.

2.3.7.4 Static LSP and pseudowire (VC) label and tunnel ranges

The SR OS reserves a range of labels for use by static LSPs and static pseudowires (VCs). That is, LSPs and pseudowires with no dynamic signaling of the label mapping. Use the following command to configure static labels for LSPs and pseudowires.

```
configure router mpls-labels static-label-range
```

The *static-label-range* value indicates the maximum number of labels for the label type.

The minimum label value starts at 32 and expands all the way to the maximum number specified. The dynamic label range exists above the static label range. This prevents fragmentation of the label range.

Note: The **configure router mpls mpls-tp** context only applies to the classic CLI.

In the classic CLI, the MPLS-TP tunnel ID range is configured as follows.

```
configure router mpls mpls-tp tp-tunnel-id-range
```

The tunnel ID range referred to here is a contiguous range of RSVP-TE tunnel IDs is reserved for use by MPLS TP, and these IDs map to the MPLS-TP tunnel numbers. There are some cases where the dynamic LSPs may have caused fragmentation to the number space such that contiguous range {max-min} is not available. In these cases, the command fails.

There is no default value for the tunnel ID range, and it must be configured to enable MPLS-TP.

If a configuration of the tunnel ID range fails, then the system gives a reason. This could be that the initially requested range, or the change to the allocated range, is not available that is tunnel IDs in that range have already been allocated by RSVP-TE. Allocated tunnel IDs are visible using a **show** command.

Changing the LSP or static VC label ranges does not require a reboot.

The static label ranges for LSPs, above, apply only to static LSPs configured using the CLI commands for MPLS-TP specified in this section. Different scalability constraints apply to static LSPs configured using the following CLI introduced in earlier SR OS releases.

```
configure router mpls static-lsp
configure router mpls interface label-map
```

The scalability applying to labels configured using this CLI is enforced as follows:

- A maximum of 1000 static LSP names may be configured with a PUSH operation.
- A maximum of 1000 LSPs with a POP or SWAP operation may be configured.

These two limits are independent of one another, giving a combined limit of 1000 PUSH and 1000 POP and SAP operations configured on a node.

The static LSP and VC label spaces are contiguous. Therefore, the dimensioning of these label spaces requires careful planning by a user as increasing the static LSP label space impacts the start of the static VC label space, which may already-deployed.

2.3.7.5 Interface configuration for MPLS-TP

It is possible for MPLS-TP paths to use both numbered IP numbered interfaces that use ARP and static ARP, or IP unnumbered interfaces. MPLS-TP requires no changes to these interfaces. It is also possible to use a new type of interface that does not require any IP addressing or next-hop resolution.

RFC 7213 provides guidelines for the usage of various Layer 2 next-hop resolution mechanisms with MPLS-TP. If protocols such as ARP are supported, then they should be used. However, in the case where no dynamic next hop resolution protocol is used, it should be possible to configure a unicast, multicast or broadcast next-hop MAC address. The rationale is to minimize the amount of configuration required for upstream nodes when downstream interfaces are changes. A default multicast MAC address for use by MPLS-TP point-to-point LSPs has been assigned by IANA (Value: 01-00-5e-90-00-00). This value is configurable on the router to support interoperability with third-party implementations that do not default to this value, and this no default value is implemented on the router.

To support these requirements, an interface type, known as an unnumbered MPLS-TP interface allows a broadcast or multicast destination MAC address to be configured.

Example: Unnumbered MPLS-TP interface configuration (MD-CLI)

```
[ex:/configure router "Base" interface "test"]
A:admin@node-2# info
    admin-state enable
    flavor unnumbered-mpls-tp
    port 2/1/1:10
    mac 04:0a:01:01:00:01
    ipv4 {
        neighbor-discovery {
            static-neighbor-unnumbered {
                mac-address 01:00:5e:90:10:00
            }
        }
    }
```

Example: Unnumbered MPLS-TP interface configuration (classic CLI)

```
A:node-2>config>router>if# info
```

```
-----------------------------------------------
            port 2/1/1:10
            mac 04:0a:01:01:00:01
            static-arp unnumbered 01:00:5e:90:10:00
            no shutdown
-----------------------------------------------
```

The *remote-mac-address* value used with static ARP may be any unicast, broadcast, or multicast address. However, a broadcast or multicast remote MAC address is only allowed with static ARP on Ethernet unnumbered interfaces when the **unnumbered-mpls-tp** command option has been configured. This also allows the interface to accept packets on a broadcast or any multicast MAC address. If a packet is received with a unicast destination MAC address, then it is checked against the configured **mac** *local-mac-address* for the interface, and dropped if it does not match. When an interface is of type **unnumbered-mpls-tp**, only MPLS-TP LSPs are allowed on that interface; other protocols are blocked from using the interface.

An unnumbered MPLS-TP interface is assumed to be point-to-point, and therefore users must ensure that the associated link is not broadcast or multicast in nature if a multicast or broadcast remote MAC address is configured.

The following is a summary of the constraints of an unnumbered MPLS-TP interface:

- It is unnumbered and may borrow or use the system interface address.
- It prevents explicit configuration of a borrowed address.
- It prevents IP address configuration.
- It prevents all protocols except MPLS.
- It prevents deletion if an MPLS-TP LSP is bound to the Interface.

MPLS-TP is only supported over Ethernet ports. The system blocks the association of an MPLS-TP LSP to an interface whose port is non-Ethernet.

If required, the IF_Num is configured under a MEP context under the MPLS interface. The **mpls-tp-mep** context is created under the interface as shown in the following information. The **if-num** command, when concatenated with the node ID, forms the IF_ID (as per RFC 6370), which is the identifier of this MEP. It is possible to configure this context whether the interface is IP numbered, IP unnumbered, or MPLS-TP unnumbered. Use the following commands to create **mpls-tp-mep** command options.

Note: This information applies to the classic CLI. MPLS Transport Profile (MPLS-TP) is only supported in the classic CLI.

Example: classic CLI

```
A:node-2>config>router>mpls>if$ info detail
----------------------------------------------
                mpls-tp-mep
                    if-num 100
                    if-num-validation enable
                    ais-enable
                exit
...
----------------------------------------------
```

The **if-num-validation** command is used to enable or disable validation of the if-num in LSP trace packet against the locally configured **if-num** for the interface over which the LSP trace packet was received at the egress LER. This is because some implementations do not perform interface validation for unnumbered MPLS-TP interfaces and instead set the **if-num** in the DSMAP TLV to 0. The default is enabled.

AIS insertion is configured using the **ais-enable** command under the **mpls-tp-mep** context on an MPLS interface.

2.3.7.6 LER configuration for MPLS-TP

2.3.7.6.1 LSP and path configuration

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

Use the commands in the following context to configure MPLS-TP tunnels and the **mpls-tp** LSP type at the LER under the LSP configuration.

```
configure router mpls lsp lsp-name [bypass-only | p2mp-lsp | mpls-tp src-tunnel-num | sr-te]
```

The *if-name* value could be numbered or unnumbered interface using an Ethernet port.

The *src-tunnel-num* value is a mandatory create time command option for MPLS-TP tunnels, and has to be assigned by the user based on the configured range of tunnel IDs.

The **src-global-id** used for the LSP ID is derived from the node-wide *global-id* value configured under the following context. A tunnel cannot be brought up unless the *global-id* is configured.

```
configure router mpls mpls-tp
```

The **from** command address of an LSP to be used in the tunnel identifier is taken to be the local node's node ID or global ID, as configured in the following context. If that is not explicitly configured, the default value of the system interface IPv4 address is used.

```
configure router mpls mpls-tp
```

The **to** *node-id* command address may be entered in 4-octet IPv4 address format or unsigned 32-bit format. This is the far-end node ID for the LSP, and does needs to be routable IP addresses.

The **from** and **to** command addresses are used as the from and to node ID in the MPLS-TP tunnel identifier used for the MEP ID.

Under the **configure router mpls lsp** context, each LSP consists of a **working-tp-path** and, optionally, a **protect-tp-path**. The **protect-tp-path** provides protection for the **working-tp-path** is 1:1 linear protection is configured. Proactive OAM, such as BFD, is configured under the MEP context of each path. Protection for the LSP is configured under the **protect-tp-path** MEP context.

The **to global-id** configuration is optional. If it is not entered, the destination global ID takes the default value of 0. Global ID values of 0 are allowed and indicate that the node's configured global ID should be used. If the local global ID value is 0, the remote **to** global ID must also be 0. The **to** global ID value cannot be changed if an LSP is in use by an SDP.

The **to** tunnel number is optional. If it is not entered, it is taken to be the same value as the source tunnel number.

LSPs are assumed to be bidirectional and co-routed. Therefore, the system assumes that the incoming interface is the same as the out-link.

The next-hop *ip-address* can only be configured if the **out-link** *interface-name* refers to a numbered IP interface. In this case, the system determines the interface to use to reach the configured next-hop, but checks that the user-entered value for the out-link corresponds to the link returned by the system. If they do not correspond, the path does not come up. If a user changes the physical port referred to in the interface configuration, BFD, if configured on the LSP, goes down. Users must ensure that an LSP is moved to a different interface with a different port configuration to change the port that it uses. This is enforced by blocking the next-hop configuration for an unnumbered interface.

There is no check made that a valid ARP entry exists before allowing a path to be un shut. Therefore, a path is only held down if BFD is down. If static ARP is not configured for the interface, it is assumed that dynamic ARP is used. The result is that if BFD is not configured, a path can come up before ARP resolution has completed for an interface. If BFD is not used, Nokia recommends that the connectivity of the path is explicitly checked using on-demand CC/CV before sending user traffic on it.

The following is a list of additional considerations for the configuration of MPLS-TP LSPs and paths:

- The **working-tp-path** command must be configured before the **protect-tp-path** command.
- The **protect-tp-path** command must be deleted first before the **working-tp-path** command.
- The **lsp-num** command option is optional. The default values are 1 for the **working-tp-path** and 2 for **protect-tp-path**.
- The **mep** context must be deleted before a path can be deleted.
- An MPLS router interface must be configured under the following context (in the MD-CLI or classic CLI) before using or specifying the **out-label** or **out-link** in the forward path for an MPLS-TP LSP.

  ```
  configure router mpls interface
  ```

  Creation of the LSP fails if the corresponding MPLS interface does not exist, even though the specified router interface may be valid.
- The system programs the MPLS-TP LSP information after an administrative enable of the TP-Path only on the very first administrative enable. The **working-tp-path** is programmed as the primary and the **protect-tp-path** is programmed as the backup.
- The system does not deprogram the IOM after an administrative disable of the MPLS-TP path. Traffic gracefully moves to the other TP-path if valid, as determined by the proactive MPLS-TP OAM. This should not result in traffic loss. However, Nokia recommends that the user moves traffic to the other TP-path through a tools command before administratively disabling an active TP-path.
- Deleting the **out-label** or **out-link** configuration under the MPLS-TP path is not allowed after it is configured. This can only be modified.
- MPLS supports deleting a TP path without administratively disabling the path. This causes MPLS to deprogram the corresponding TP-path forwarding information from IOM. This can cause traffic loss for users that are bound to the MPLS-TP LSP.
- MPLS does not deprogram the IOM on a specific interface that has been administratively disabled or cleared unless the interface is a system interface. However, if MPLS informs the TP-OAM module that the MPLS interface has gone down, it triggers a switch to the standby **tp-path** if the associated interface went down and if it is valid.
- If a MEP is defined and administratively disabled, the corresponding path is also operationally down. The MEP admin state is applicable only when a MEP is created from an MPLS-TP path.
- It is not mandatory to configure BFD or protection on an MPLS-TP path to bring the LSP up.

- If **protect-tp-path mep bfd-enable cc** is configured, CC-only mode using ACh channel 0x07 is used. If **bfd-enable cc_cv** is configured, BFD CC packets use channel 0x22 and CV packets use channel 0x23.
- Under the MEP context, the **protect-tp-path mep bfd-trap-suppression** command allows the reception of AIS packets on the path to suppress BFD Down traps if a BFD session goes down on that path.

The protection template is associated with an LSP as a part of the MEP on the protect path. If only a working path is configured, the protection template is not configured.

BFD cannot be enabled under the MEP context unless a named BFD template is configured.

2.3.7.6.2 Support for downstream mapping information

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

To validate the downstream mapping for an LSP, a node sending a DSMAP TLV must include the incoming and (optionally) outgoing interface number values for the interfaces that it expects the LSP to transit. Additionally, it includes the out-label for the LSP in the label TLV for the DSMAP in the echo request message.

The incoming and outgoing interface number values correspond to the incoming and outgoing interfaces transited by an LSP at the next hop LER and LSR configured using the **dsmap** in the configuration that follows.

Example: classic CLI

```
A:node-2>config>router>mpls# info
----------------------------------------------
...
            mpls-tp
                no shutdown
                global-id 65535
                node-id 10.0.0.3
                tp-tunnel-id-range 100 1000
                transit-path "LSP-PE-1-PE-2"
                    no shutdown
                    forward-path
                        mip
                            dsmap "10:100"
                        exit
                    exit
                    reverse-path
                        mip
                            dsmap "10:100"
                        exit
                    exit
                exit
            exit
            lsp "LSP-PE-1-PE-2" mpls-tp 100
                no shutdown
                working-tp-path
                    no shutdown
                    mep
                        no shutdown
                        dsmap "10:100"
                    exit
                exit
```

```
                protect-tp-path
                    no shutdown
                    mep
                        no shutdown
                        dsmap "20:200"
                    exit
                exit
            exit
-----------------------------------------------
```

A node sending a DSMAP TLV includes the *in-if-num* and *out-if-num* (if configured) values. Additionally, it includes the out-label for the LSP in the label TLV for the DSMAP in the echo request message.

2.3.7.6.3 Proactive CC and CV (using BFD) configuration

Generally applicable proactive OAM command options are configured using templates.

Proactive CC and CV uses BFD command options such as Tx/Rx timer intervals, multiplier, and other session/fault management BFD command options. These are configured using a BFD template. The BFD template may be used for non-MPLS-TP applications of BFD, and therefore contains the full set of possible configuration command options for BFD. Only a sub-set of these may be used for each application.

Generic MPLS-TP OAM and fault management command options are configured in the OAM Template.

Named templates are referenced from the MPLS-TP path MEP configuration, so different values are possible for the working and protect paths of a tunnel.

Example: BFD template configuration (MD-CLI)

```
[ex:/configure bfd]A:admin@node-2# info
    bfd-template "test1" {
        echo-receive 1000
        multiplier 10
        receive-interval 1000
        type cpm-np
    }
```

Example: BFD template configuration (classic CLI)

In the classic CLI, the BFD template uses a **begin** and **commit** model. To edit any value within the BFD template, a **begin** command must be executed before the template context has been entered. However, a value is stored temporarily in the template-module until the **commit** command is issued. Values are actually used after the commit is issue.

```
A:node-2>config>router>bfd# info detail
-----------------------------------------------
            bfd-template "test1"
                type "cpm-np"
                receive-interval 1000
                multiplier 10
                echo-receive 1000
            exit
-----------------------------------------------
```

The command options are as follows:

- **transmit-interval** *transmit-interval* and the **receive-interval** *receive-interval*

These are the transmit and receive timers for BFD packets. If the template is used for MPLS-TP, then these are the timers used by CC packets. Values are in ms: 10 ms to 100 000 ms, with 1 millisecond granularity. Default 10 milliseconds for CPM3 or better, 1 second for other hardware. For MPLS-TP CV packets, a transmit interval of 1 second is always used.

- **multiplier** *multiplier*
  Integer 3 to 20. Default: 3. This command option is ignored for MPLS-TP combined cc-cv BFD sessions, and the default of 3 used, as per RFC 6428.
- **echo-receive** *echo-interval*
  This command option sets the minimum echo receive interval (in milliseconds), for a session. Values: 100 to 100 000 milliseconds. Default: 100. This command option is not used by a BFD session for MPLS-TP.
- **type** *cpm-np*
  This command option selects the CPM network processor as the local termination point for the BFD session. This is enabled by default.

If the BFD timer values as shown above are changed in a template, any BFD sessions on MEPs to which that template is bound tries to renegotiate their timers to the new values.

Caution: The BFD implementations in some MPLS-TP peer nodes may not be able to manage renegotiation, as allowed by Section 3.7.1 of RFC 6428, and may take the BFD session down. This can result in unwanted behavior, such as an unexpected protection switching event. We recommend that users of the system exercise caution when modifying the BFD timer values after a BFD session is up.

Note: The **configure router mpls mpls-tp** context only applies to the classic CLI.

In the classic CLI, a BFD template is referenced from the OAM template. Use the following command to configure an OAM template.

```
configure router mpls mpls-tp oam-template
```

Example: OAM template configuration (classic CLI)

```
A:node-2>config>router>mpls# info
----------------------------------------------
...
            mpls-tp
                no shutdown
                oam-template "test1"
                    bfd-template "test1"
                    hold-time-down 500
                    hold-time-up 300
                exit
            exit
...
----------------------------------------------
```

The options are as follows:

- **hold-time-down** *interval*

  Range: 0 to 5000 deciseconds, 10 milliseconds intervals, default 0. This is equivalent to the standardized hold-off timer.
- **hold-time-up** *interval*

Range: 0 to 500 centiseconds in 100 milliseconds intervals, default 2 seconds. This is an additional timer that can be used to reduce BFD bouncing.

- **bfd-template** *name*

  The named BFD template to use for any BFD sessions enabled under a MEP for which the OAM template is configured.

An OAM template is then applied to a MEP as described in the preceding information.

2.3.7.6.4 Protection templates and linear protection configuration

Protection templates defines the generally applicable protection parameters for an MPLS-TP tunnel. Only linear protection is supported, and so the application of a named template to an MPLS-TP tunnel implies that linear protection is used.

Note: The **configure router mpls mpls-tp** context only applies to the classic CLI.

Example: Protection template configuration (classic CLI)

```
A:node-2>config>router>mpls# info
----------------------------------------------
...
            mpls-tp
                no shutdown
                protection-template "test1"
                    revertive
                    wait-to-restore 200
                    rapid-psc-timer 100
                    slow-psc-timer 60
                exit

                exit
            exit
```

The allowed values are as follows:

- **wait-to-restore** *interval*

  Range: 0 to 720 seconds, 1 second intervals. Default 300 seconds. This is applicable to the revertive mode only.

- **rapid-psc-timer** *interval*

  [10, 100, 1000 milliseconds]. Default: 100 milliseconds

- **slow-psc-timer interval**

  5 to 60 seconds. Default: 5 seconds

- **revertive**

  Selects revertive behavior. Default: no revertive.

Use the commands in the following context to enact LSP linear protection operations.

```
tools perform router mpls tp-tunnel
```

To minimize outage times, use the following commands to switch all the relevant MPLS-TP paths.

```
tools perform router mpls tp-tunnel force
tools perform router mpls tp-tunnel manual
```

After switching the relevant MPLS TP paths, execute the following commands:

- **MD-CLI**

```
clear router mpls interface
configure router mpls interface admin-state disable
```

- **classic CLI**

```
clear router mpls interface
configure router mpls interface shutdown
```

2.3.7.7 Intermediate LSR configuration for MPLS-TP LSPs

Note: This information applies to the classic CLI. MPLS-TP is only supported in the classic CLI.

Use the following commands in the following contexts to configure forward and reverse directions of the MPLS-TP LSP path at a transit LSR.

```
configure router mpls mpls-tp transit-path forward-path
configure router mpls mpls-tp transit-path path-id
configure router mpls mpls-tp transit-path reverse-path
```

In the **transit-path path-id** context, the **src-tunnel-num** and **dest-tunnel-num** command options are consistent with the source and destination of a label mapping message for a signaled LSP.

If the **dest-tunnel-num** command option is not configured, the **dest-tunnel-num** value is assumed to be the same as the **src-tunnel-num** value.

If any of the global ID values are not entered, the value is assumed to be 0.

If the **src-global-id** value is entered, but the **dest-global-id** value is not configured, the **dest-global-id** value is the same as the **src-global-id** value.

The **transit-path path-id lsp-num** must match the value configured in the LER for a specified path. If no explicit **lsp-num** is configured, then **working-path** or **protect-path** must be specified (equating to 1 or 2 in the system).

The forward path must be configured before the reverse path. The configuration of the reverse path is optional.

The LSP ID (the **path-id**) options apply to the downstream direction of the forward LSP path, and are used to populate the MIP ID for the path at this LSR.

The reverse path configuration must be deleted before the forward path.

The **forward-path** (and **reverse-path** if applicable) command options can be configured with or without the path ID, but they must be configured if MPLS-TP OAM is to be able to identify the LSR MIP.

The **transit-path** can be enabled (as long as the **forward-path** or **reverse-path** options have been configured properly) with or without identifiers.

The **path-id** *path-name* must be unique on the node. There is a one to one mapping between a specified path name and path ID.

Traffic cannot pass through the transit path if the transit path is disabled.

2.3.8 MPLS-TP show commands

2.3.8.1 Static MPLS labels

Use the following command to display MPLS label ranges.

```
show router mpls-labels label-range
```

Output example: MPLS label range information

```
===============================================================================
Label Ranges
===============================================================================
Label Type      Start Label End Label   Aging       Available   Total
-------------------------------------------------------------------------------
Static          32          18431       -           18400       18400
Dynamic         18432       524287      0           505856      505856
    Seg-Route   0           0           -           0           505856
===============================================================================
```

2.3.8.2 Displaying MPLS-TP tunnel information

Use the following command to display information for a specific MPLS-TP LSP.

```
show router mpls tp-lsp "lsp-32"
```

Output example: MPLS-TP LSP information

```
===============================================================================
MPLS MPLS-TP LSPs (Originating)
===============================================================================
LSP Name                            To              Tun     Protect   Adm  Opr
                                                    Id      Path
-------------------------------------------------------------------------------
lsp-32                              0.0.3.234       32      No        Up   Up
-------------------------------------------------------------------------------
LSPs : 1
===============================================================================
```

Use the following command to display detailed information for a specific MPLS-TP LSP.

```
show router mpls tp-lsp "lsp-32" detail
```

Output example: MPLS-TP LSP detailed information

```
===============================================================================
MPLS MPLS-TP LSPs (Originating) (Detail)
===============================================================================
```

```
-------------------------------------------------------------------------------
Type : Originating
-------------------------------------------------------------------------------
LSP Name    : lsp-32
LSP Type    : MplsTp                          LSP Tunnel ID  : 32
From Node Id: 0.0.3.233+                      To Node Id     : 0.0.3.234
Adm State   : Up                              Oper State     : Up
LSP Up Time : 0d 04:50:47                     LSP Down Time  : 0d 00:00:00
Transitions : 1                               Path Changes   : 2

DestGlobalId: 42                              DestTunnelNum  : 32
```

2.3.8.3 MPLS-TP path configuration

MPLS-TP path configuration can reuse and augment the output of current **show** commands for static LSPs. They also shows whether BFD is enabled on a specified path. If this is referring to a transit path, this displays the path-id (7 parameters) for a specified transit-path-name, or the transit path name for a specified pathID (7 parameters).

Use the following command to display MPLS-TP LSP path information.

```
show router mpls tp-lsp path
```

Output example: MPLS-TP LSP path information

```
===============================================================================
MPLS-TP LSP Path Information
===============================================================================
LSP Name      : lsp-32                        To           : 0.0.3.234
Admin State   : Up                            Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       32        32        AtoB_1          Up     Down
Protect                       2080      2080      AtoC_1          Up     Up
===============================================================================
LSP Name      : lsp-33                        To           : 0.0.3.234
Admin State   : Up                            Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       33        33        AtoB_1          Up     Down
Protect                       2082      2082      AtoC_1          Up     Up
===============================================================================
LSP Name      : lsp-34                        To           : 0.0.3.234
Admin State   : Up                            Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       34        34        AtoB_1          Up     Down
Protect                       2084      2084      AtoC_1          Up     Up
===============================================================================
LSP Name      : lsp-35                        To           : 0.0.3.234
Admin State   : Up                            Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       35        35        AtoB_1          Up     Down
Protect                       2086      2086      AtoC_1          Up     Up
===============================================================================
```

```
LSP Name      : lsp-36                          To           : 0.0.3.234
Admin State   : Up                              Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       36        36        AtoB_1          Up     Down
Protect                       2088      2088      AtoC_1          Up     Up
===============================================================================
LSP Name      : lsp-37                          To           : 0.0.3.234
Admin State   : Up                              Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       37        37        AtoB_1          Up     Down
Protect                       2090      2090      AtoC_1          Up     Up
===============================================================================
LSP Name      : lsp-38                          To           : 0.0.3.234
Admin State   : Up                              Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       38        38        AtoB_1          Up     Down
Protect                       2092      2092      AtoC_1          Up     Up
===============================================================================
LSP Name      : lsp-39                          To           : 0.0.3.234
Admin State   : Up                              Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       39        39        AtoB_1          Up     Down
Protect                       2094      2094      AtoC_1          Up     Up
===============================================================================
LSP Name      : lsp-40                          To           : 0.0.3.234
Admin State   : Up                              Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       40        40        AtoB_1          Up     Down
Protect                       2096      2096      AtoC_1          Up     Up
===============================================================================
LSP Name      : lsp-41                          To           : 0.0.3.234
Admin State   : Up                              Oper State   : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       41        41        AtoB_1          Up     Down
Protect                       2098      2098      AtoC_1          Up     Up
```

Use the following command to display MPLS-TP LSP working-path information.

```
show router mpls tp-lsp "lsp-32" path working
```

Output example: MPLS-TP LSP working-path information

```
===============================================================================
MPLS-TP LSP Working Path Information
    LSP: "lsp-32"
===============================================================================
LSP Name      : lsp-32                          To           : 0.0.3.234
Admin State   : Up                              Oper State   : Up
```

```
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Working                       32        32        AtoB_1          Up     Down
===============================================================================
```

Use the following command to display MPLS-TP LSP protect path information.

```
show router mpls tp-lsp "lsp-32" path protect
```

Output example: MPLS-TP LSP protect path information

```
===============================================================================
MPLS-TP LSP Protect Path Information
    LSP: "lsp-32"
===============================================================================
LSP Name      : lsp-32                          To            : 0.0.3.234
Admin State   : Up                              Oper State    : Up
-------------------------------------------------------------------------------
Path        NextHop           InLabel   OutLabel  Out I/F         Admin  Oper
-------------------------------------------------------------------------------
Protect                       2080      2080      AtoC_1          Up     Up
===============================================================================
```

Use the following command to display detailed MPLS-TP LSP protect path information.

```
show router mpls tp-lsp "lsp-32" path protect detail
```

Output example: Detailed MPLS-TP LSP protect path information

```
===============================================================================
MPLS-TP LSP Protect Path Information
    LSP: "lsp-32" (Detail)
===============================================================================
LSP Name      : lsp-32                          To            : 0.0.3.234
Admin State   : Up                              Oper State    : Up

Protect path information
-------------------------------------------------------------------------------
Path Type     : Protect                         LSP Num       : 2
Path Admin    : Up                              Path Oper     : Up
Out Interface : AtoC_1                          Next Hop Addr : n/a
In Label      : 2080                            Out Label     : 2080
Path Up Time  : 0d 04:52:17                     Path Dn Time  : 0d 00:00:00
Active Path   : Yes                             Active Time   : 0d 00:52:56

MEP information
MEP State     : Up                              BFD           : cc
OAM Templ     : privatebed-oam-template         CC Status     : inService
                                                CV Status     : unknown
Protect Templ : privatebed-protection-template  WTR Count Down: 0 seconds
RX PDU        : SF (1,1)                        TX PDU        : SF (1,1)
Defects       :
===============================================================================
```

Use the following command to display detailed MPLS-TP LSP working-path information.

```
show router mpls tp-lsp "lsp-32" path working detail
```

Output example: MPLS-TP LSP working path information

```
===============================================================================
MPLS-TP LSP Working Path Information
    LSP: "lsp-32" (Detail)
===============================================================================
LSP Name      : lsp-32                            To            : 0.0.3.234
Admin State   : Up                                Oper State    : Up

Working path information
-------------------------------------------------------------------------------
Path Type     : Working                           LSP Num       : 1
Path Admin    : Up                                Path Oper     : Down
Down Reason   : ccFault ifDn
Out Interface : AtoB_1                            Next Hop Addr : n/a
In Label      : 32                                Out Label     : 32
Path Up Time  : 0d 00:00:00                       Path Dn Time  : 0d 00:53:01
Active Path   : No                                Active Time   : n/a

MEP information
MEP State     : Up                                BFD           : cc
OAM Templ     : privatebed-oam-template           CC Status     : outOfService
                                                  CV Status     : unknown
===============================================================================
```

2.3.8.4 MPLS-TP protection

Use the following command to show information about the protection configuration for a specified tunnel, which path in a tunnel is currently working and which is protect, and whether the working or protect is currently active.

```
show router mpls tp-lsp protection
```

Output example: MPLS-TP protection information

```
===============================================================================
MPLS-TP LSP Protection Information
Legend: W-Working, P-Protect,
===============================================================================
LSP Name                      Admin Oper  Path    Ingr/Egr      Act. Rx PDU
                              State State   State Label         Path Tx PDU
-------------------------------------------------------------------------------
lsp-32                        Up    Up    W Down      32/32     No   SF (1,1)
                                          P Up      2080/2080   Yes  SF (1,1)
lsp-33                        Up    Up    W Down      33/33     No   SF (1,1)
                                          P Up      2082/2082   Yes  SF (1,1)
lsp-34                        Up    Up    W Down      34/34     No   SF (1,1)
                                          P Up      2084/2084   Yes  SF (1,1)
lsp-35                        Up    Up    W Down      35/35     No   SF (1,1)
                                          P Up      2086/2086   Yes  SF (1,1)
lsp-36                        Up    Up    W Down      36/36     No   SF (1,1)
                                          P Up      2088/2088   Yes  SF (1,1)
lsp-37                        Up    Up    W Down      37/37     No   SF (1,1)
                                          P Up      2090/2090   Yes  SF (1,1)
lsp-38                        Up    Up    W Down      38/38     No   SF (1,1)
                                          P Up      2092/2092   Yes  SF (1,1)
lsp-39                        Up    Up    W Down      39/39     No   SF (1,1)
                                          P Up      2094/2094   Yes  SF (1,1)
lsp-40                        Up    Up    W Down      40/40     No   SF (1,1)
```

```
                                          P Up      2096/2096   Yes  SF (1,1)
lsp-41                        Up    Up    W Down      41/41     No   SF (1,1)
                                          P Up      2098/2098   Yes  SF (1,1)
-------------------------------------------------------------------------------
No. of MPLS-TP LSPs: 10
===============================================================================
```

2.3.8.5 MPLS TP node configuration

Use the following commands to show the global ID, node ID, and other general MPLS-TP configurations for the node.

Use this command to display MPLS-TP OAM-template information.

```
show router mpls mpls-tp oam-template
```

Output example: OAM-template information

```
===============================================================================
MPLS-TP OAM Templates
===============================================================================
Template Name : privatebed-oam-template Router ID : 1
BFD Template : privatebed-bfd-template Hold-Down Time: 0 centiseconds
Hold-Up Time : 20 deciseconds
===============================================================================
```

Use the following command to display MPLS-TP protection-template information.

```
show router mpls mpls-tp protection-template
```

Output example: MPLS-TP protection-template information

```
===============================================================================
MPLS-TP Protection Templates
===============================================================================
Template Name : privatebed-protection-template Router ID : 1
Protection Mode: one2one Direction : bidirectional
Revertive : revertive Wait-to-Restore: 300sec
Rapid-PSC-Timer: 10ms Slow-PSC-Timer : 5sec
===============================================================================
```

Use the following command to display MPLS-TP system configuration information.

```
show router mpls mpls-tp status
```

Output example: MPLS-TP system configuration information

```
===============================================================================
MPLS-TP Status
===============================================================================
Admin Status : Up
Global ID : 42 Node ID : 0.0.3.233
Tunnel Id Min : 1 Tunnel Id Max : 4096
===============================================================================
*A:mlstp-dutA# show router mpls mpls-tp transit-path
- transit-path [<path-name>] [detail]
<path-name> : [32 chars max]
```

```
<detail> : keyword - Display detailed information.
```

Use the following command to display MPLS-TP tunnel information.

```
show router mpls mpls-tp transit-path "tp-32"
```

Output example: MPLS-TP tunnel information

```
===============================================================================
MPLS-TP Transit tp-32 Path Information
===============================================================================
Path Name : tp-32
Admin State : Up Oper State : Up
-------------------------------------------------------------------
Path NextHop InLabel OutLabel Out I/F
-------------------------------------------------------------------
FP 2080 2081 CtoB_1
RP 2081 2080 CtoA_1
===============================================================================
```

Use the following command to display detailed MPLS-TP tunnel information.

```
show router mpls mpls-tp transit-path "tp-32" detail
```

Output example: Detailed MPLS-TP tunnel information

```
===============================================================================
MPLS-TP Transit tp-32 Path Information (Detail)
===============================================================================
Path Name : tp-32
Admin State : Up Oper State : Up
-------------------------------------------------------------------------------
Path ID configuration
Src Global ID : 42 Dst Global ID : 42
Src Node ID : 0.0.3.234 Dst Node ID : 0.0.3.233
LSP Number : 2 Dst Tunnel Num: 32
Forward Path configuration
In Label : 2080 Out Label : 2081
Out Interface : CtoB_1 Next Hop Addr : n/a
Reverse Path configuration
In Label : 2081 Out Label : 2080
Out Interface : CtoA_1 Next Hop Addr : n/a
===============================================================================
```

2.3.8.6 MPLS-TP interfaces

Use the following command to display MPLS-TP information for the specified interface.

```
show router interface "AtoB_1"
```

Output example: MPLS-TP information for the specified interface

```
===============================================================================
Interface Table (Router: Base)
===============================================================================
Interface-Name                   Adm         Opr(v4/v6)  Mode    Port/SapId
   IP-Address                                                    PfxState
```

```
-------------------------------------------------------------------------------
AtoB_1                          Down        Down/--     Network 1/2/3:1
   Unnumbered If[system]                                        n/a
-------------------------------------------------------------------------------
Interfaces : 1
```

2.3.8.7 MPLS-TP tool and debug commands

Use the following commands to show debug information for MPLS-TP tunnels.

```
tools dump router mpls tp-tunnel lsp-name [clear]
tools dump router mpls tp-tunnel id tunnel-id [clear]
```

Use the following command to show debug information for a specific MPLS-TP tunnel.

```
tools dump router mpls tp-tunnel "lsp-32"
```

Output example: MPLS-TP debug information for a specific MPLS-TP tunnel

```
Idx: 1-32 (Up/Up): pgId 4, paths 2, operChg 1, Active: Protect
  TunnelId: 42::0.0.3.233::32-42::0.0.3.234::32
  PgState: Dn, Cnt/Tm: Dn 1/000 04:00:48.160 Up:3/000 00:01:25.840
  MplsMsg: tpDn 0/000 00:00:00.000, tunDn 0/000 00:00:00.000
           wpDn 0/000 00:00:00.000, ppDn 0/000 00:00:00.000
           wpDel 0/000 00:00:00.000, ppDel 0/000 00:00:00.000
           tunUp 1/000 00:00:02.070
  Paths:
   Work (Up/Dn): Lsp 1, Lbl 32/32, If 2/128 (1/2/3 : 0.0.0.0)
    Tmpl: ptc: , oam: privatebed-oam-template (bfd: privatebed-bfd-template(np)-
10 ms)
    Bfd: Mode CC state Dn/Up handle 160005/0
    Bfd-CC (Cnt/Tm): Dn 1/000 04:00:48.160 Up:1/000 00:01:23.970
    State:  Admin Up (1::1::1)  port Up , if Dn ,  operChg 2
    DnReasons: ccFault ifDn

   Protect (Up/Up): Lsp 2, Lbl 2080/2080, If 3/127 (5/1/1 : 0.0.0.0)
    Tmpl: ptc: privatebed-protection-template, oam: privatebed-oam-template (bfd:
privatebed-bfd-template(np)-10 ms)
    Bfd: Mode CC state Up/Up handle 160006/0
    Bfd-CC (Cnt/Tm): Dn 0/000 00:00:00.000 Up:1/000 00:01:25.410
    State:  Admin Up (1::1::1)  port Up , if Up ,  operChg 1

  Aps: Rx - 5, raw 3616, nok 0(), txRaw - 3636, revert Y
   Pdu: Rx - 0x1a-21::0101 (SF), Tx - 0x1a-21::0101 (SF)
   State: PF:W:L LastEvt pdu (L-SFw/R-SFw)
   Tmrs: slow
   Defects: None  Now: 000 05:02:19.130
  Seq  Event   state     TxPdu       RxPdu       Dir    Act          Time
  ===  ======  ========  ==========  ==========  =====  ====  ================
  000   start    UA:P:L    SF (0,0)    NR (0,0)  Tx-->  Work  000 00:00:02.080
  001     pdu    UA:P:L    SF (0,0)    SF (0,0)  Rx<--  Work  000 00:01:24.860
  002     pdu    UA:P:L    SF (0,0)    NR (0,0)  Rx<--  Work  000 00:01:26.860
  003     pUp        NR    NR (0,0)    NR (0,0)  Tx-->  Work  000 00:01:27.440
  004     pdu        NR    NR (0,0)    NR (0,0)  Rx<--  Work  000 00:01:28.760
  005     wDn    PF:W:L    SF (1,1)    NR (0,0)  Tx-->  Prot  000 04:00:48.160
  006     pdu    PF:W:L    SF (1,1)    NR (0,1)  Rx<--  Prot  000 04:00:48.160
  007     pdu    PF:W:L    SF (1,1)    SF (1,1)  Rx<--  Prot  000 04:00:51.080
```

In the classic CLI, use the following command to view debug information for the control channel status.

```
debug service id 700 sdp 200:700 event-type control-channel-status
```

Output example: Control channel debug information

```
1 2012/08/31 09:56:12.09 EST MINOR: DEBUG #2001 Base PW STATUS SIG PKT (RX):
"PW STATUS SIG PKT (RX)::
Sdp Bind 200:700 Instance 3
    Version          : 0x0
    PW OAM Msg Type  : 0x27
    Refresh Time     : 0xa
    Total TLV Length : 0x8
    Flags            : 0x0
    TLV Type         : 0x96a
    TLV Len          : 0x4
    PW Status Bits   : 0x0
"

2 2012/08/31 09:56:22.09 EST MINOR: DEBUG #2001 Base PW STATUS SIG PKT (RX):
"PW STATUS SIG PKT (RX)::
Sdp Bind 200:700 Instance 3
    Version          : 0x0
    PW OAM Msg Type  : 0x27
    Refresh Time     : 0xa
    Total TLV Length : 0x8
    Flags            : 0x0
    TLV Type         : 0x96a
    TLV Len          : 0x4
    PW Status Bits   : 0x0
"

3 2012/08/31 09:56:29.44 EST MINOR: DEBUG #2001 Base PW STATUS SIG PKT (TX):
"PW STATUS SIG PKT (TX)::
Sdp Bind 200:700 Instance 3
    Version          : 0x0
    PW OAM Msg Type  : 0x27
    Refresh Time     : 0x1e
    Total TLV Length : 0x8
    Flags            : 0x0
    TLV Type         : 0x96a
    TLV Len          : 0x4
    PW Status Bits   : 0x0
```

2.4 Traffic Engineering

Without Traffic Engineering (TE), routers route traffic according to the SPF algorithm, disregarding congestion or packet types.

With TE, network traffic is routed efficiently to maximize throughput and minimize delay. TE facilitates traffic flows to be mapped to the destination through a different (less congested) path other than the one selected by the SPF algorithm.

MPLS directs a flow of IP packets along a label switched path (LSP). LSPs are simplex, meaning that the traffic flows in one direction (unidirectional) from an ingress router to an egress router. Two LSPs are required for duplex traffic. Each LSP carries traffic in a specific direction, forwarding packets from one router to the next across the MPLS domain.

When an ingress router receives a packet, it adds an MPLS header to the packet and forwards it to the next hop in the LSP. The labeled packet is forwarded along the LSP path until it reaches the destination point. The MPLS header is removed and the packet is forwarded based on Layer 3 information such as the IP destination address. The physical path of the LSP is not constrained to the shortest path that the IGP would choose to reach the destination IP address.

2.4.1 TE metric (IS-IS and OSPF)

When the use of the TE metric is selected for an LSP, the shortest path computation after the TE constraints are applied selects an LSP path based on the TE metric instead of the IGP metric. The user configures the TE metric under the MPLS interface. Both the TE and IGP metrics are advertised by OSPF and IS-IS for each link in the network. The TE metric is part of the TE extensions of both IGP protocols.

A typical application of the TE metric is to allow CSPF to represent a dual TE topology for the purpose of computing LSP paths.

An LSP dedicated for real-time and delay sensitive user and control traffic has its path computed by CSPF using the TE metric. The user configures the TE metric to represent the delay figure, or a combined delay/jitter figure, of the link. In this case, the shortest path satisfying the constraints of the LSP path effectively represents the shortest delay path.

An LSP dedicated for non-delay sensitive user and control traffic has its path computed by CSPF using the IGP metric. The IGP metric could represent the link bandwidth or some other figure as required.

When the use of the TE metric is enabled for an LSP, CSPF first prunes all links in the network topology that do not meet the constraints specified for the LSP path. These constraints include bandwidth, admin-groups, and hop limit. CSPF then runs an SPF on the remaining links. The shortest path among the all SPF paths is selected based on the TE metric instead of the IGP metric which is used by default. The TE metric is only used in CSPF computations for MPLS paths and not in the regular SPF computation for IP reachability.

2.4.2 Admin group support on facility bypass backup LSP

This feature provides for the inclusion of the LSP primary path admin-group constraints in the computation of a Fast Reroute (FRR) facility bypass backup LSP to protect the primary LSP path by all nodes in the LSP path.

This feature is supported with the following LSP types and in both intra-area and inter-area TE where applicable:

- primary path of a RSVP P2P LSP
- S2L path of an RSVP P2MP LSP instance
- LSP template for an S2L path of an RSVP P2MP LSP instance
- LSP template for auto-created RSVP P2P LSP in intra-area TE

2.4.2.1 Actions at head-end node

The user enables the signaling of the primary LSP path admin-group constraints in the FRR object at the ingress LER with the following CLI command:

config>router>mpls>lsp>fast-reroute>propagate-admin-group

When this command is enabled at the ingress LER, the admin-group constraints configured in the context of the P2P LSP primary path, or the ones configured in the context of the LSP and inherited by the primary path, are copied into the FAST_REROUTE object. The admin-group constraints are copied into the **include-any** or **exclude-any** fields.

The ingress LER propagates these constraints to the downstream nodes during the signaling of the LSP to allow them to include the admin-group constraints in the selection of the FRR backup LSP for protecting the LSP primary path.

The ingress LER inserts the FAST_REROUTE object by default in a primary LSP path message. If the user disables the object using the following command, the admin-group constraints are not propagated: **config>router>mpls>no frr-object**.

The same admin-group constraints can be copied into the Session Attribute object. They are intended for the use of an LSR, typically an ABR, to expand the ERO of an inter-area LSP path. They are also used by any LSR node in the path of a CSPF or non-CSPF LSP to check the admin-group constraints against the ERO regardless if the hop is strict or loose. These are governed strictly by the command:

config>router>mpls>lsp>propagate-admin-group

In other words, the user may decide to copy the primary path admin-group constraints into the FAST_REROUTE object only, or into the Session Attribute object only, or into both.

The PLR rules for processing the admin-group constraints can make use of either of the two object admin-group constraints.

2.4.2.2 Actions at PLR node

The user enables the use of the admin-group constraints in the association of a manual or dynamic bypass LSP with the primary LSP path at a Point-of-Local Repair (PLR) node using the following global command:

config>router>mpls>admin-group-frr

When this command is enabled, each PLR node reads the admin-group constraints in the FAST_REROUTE object in the Path message of the LSP primary path. If the FAST_REROUTE object is not included in the Path message, then the PLR reads the admin-group constraints from the Session Attribute object in the Path message.

If the PLR is also the ingress LER for the LSP primary path, then it just uses the admin-group constraint from the LSP or path level configurations.

Whether the PLR node is also the ingress LER or just an LSR for the protected LSP primary path, the outcome of the ingress LER configuration dictates the behavior of the PLR node and is summarized in Table 9: Bypass LSP admin-group constraint behavior.

Table 9: Bypass LSP admin-group constraint behavior

	Ingress LER configuration	Session attribute	FRR object	Bypass LSP at PLR (LER/LSF) follows admin-group constraints
1	frr-object lsp>no propagate-admin group	Admin color constraints not sent	Admin color constraints sent	Yes

	Ingress LER configuration	Session attribute	FRR object	Bypass LSP at PLR (LER/LSF) follows admin-group constraints
	lsp>frr>propagate-admin-group			
2	frr-object lsp>propagate-admin-group lsp>frr>propagate-admin group	Admin color constraints sent	Admin color constraints sent	Yes
3	frr-object lsp>propagate-admin group lsp>frr>no propagate-admin-group	Admin color constraints sent	Admin color constraints not sent	No
4	No frr-object lsp>propagate-admin group lsp>frr>propagate-admin-group	Admin color constraints sent	Not present	Yes
5	No frr-object lsp>no propagate-admin group lsp>frr>propagate-admin-group	Admin color constraints not sent	Not present	No
6	No frr-object lsp>propagate-admin group lsp>frr>no propagate-admin-group	Admin color constraints sent	Not present	Yes

The PLR node then uses the admin-group constraints along with other constraints, such as hop-limit and SRLG, to select a manual or dynamic bypass among those that are already in use.

If none of the manual or dynamic bypass LSP satisfies the admin-group constraints or the other constraints, the PLR node requests CSPF for a path that merges the closest to the protected link or node and that includes or excludes the specified admin-group IDs.

If the user changes the configuration of the above command, there is no effect on existing bypass associations. The change only applies to new attempts to find a valid bypass.

2.4.3 Manual and timer resignal of RSVP-TE bypass LSP

The **config>router>mpls>bypass-resignal-timer** command triggers the periodic global re-optimization of all dynamic bypass LSP paths associated with RSVP P2P LSP. The operation is performed at each expiry of the user-configurable bypass LSP resignal timer.

When this command is enabled, MPLS requests to CSPF for the best path for each dynamic bypass LSP originated on this node. The constraints, hop limit, SRLG and admin-group constraints, of the first associated LSP primary path that originally triggered the signaling of the bypass LSP must be satisfied. To do this, MPLS saves the original Path State Block (PSB) of that LSP primary path, even if the latter is torn down.

If CSPF returns no path or returns a new path with a cost that is lower than the current path, MPLS does not signal the new bypass path. If CSPF returns a new path with a cost that is lower than the current one, MPLS signals it. Also, if the new bypass path is SRLG strict disjoint with the primary path of the original PSB while the current path is SRLG loose disjoint, the manual bypass path is resignaled regardless of cost comparison.

After the new path is successfully signaled, MPLS evaluates each PSB of each PLR (that is, each unique avoid-node or avoid-link constraint) associated with the current bypass LSP path to check if the corresponding LSP primary path constraints are still satisfied by the new bypass LSP path. If so, the PSB association is moved to the new bypass LSP.

Each PSB for which the constraints are not satisfied remains associated with the PLR on the current bypass LSP and is checked at the next background PSB re-evaluation, or at the next timer or manual bypass re-optimization. Additionally, if SRLG FRR loose disjointness is configured using the **configure router mpls srlg-frr** command and the current bypass LSP is SRLG disjoint with a primary path while the new bypass LSP is not SRLG disjoint, the PSB association is not moved.

If a specific PLR associated with a bypass LSP is active, the corresponding PSBs remain associated with the current PLR until the Global Revertive Make-Before-Break (MBB) tears down all corresponding primary paths, which also causes the current PLR to be removed.

Note: While it is in the preceding state, the older PLR does not get any new PSB association until the PLR is removed. When the last PLR is removed, the older bypass LSP is torn down.

Additionally, PSBs that have not been moved by the dynamic or manual re-optimization of a bypass LSP, as a result of the PSB constraints not being met by the new signaled bypass LSP path, are re-evaluated by the FRR background task, which handles cases where the PSB has requested node protection but its current PLR is a link-protect.

This feature is not supported with inter-area dynamic bypass LSP and bypass LSP protecting S2L paths of a P2MP LSP.

The **tools>perform>router>mpls>resignal-bypass** command performs a manual re-optimization of a specific dynamic or manual bypass LSP, or of all dynamic bypass LSPs.

The name of a manual bypass LSP is configured by the user. The name of a dynamic bypass LSP is displayed in the output of **show>router>mpls>bypass-tunnel dynamic detail**.

The **delay** option triggers the global re-optimization of all dynamic bypass LSPs at the expiry of the specified delay. Effectively, this option forces the global bypass resignal timer to expire after an amount of time equal to the value of the **delay** parameter. This option has no effect on a manual bypass LSP.

However, when the bypass LSP name is specified, the named dynamic or manual bypass LSP is signaled and the associations moved only if the new bypass LSP path has a lower cost than the current one. This behavior is different from that of the similar command for the primary or secondary active path of an LSP, which signals and switches to the new path regardless of the cost comparison. This handling is required

because a bypass LSP can have a large number of PSB associations and the associated processing churn is much higher.

In the specific case where the name corresponds to a manual bypass LSP, the LSP is torn down and resignaled using the new path provided by CSPF if no PSB associations exist. If one or more PSB associations exist but no PLR is active, the command fails and the user is prompted to explicitly enter the **force** option. In this case, the manual bypass LSP is torn down and resignaled, temporarily leaving the associated LSP primary paths unprotected. If one or more PLRs associated with the manual bypass LSP is active, the command fails.

Finally, and as with the timer based resignal, the PSB associations are checked for the SRLG and admin group constraints using the updated information provided by CSPF for the current path and new path of the bypass LSP. More details are provided in sections RSVP-TE bypass LSP path SRLG information update in manual and timer resignal MBB and RSVP-TE bypass LSP path administrative group information update in manual and timer resignal MBB.

2.4.3.1 RSVP-TE bypass LSP path SRLG information update in manual and timer resignal MBB

This feature enhances procedures of the timer and manual resignal (both **delay** and **lsp** options) of the RSVP-TE bypass LSP path by updating the SRLG information of the links of the current path and checking for SRLG disjointness constraint. The following sequence describes the timer and manual resignal enhancements:

1. CSPF updates the SRLG membership of the current bypass LSP path and checks if the path violates the SRLG constraint of the first primary path that was associated with a PLR of this bypass LSP. This is referred to as the initial Path State Block (initial PSB).
2. CSPF attempts a new path computation for the bypass LSP using the initial PSB constraints.
3. MPLS uses the information returned by CSPF and determines if the new bypass path is more optimal.
   a. If SRLG FRR strict disjointness is configured (**configure>router>mpls>srlg-frr strict**) and CSPF indicates the updated SRLG information of current path violated the SRLG constraint of the PLR of the initial PSB, the new path is more optimal.
   b. Otherwise, MPLS performs additional checks using the PLR of the initial PSB to determine if the new path is more optimal. Table 10: Determination of bypass LSP path optimality summarizes the possible cases of bypass path optimality determination.

Table 10: Determination of bypass LSP path optimality

PLR SRLG constraint check[1]		SRLG FRR configuration (strict/loose)	Path cumulative cost comparison[1]	Path cumulative SRLG weight comparison[1]	More optimal path
Current path	New path				
Disjoint	Disjoint	—	New Cost < Current Cost	—	New
Disjoint	Disjoint	—	New Cost ≥ Current Cost	—	Current

[1] This check of the current path makes use of the updated SRLG and cost information provided by CSPF.

PLR SRLG constraint check[1]		SRLG FRR configuration (strict/loose)	Path cumulative cost comparison[1]	Path cumulative SRLG weight comparison[1]	More optimal path
Current path	New path				
Disjoint	Not Disjoint	—	—	—	Current
Not Disjoint	Not Disjoint	—	—	—	New
Not Disjoint	Not Disjoint	Strict	—	—	Current
Not Disjoint	Not Disjoint	Loose	New Cost < Current Cost	—	New
Not Disjoint	Not Disjoint	Loose	New Cost > Current Cost	—	Current
Not Disjoint	Not Disjoint	Loose	New Cost = Current Cost	New SRLG Weight < Current SRLG Weight	New
Not Disjoint	Not Disjoint	Loose	New Cost = Current Cost	New SRLG Weight ≥ Current SRLG Weight	Current

4. If the path returned by CSPF is found to be a more optimal bypass path with respect to the PLR of the initial PSB, the following sequence of actions is taken:
   a. MPLS signals and programs the new path.
   b. MPLS moves to the new bypass path the PSB associations of all PLRs which evaluation against Table 10: Determination of bypass LSP path optimality results in the new bypass path being more optimal.
   c. Among the remaining PLRs, MPLS does one of the following:
      - If the updated SRLG information of the current bypass path changed and SRLG FRR loose disjointness is configured (**configure**>**router**>**mpls**>**srlg-frr**), MPLS keeps this PLR PSB association with the current bypass path.
      - If the updated SRLG information of the current bypass path changed and SRLG strict disjointness is configured (**configure**>**router**>**mpls**>**srlg-frr strict**), MPLS evaluates the SRLG constraint of each PLR and performs the following actions:
        – MPLS keeps with the current bypass path the PSB associations of all PLRs where the SRLG constraint is not violated by the updated SRLG information of the current bypass path.

          These PSBs are re-evaluated at the next timer or manual resignal MBB following the same procedure, as described in RSVP-TE bypass LSP path SRLG information update in manual and timer resignal MBB.

[1] This check of the current path makes use of the updated SRLG and cost information provided by CSPF.

– MPLS detaches from current bypass path the PSB associations of all PLRs where the SRLG constraint is violated by the updated SRLG information of the current bypass path.

These orphaned PSBs are re-evaluated by the FRR background task, which checks unprotected PSBs on a regular basis and following the same procedure, as described in RSVP-TE bypass LSP path SRLG information update in manual and timer resignal MBB.

5. If the path returned by CSPF is found to be less optimal then the current bypass path or if CSPF did not return a new path, the following actions are performed:
   - If the updated SRLG information of the current bypass path did not change, MPLS keeps the current bypass path and the PSB associations of all PLRs.
   - If the updated SRLG information of the current bypass path changed and SRLG FRR loose disjointness is configured (**configure**>**router**>**mpls**>**srlg-frr**), MPLS keeps the current bypass path and the PSB associations of all PLRs.
   - If the updated SRLG information of the current bypass path changed and SRLG strict disjointness is configured (**configure**>**router**>**mpls**>**srlg-frr strict**), MPLS evaluates the SRLG constraint of each PLR and performs the following actions:
     – MPLS keeps with the current bypass path the PSB associations of all PLRs where the SRLG constraint is not violated by the updated SRLG information of the current bypass path.

     These PSBs are re-evaluated at the next timer or manual resignal MBB following the same procedure, as described in RSVP-TE bypass LSP path SRLG information update in manual and timer resignal MBB.

     – MPLS detaches from current bypass path the PSB associations of all PLRs where the SRLG constraint is violated by the updated SRLG information of the current bypass path.

     These orphaned PSBs are re-evaluated by the FRR background task, which checks unprotected PSBs on a regular basis and following the same procedure, as described in RSVP-TE bypass LSP path SRLG information update in manual and timer resignal MBB.

2.4.3.2 RSVP-TE bypass LSP path administrative group information update in manual and timer resignal MBB

This feature enhances procedures of the timer and manual resignal (both **delay** and **lsp** options) of a RSVP-TE bypass LSP path by updating the administrative group information of the current path links and checking for administrative group constraints. The following sequence describes the timer and manual resignal enhancements:

1. CSPF updates the administrative group membership of the current bypass LSP path and checks if the path violates the administrative group constraints of the first primary path which was associated with this bypass LSP. This is referred to as the initial PSB.
2. CSPF attempts a new path computation for the bypass LSP using the PLR constraints of the initial PSB.
3. MPLS uses the information returned by CSPF and determines if the new bypass path is more optimal.
   a. If CSPF indicated the updated administrative group information of current path violated the administrative group constraint of the initial PSB, then the new path is more optimal.
   b. Otherwise, the new path is more optimal only if its metric is lower than the updated metric of the current bypass path.

4. If the path returned by CSPF is found to be a more optimal bypass path, MPLS signals and programs the new path. Because the administrative group constraint is not part of the PLR definition, MPLS evaluates the PSBs of all PLRs associated with the current bypass, and takes the following actions:

   a. MPLS moves to the new bypass path the PSB associations in which the administrative group constraints are not violated by the new bypass path.

   b. Among the remaining PSBs, MPLS does the following:

   - MPLS keeps with the current bypass path the PSB associations in which the administrative group constraints are not violated by the updated administrative group information of the current bypass path.

     These PSBs are re-evaluated at the next timer or manual resignal MBB following the same procedure, as described in RSVP-TE bypass LSP path administrative group information update in manual and timer resignal MBB.

   - MPLS detaches from current bypass path the PSB associations in which the administrative group constraints are violated by the updated administrative group information of the current bypass path.

     These orphaned PSBs are re-evaluated by the FRR background task, which checks unprotected PSBs on a regular basis and following the same procedure, as described in RSVP-TE bypass LSP path administrative group information update in manual and timer resignal MBB.

5. If the path returned by CSPF is found to be less optimal than the current bypass path or if CSPF did not return a new path, the following actions are performed:

   - If the updated administrative group information of the current bypass path did not change, MPLS keeps the current bypass path and all PSB associations.
   - If the updated administrative group information of the current bypass path has changed, MPLS evaluates the PSBs of all PLRs associated with the current bypass, and performs the following actions:
     - MPLS keeps with the current bypass path the PSB associations in which the administrative group constraints are not violated by the updated administrative group information of the current bypass path.
     - MPLS detaches from current bypass path the PSB associations in which the administrative group constraints are violated by the updated administrative group information of the current bypass path.

       These orphaned PSBs are re-evaluated by the FRR background task, which checks unprotected PSBs on a regular basis and following the same procedure, as described in RSVP-TE bypass LSP path administrative group information update in manual and timer resignal MBB.

2.4.4 RSVP-TE LSP active path administrative group information update in timer resignal MBB

This feature enhances the procedures of the timer resignal and of the **delay** option of the manual resignal of the active path of a RSVP-TE LSP. The feature updates the administrative group information of the links of the current path and checks for administrative group constraint. MPLS performs the following sequence of actions:

1. CSPF checks the validity and updates the administrative group membership of the current active path. The validity of the path means that each TE link used by the path is still in the TE-DB, which ensures the continuous path form ingress to egress.

2. CSPF attempts a new path computation for the active path.
   - If CSPF returns a new path, MPLS performs the following actions:
     – If CSPF finds the current path is invalid, MPLS signals and programs the new path.
     – If the updated administrative group membership of the current path violates the path administrative group constraint, MPLS signals and programs the new path.
     – If the updated administrative group membership of current path does not violate the path administrative group constraint, MPLS signals the new path only if its cumulative metric is different from the updated cumulative metric of the current path.
   - If CSPF returns no path, MPLS keeps the current path regardless of whether the updated administrative group membership of the current path violates the path administrative group constraint.

     This behavior of SR OS prevents unnecessary blackholing of traffic as a result of potential TE database churn, in which case a compliant path for the administrative group constraint is found at the next resignal timer expiry.

2.4.5 DiffServ traffic engineering

DiffServ traffic engineering (TE) provides the ability to manage bandwidth on a per-TE class basis as per RFC 4124. In the base traffic engineering, LER computes LSP paths based on available BW of links on the path. DiffServ TE adds ability to perform this on a per-TE class basis.

A TE class is a combination of Class Type and LSP priority. A Class Type is mapped to one or more system Forwarding Classes using a configuration profile. The operator sets different limits for admission control of LSPs in each TE class over each TE link. Eight TE classes are supported. Admission control of LSP paths bandwidth reservation is performed using the Maximum Allocation Bandwidth Constraint Model as per RFC 4125.

2.4.5.1 Mapping of traffic to a DiffServ LSP

An LER allows the operator to map traffic to a DiffServ LSP using one of the following methods:

- explicit RSVP SDP configuration of a VLL, VPLS, or VPRN service
- class-based forwarding in an RSVP SDP. The operator can enable the checking by RSVP that a Forwarding Class (FC) mapping to an LSP under the SDP configuration is compatible with the DiffServ Class Type (CT) configuration for this LSP.
- the **auto-bind-tunnel** RSVP-TE option in a VPRN service
- static routes with indirect next-hop being an RSVP LSP name

2.4.5.2 Admission control of classes

There are a couple of admission control decisions made when an LSP with a specified bandwidth is to be signaled. The first is in the head-end node. CSPF only considers network links that have sufficient bandwidth. Link bandwidth information is provided by IGP TE advertisement by all nodes in that network.

Another decision made is local CAC and is performed when the RESV message for the LSP path is received in the reverse direction by a SR OS in that path. The bandwidth value selected by the egress LER

is checked against link bandwidth, otherwise the reservation is rejected. If accepted, the new value for the remaining link bandwidth is advertised by IGP at the next advertisement event.

Both of these admission decisions are enhanced to be performed at the TE class level when DiffServ TE is enabled. In other words, CSPF in the head-end node must check the LSP bandwidth against the 'unreserved bandwidth' advertised for all links in the path of the LSP for that TE class which consists of a combination of a CT and a priority. Same for the admission control at SR OS receiving the Resv message.

2.4.5.2.1 Maximum allocation model

The admission control rules for this model are described in RFC 4125. Each CT shares a percentage of the Maximum Reservable Link Bandwidth through the user-configured BC for this CT. The Maximum Reservable Link Bandwidth is the link bandwidth multiplied by the RSVP interface subscription factor.

The sum of all BC values across all CTs does not exceed the Maximum Reservable Link Bandwidth. In other words, the following rule is enforced:

SUM (BCc) =< Max-Reservable-Bandwidth, 0 ≤ c ≤ 7

An LSP of class-type CTc, setup priority p, holding priority h (h=<p), and bandwidth B is admitted into a link if the following condition is satisfied:

B ≤ Unreserved Bandwidth for TE-Class[i]

where TE-Class [i] maps to < CTc, p > in the definition of the TE classes on the node. The bandwidth reservation is effected at the holding priority; that is, in TE-class [j] = <CTc, h>. As such, the reserved bandwidth for CTc and the unreserved bandwidth for the TE classes using CTc are updated as follows:

Reserved(CTc) = Reserved(CTc) + B

Unreserved TE-Class [j] = BCc - SUM (Reserved(CTc,q)) for 0≤ q ≤ h

Unreserved TE-Class [i] = BCc - SUM (Reserved(CTc,q)) for 0≤ q ≤ p

The same is done to update the unreserved bandwidth for any other TE class making use of the same CTc. These new values are advertised to the rest of the network at the next IGP-TE flooding.

When DiffServ is disabled on the node, this model degenerates into a single default CT internally with eight preemption priorities and a non-configurable BC equal to the Maximum Reservable Link Bandwidth. This would behave exactly like CT0 with eight preemption priorities and BC= Maximum Reservable Link Bandwidth if DiffServ was enabled.

2.4.5.2.2 Russian doll model

The RDM model is defined using the following equations:

SUM (Reserved (CTc)) ≤ BCb

where the SUM is across all values of **c** in the range b ≤ c ≤ (MaxCT - 1), and **BCb** is the bandwidth constraint of **CTb**.

BC0= Max-Reservable-Bandwidth, so that:

SUM (Reserved(CTc)) ≤ Max-Reservable-Bandwidth,

where the **SUM** is across all values of **c** in the range 0 ≤ c ≤ (MaxCT - 1)

An LSP of class-type **CTc**, setup priority **p**, holding priority **h (h=<p)**, and bandwidth **B** is admitted into a link if the following condition is satisfied:

B ≤ Unreserved Bandwidth for TE-Class[i]

where **TE-Class [i]** maps to **<CTc, p>** in the definition of the TE classes on the node. The bandwidth reservation is effected at the holding priority, that is, in **TE-class [j] = <CTc, h>**. As such, the reserved bandwidth for CTc and the unreserved bandwidth for the TE classes using CTc are updated as follows:

Reserved(CTc) = Reserved(CTc) + B

Unreserved TE-Class [j] = Unreserved (CTc, h) = Min [

BCc - SUM (Reserved (CTb, q) for 0≤q ≤ h, c ≤ b ≤ 7,

BC(c-1) – SUM (Reserved (CTb, q) for 0≤q ≤ h, (c-1) ≤ b ≤ 7,

…….

BC0 - SUM (Reserved (CTb, q) for 0≤q ≤ h, 0 ≤ b ≤ 7]

Unreserved TE-Class [i] = Unreserved (CTc, p) = Min [

BCc - SUM (Reserved (CTb, q) for 0≤q ≤ p, c ≤ b ≤ 7,

BC(c-1) – SUM (Reserved (CTb, q) for 0≤q ≤ p, (c-1) ≤ b ≤ 7,

…….

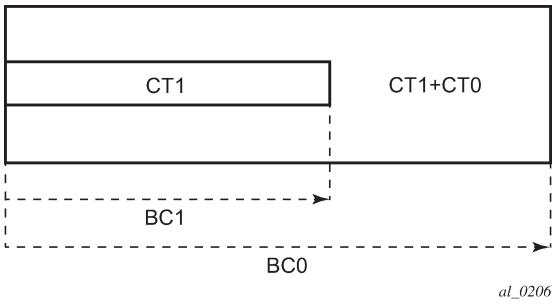
BC0 - SUM (Reserved (CTb, q) for 0≤q ≤ p, 0 ≤ b ≤7]

The same is done to update the unreserved bandwidth for any other TE class making use of the same CTc. These new values are advertised to the rest of the network at the next IGP-TE flooding.

2.4.5.2.2.1 Example CT bandwidth sharing with RDM

Below is a simple example with two CT values (CT0, CT1) and one priority 0 as shown in Figure 24: RDM with two class types.

Figure 24: RDM with two class types



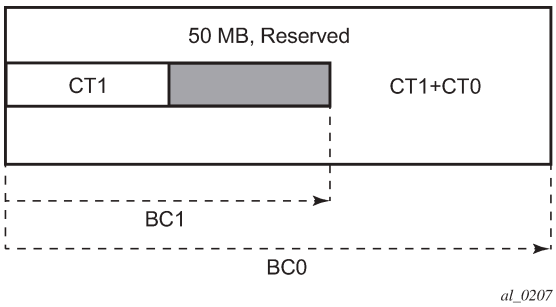
Suppose CT1 bandwidth, or the CT1 percentage of Maximum Reservable Bandwidth to be more accurate is 100 Mb/s and CT2 bandwidth is 100 Mb/s and link bandwidth is 200 Mb/s. BC constraints can be calculated as follows.

BC1 = CT1 Bandwidth = 100 Mb/s.

BC0 = {CT1 Bandwidth} + {CT0 Bandwidth} = 200 Mb/s.

Suppose an LSP comes with CT1, setup and holding priorities of 0 and a bandwidth of 50 Mb/s.

Figure 25: First LSP reservation



According to the RDM admission control policy:

Reserved (CT1, 0) = 50 ≤ 100 Mb/s

Reserved (CT0, 0) + Reserved (CT1, 0) = 50 ≤ 200 Mb/s

This results in the following unreserved bandwidth calculation.

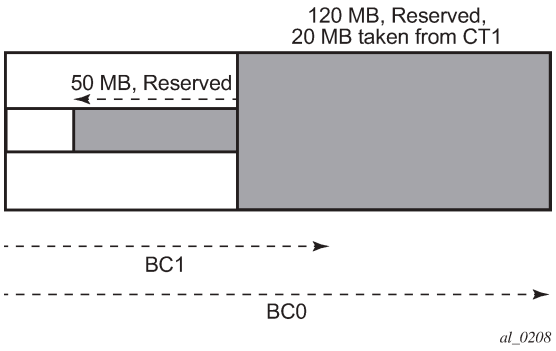
Unreserved (CT1, 0) = BC1 – Reserved (CT1, 0) = 100 – 50 = 50 Mb/s

Unreserved (CT0, 0) = BC0 – Reserved (CT0, 0) – Reserved (CT1, 0) = 200 – 0 – 50= 150 Mb/s.

The bandwidth reserved by a doll is not available to itself or any of the outer dolls.

Suppose now another LSP comes with CT0, setup and holding priorities of 0 and a bandwidth 120 Mb/s.

Figure 26: Second LSP reservation



Reserved (CT0, 0) = 120 ≤ 150 Mb/s

Reserved (CT0, 0) + Reserved (CT1, 0) = 120 + 50 = 170 ≤ 200 Mb/s

Unreserved (CT0, 0) = 150 -120 = 30 Mb/s

If we simply checked BC1, the formula would yield the wrong results:

Unreserved (CT1, 0) = BC1 – Reserved (CT1, 0) = 100 -50 = 50 Mb/s

Because of the encroaching of CT0 into CT1, we would need to deduct the overlapping reservation. This would then yield:

Unreserved (CT1, 0) = BC0 – Reserved (CT0, 0) – Reserved (CT1, 0) = 200 – 120 - 50 = 30 Mb/s, which is the correct figure.

Extending the formula with both equations:

Unreserved (CT1, 0) = Min [BC1 – Reserved (CT1, 0), BC0 – Reserved (CT0, 0) – Reserved (CT1, 0)] = Min [100 – 50, 200 – 120 – 50] = 30 Mb/s

An outer doll can encroach into an inner doll, reducing the bandwidth available for inner dolls.

2.4.5.3 RSVP control plane extensions

RSVP uses the Class Type object to carry LSP class-type information during path setup. Eight values are supported for class-types 0 through 7 as per RFC 4124. Class type 0 is the default class that is supported today on the router.

One or more forwarding classes map to a DiffServ class type trough a system level configuration.

2.4.5.4 IGP extensions

IGP extensions are defined in RFC 4124. DiffServ TE advertises link available bandwidth, referred to as unreserved bandwidth, by OSPF TE or IS-IS TE on a per TE class basis. A TE class is a combination of a class type and an LSP priority. To reduce the amount of per TE class flooding required in the network, the number of TE classes is set to eight. This means that eight class types can be supported with a single priority or four class types with two priorities, and so on. In that case, the operator configures the wanted class type on the LSP such that RSVP-TE can signal it in the class-type object in the path message.

IGP continues to advertise the existing Maximum Reservable Link Bandwidth TE parameter to mean the maximum bandwidth that can be booked on a specified interface by all classes. The value advertised is adjusted with the link subscription factor.

2.4.5.5 DiffServ TE configuration and operation

2.4.5.5.1 RSVP protocol level

About this task

The following are the configuration steps at the RSVP protocol level:

Procedure

Step 1. The operator enables DiffServ TE by executing the **diffserv-te** command in the **config>router>rsvp** context. When this command is enabled, IS-IS and OSPF start advertising available bandwidth for each TE class configured under the **diffserv-te** node. The operator can disable DiffServ TE globally by using the no form of the command.

Step 2. The enabling or disabling of DiffServ on the system requires that the RSVP and MPLS protocol be shutdown. The operator must execute the **no shutdown** command in each context after

all parameters under both protocols are defined. When saved in the configuration file, the **no shutdown** command is automatically inserted under both protocols to make sure they come up after a node reboot.

Step 3. IGP advertises the available bandwidth in each TE class in the unreserved bandwidth TE parameter for that class for each RSVP interface in the system.

Step 4. In addition, IGP continues to advertise the existing Maximum Reservable Link Bandwidth TE parameter so the maximum bandwidth that can be booked on a specific interface by all classes. The value advertised is adjusted with the link subscription factor configured in the **config>router>rsvp>if>subscription** *percentage* context.

Step 5. The operator can overbook (underbook) the maximum reservable bandwidth of a CT by overbooking (underbooking) the interface maximum reservable bandwidth by configuring the appropriate value for the **subscription** *percentage* parameter.

Step 6. The **diffserv-te** command only has effect if the operator has already enabled TE at the IS-IS or OSPF, or both, routing protocol levels:

config>router>isis>traffic-engineering

config>router>ospf>traffic-engineering

Step 7. The following DiffServ TE parameters are configured globally under the **diffserv-te** node. They apply to all RSVP interfaces on the system. When configured, these parameters can only be changed after shutting down the MPLS and RSVP protocols:

a. Definition of TE classes, TE Class = {Class Type (CT), LSP priority}. Eight TE classes can be supported. There is no default TE class when DiffServ is enabled. The operator must explicitly define each TE class. However, when DiffServ is disabled there is an internal use of the default CT (CT0) and eight preemption priorities as shown in Table 11: Internal TE class definition when DiffServ TE is disabled.

Table 11: Internal TE class definition when DiffServ TE is disabled

Class type (CT internal)	LSP priority
0	7
0	6
0	5
0	4
0	3
0	2
0	1
0	0

b. A mapping of the system forwarding class to CT. The default settings are shown in Table 12: Default mapping of forwarding class to TE class.

Table 12: Default mapping of forwarding class to TE class

FC ID	FC name	FC designation	Class type (CT)
7	Network Control	NC	7
6	High-1	H1	6
5	Expedited	EF	5
4	High-2	H2	4
3	Low-1	L1	3
2	Assured	AF	2
1	Low-2	L2	1
0	Best Effort	BE	0

c. Configuration of the percentage of RSVP interface bandwidth each CT shares, for example, the Bandwidth Constraint (BC), using the **class-type-bw** command. The absolute value of the CT share of the interface bandwidth is derived as the percentage of the bandwidth advertised by IGP in the maximum reservable link bandwidth TE parameter, for example, the link bandwidth multiplied by the RSVP interface **subscription** *percentage* parameter. Note that this configuration also exists at the RSVP interface level and the interface specific configured value overrides the global configured value. The BC value can be changed at any time. The operator can specify the BC for a CT which is not used in any of the TE class definition but that does not get used by any LSP originating or transiting this node.

d. Configuration of the Admission Control Policy to be used: the Maximum Allocation Model (MAM) and the Russian Doll Model (RDM) are supported. The **mam** and **rdm** values represent the bandwidth constraint models for the admission control of an LSP reservation to a link. For more details of the MAM and RFM admission control policies, see Admission control of classes.

2.4.5.5.2 RSVP interface level

The following are the configuration steps at the RSVP interface level:

1. The operator configures the percentage of RSVP interface bandwidth each CT shares, for example, the BC, using the **class-type-bw** command. The value entered at the interface level overrides the global value configured under the **diffserv-te** node.
2. The operator can overbook (underbook) the maximum reservable bandwidth of a specific CT by overbooking (underbooking) the interface maximum reservable bandwidth via configuring the appropriate value for the **subscription** *percentage* parameter in the **config>router>rsvp>interface** context.

Note: Both the BC value and the subscription parameter can be changed at any time.

2.4.5.5.3 LSP and LSP path levels

The following are the configuration steps at the LSP and LSP path levels:

1. The operator configures the CT in which the LSP belongs by configuring the **class-type** *ct-number* command at the LSP level or the path level, or both. The path level value overrides the LSP level value. By default, an LSP belongs to CT0.
2. Only one CT per LSP path is allowed per RFC 4124, *Protocol Extensions for Support of Diffserv-aware MPLS Traffic Engineering*. A multiclass LSP path is achieved through mapping multiple system Forwarding Classes to a CT.
3. The signaled CT of a dynamic bypass must always be CT0 regardless of the CT of the primary LSP path. The setup and hold priorities must be set to default values, for example, 7 and 0 respectively. This assumes that the operator configured a couple of TE classes, one which combines CT0 and a priority of 7 and the other which combines CT0 and a priority of 0. If not, the bypass LSP is not signaled and goes into the down state.
4. The operator cannot configure the CT, setup priority, and holding priority of a manual bypass. They are always signaled with CT0 and the default setup and holding priorities.
5. The signaled CT, setup priority and holding priority of a detour LSP matches those of the primary LSP path it is associated with.
6. The operator can also configure the setup and holding priorities for each LSP path.
7. An LSP which does not have the CT explicitly configured behaves like a CT0 LSP when DiffServ is enabled.

If the operator configured a combination of a CT and a setup priority or a combination of a CT and a holding priority, or both, for an LSP path that are not supported by the user-defined TE classes, the LSP path is kept in a down state and error code is shown within the show command output for the LSP path.

2.4.6 DiffServ TE LSP class type change under failure

An option to configure a main Class Type (CT) and a backup CT for the primary path of a DiffServ TE LSP is provided. The main CT is used under normal operating conditions, for example, when the LSP is established the first time and when it gets re-optimized because of timer based or manual resignal. The backup CT is used when the LSP retries under failure.

The use of backup Class Type (CT) by an LSP is enabled by executing the **config>router>mpls>lsp>primary>backup-class-type** *ct-number* command at the LSP primary path level.

When this option is enabled, the LSP uses the CT configured using the following commands (whichever is inherited at the primary path level) as the main CT:

- config>router>mpls>lsp>class-type *ct-number*
- config>router>mpls>lsp>primary>class-type *ct-number*

The main CT is used at initial establishment and during a manual or a timer based resignal Make-Before-Break (MBB) of the LSP primary path. The backup CT is used temporarily to signal the LSP primary path when it fails and goes into retry.

Note that any valid values may be entered for the backup CT and main CT, but they cannot be the same. No check is performed to make sure that the backup CT is a lower CT in DiffServ Russian-Doll Model (RDM) admission control context.

The secondary paths of the same LSP are always signaled using the main CT as in existing implementation.

2.4.6.1 LSP primary path retry procedures

This feature behaves according to the following rules:

- When an LSP primary path retries because of a failure, for example, it fails after being in the up state, or undergoes any type of MBB, MPLS retries a new path for the LSP using the main CT. If the first attempt failed, the head-end node performs subsequent retries using the backup CT. This procedure must be followed regardless if the currently used CT by this path is the main or backup CT. This applies to both CSPF and non-CSPF LSPs.
- The triggers for using the backup CT after the first retry attempt are:
  - A local interface failure or a control plane failure (hello timeout, and so on).
  - Receipt of a PathErr message with a notification of a FRR protection becoming active downstream or receipt, or both, of a Resv message with a 'Local-Protection-In-Use' flag set. This invokes the FRR Global Revertive MBB.
  - Receipt of a PathErr message with error code=25 (Notify) and sub-code=7 (Local link maintenance required) or a sub-code=8 (Local node maintenance required). This invokes the TE Graceful Shutdown MBB. Note that in this case, only a single attempt is performed by MBB as in current implementation; only the main CT is retried.
  - Receipt of a Resv refresh message with the 'Preemption pending' flag set or a PathErr message with error code=34 (Reroute) and a value=1 (Reroute request soft preemption). This invokes the soft preemption MBB.
  - Receipt of a ResvTear message.
  - A configuration change MBB.
- When an unmapped LSP primary path goes into retry, it uses the main CT until the number of retries reaches the value of the new main-ct-retry-limit parameter. If the path did not come up, it must start using the backup CT at that point in time. By default, this parameter is set to infinite value. The new main-ct-retry-limit parameter has no effect on an LSP primary path, which retries because of a failure event. This parameter is configured using the **main-ct-retry-limit** command in the **config>router>mpls>lsp** context. If the user entered a value of the **main-ct-retry-limit** parameter that is greater than the LSP retry-limit, the number of retries still stops when the LSP primary path reaches the value of the LSP retry-limit. In other words, the meaning of the LSP retry-limit parameter is not changed and always represents the upper bound on the number of retries. The unmapped LSP primary path behavior applies to both CSPF and non-CSPF LSPs.
- An unmapped LSP primary path is a path that never received a Resv in response to the first path message sent. This can occur when performing a "shut/no-shut" on the LSP or LSP primary path or when the node reboots. An unmapped LSP primary path goes into retry if the retry timer expired or the head-end node received a PathErr message before the retry timer expired.
- When the **clear>router>mpls>lsp** command is executed, the retry behavior for this LSP is the same as in the case of an unmapped LSP.
- If the value of the parameter main-ct-retry-limit is changed, the new value is only used at the next time the LSP path is put into a "no-shut" state.
- The following is the behavior when the user changes the main or backup CT:

  - If the user changes the LSP level CT, all paths of the LSP are torn down and resignaled in a break-before-make fashion. Specifically, the LSP primary path is torn down and resignaled even if it is currently using the backup CT.
  - If the user changes the main CT of the LSP primary path, the path is torn down and resignaled even if it is currently using the backup CT.
  - If the user changes the backup CT of an LSP primary path when the backup CT is in use, the path is torn down and is resignaled.
  - If the user changes the backup CT of an LSP primary path when the backup CT is not in use, no action is taken. If however, the path was in global Revertive, gshut, or soft preemption MBB, the MBB is restarted. This actually means the first attempt is with the main CT and subsequent ones, if any, with the new value of the backup CT.
  - Consider the following priority of the various MBB types from highest to lowest: Delayed Retry, Preemption, Global Revertive, Configuration Change, and TE Graceful Shutdown. If an MBB request occurs while a higher priority MBB is in progress, the latter MBB is restarted. This actually means the first attempt is with the main CT and subsequent ones, if any, with the new value of the backup CT.

- If the least-fill option is enabled at the LSP level, then CSPF must use least-fill equal cost path selection when the main or backup CT is used on the primary path.
- When the resignal timer expires, CSPF tries to find a path with the main CT. The head-end node must resignal the LSP even if the new path found by CSPF is identical to the existing one because the idea is to restore the main CT for the primary path. If a path with main CT is not found, the LSP remains on its current primary path using the backup CT. This means that the LSP primary path with the backup CT may no longer be the most optimal one. Furthermore, if the least-fill option was enabled at the LSP level, CSPF does not check if there is a more optimal path, with the backup CT, according to the least-fill criterion and, so, does not raise a trap to indicate the LSP path is eligible for least-fill re-optimization.
- When the user performs a manual resignal of the primary path, CSPF tries to find a path with the main CT. The head-end node must resignal the LSP as in current implementation.
- If a CPM switchover occurs while an the LSP primary path was in retry using the main or backup CT, for example, was still in operationally down state, the path retry is restarted with the main CT until it comes up. This is because the LSP path retry count is not synchronized between the active and standby CPMs until the path becomes up.
- When the user configured secondary standby and non-standby paths on the same LSP, the switchover behavior between primary and secondary is the same as in existing implementation.

This feature is not supported on a P2MP LSP.

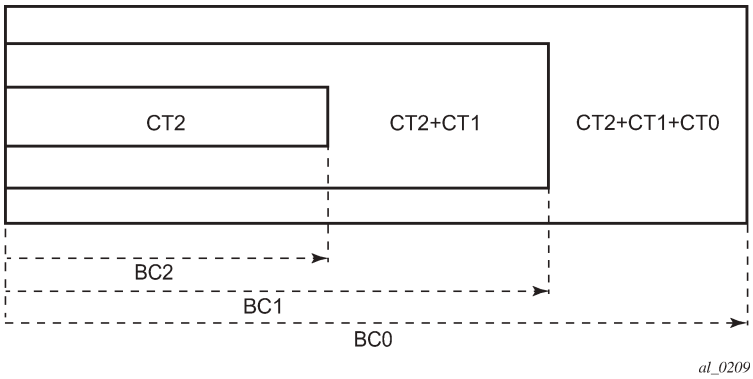
2.4.6.2 Bandwidth sharing across class types

To allow different levels of booking of network links under normal operating conditions and under failure conditions, it is necessary to allow sharing of bandwidth across class types.

This feature introduces the Russian-Doll Model (RDM) DiffServ TE admission control policy described in RFC 4127, *Russian Dolls Bandwidth Constraints Model for Diffserv-aware MPLS Traffic Engineering*. This mode is enabled using the following command: **config>router>rsvp>diffserv-te rdm**.

The Russian Doll Model (RDM) LSP admission control policy allows bandwidth sharing across Class Types (CTs). It provides a hierarchical model by which the reserved bandwidth of a CT is the sum of the reserved bandwidths of the numerically equal and higher CTs. Figure 27: RDM admission control policy example shows an example.

Figure 27: RDM admission control policy example



CT2 has a bandwidth constraint BC2 which represents a percentage of the maximum reservable link bandwidth. Both CT2 and CT1 can share BC1 which is the sum of the percentage of the maximum reservable bandwidth values configured for CT2 and CT1 respectively. Finally, CT2, CT1, and CT0 together can share BC0 which is the sum of the percentage of the maximum reservable bandwidth values configured for CT2, CT1, and CT0 respectively. The maximum value for BC0 is of course the maximum reservable link bandwidth.

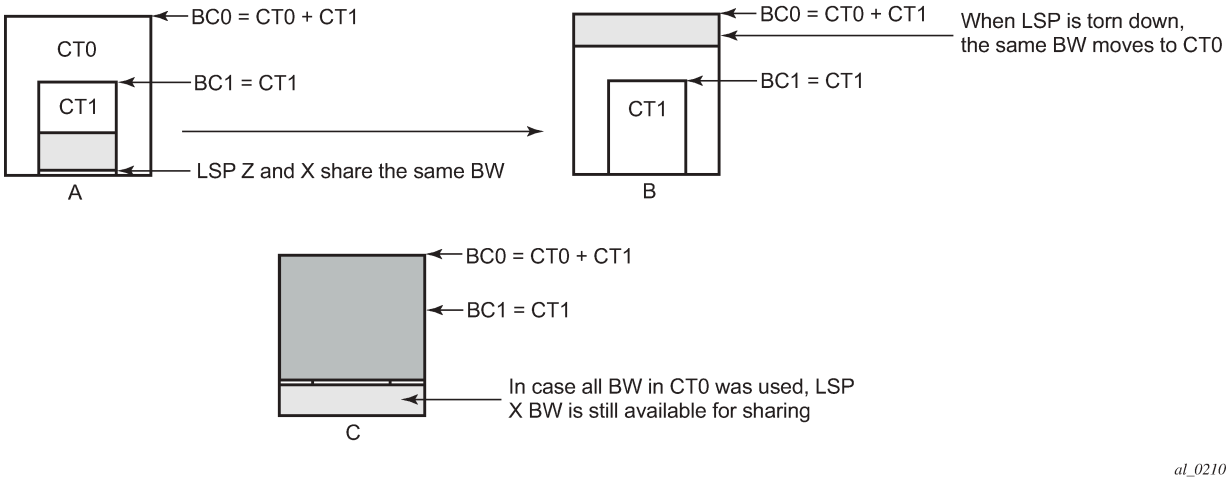
What this means in practice is that CT0 LSPs can use up to BC0 in the absence of LSPs in CT1 and CT2. When this occurs and a CT2 LSP with a reservation less than or equal to BC2 requests admission, it is only admitted by preempting one or more CT0 LSPs of lower holding priority than this LSP setup priority. Otherwise, the reservation request for the CT2 LSP is rejected.

It is required that multiple paths of the same LSP share common link bandwidth because they are signaled using the Shared Explicit (SE) style. Specifically, two instances of a primary path, one with the main CT and the other with the backup CT, must temporarily share bandwidth while MBB is in progress. Also, a primary path and one or many secondary paths of the same LSP must share bandwidth whether they are configured with the same or different CTs.

2.4.6.3 Downgrading the CT of bandwidth sharing LSP paths

Consider a link configured with two class types CT0 and CT1 and making use of the RDM admission control model as shown in Figure 28: Sharing bandwidth when an LSP primary path is downgraded to backup CT.

Figure 28: Sharing bandwidth when an LSP primary path is downgraded to backup CT



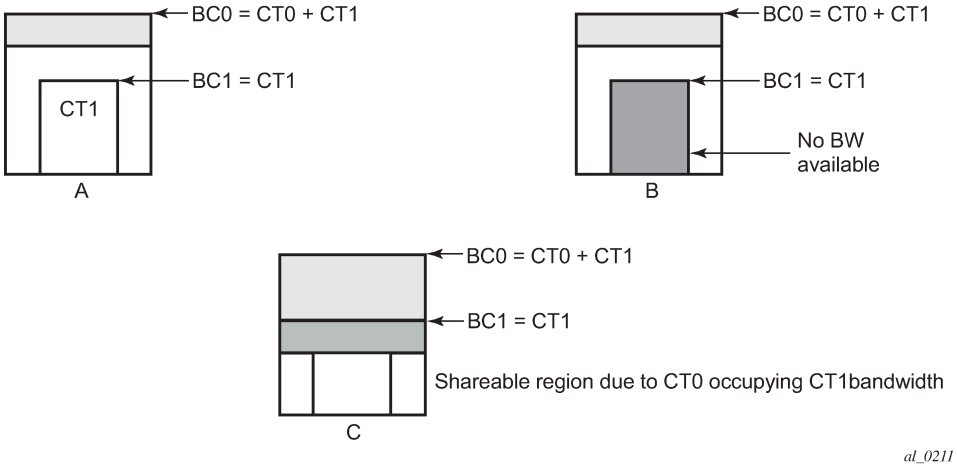
Consider an LSP path Z occupying bandwidth B at CT1. BC0 being the sum of all CTs below it, the bandwidth occupied in CT1 is guaranteed to be available in CT0. When new path X of the same LSP for CT0 is setup, it uses the same bandwidth B as used by path Z as shown in Figure 28: Sharing bandwidth when an LSP primary path is downgraded to backup CT (a). When path Z is torn down the same bandwidth now occupies CT0 as shown in Figure 28: Sharing bandwidth when an LSP primary path is downgraded to backup CT (b). Even if there were no new BW available in CT0 as can be seen in Figure 28: Sharing bandwidth when an LSP primary path is downgraded to backup CT (c), path X can always share the bandwidth with path Z.

CSPF at the head-end node and CAC at the transit LSR node shares bandwidth of an existing path when its CT is downgraded in the new path of the same LSP.

2.4.6.4 Upgrading the CT of bandwidth sharing LSP paths

When upgrading the CT the following issue can be apparent. Assume an LSP path X exists with CT0. An attempt is made to upgrade this path to a new path Z with CT1 using an MBB.

Figure 29: Sharing bandwidth when an LSP primary path is upgraded to main CT



In Figure 29: Sharing bandwidth when an LSP primary path is upgraded to main CT (a), if the path X occupies the bandwidth as shown it cannot share the bandwidth with the new path Z being setup. If a condition exists, as shown in Figure 29: Sharing bandwidth when an LSP primary path is upgraded to main CT, (b) the path Z can never be setup on this particular link.

Consider Figure 29: Sharing bandwidth when an LSP primary path is upgraded to main CT (c). The CT0 has a region that overlaps with CT1 as CT0 has incursion into CT1. This overlap can be shared. However, to find whether such an incursion has occurred and how large the region is, it is required to know the reserved bandwidths in each class. Currently, IGP-TE advertises only the unreserved bandwidths. Hence, it is not possible to compute these overlap regions at the head end during CSPF. Moreover, the head end needs to then try and mimic each of the traversed links exactly which increases the complexity.

CSPF at the head-end node only attempts to signal the LSP path with an upgraded CT if the advertised bandwidth for that CT can accommodate the bandwidth. In other words, it assumes that in the worst case this path does not share bandwidth with another path of the same LSP using a lower CT.

2.5 Advanced MPLS/RSVP features

This section describes advanced MPLS/RSVP features.

2.5.1 Extending RSVP LSP to use loopback interfaces other than router-id

It is possible to configure the address of a loopback interface, other than the router-id, as the destination of an RSVP LSP, or a P2MP S2L sub-LSP. In the case of a CSPF LSP, CSPF searches for the best path that matches the constraints across all areas and levels of the IGP where this address is reachable. If the address is the router-id of the destination node, then CSPF selects the best path across all areas and levels of the IGP for that router-id; regardless of which area and level the router-id is reachable as an interface.

In addition, the user can now configure the address of a loopback interface, other than the router-id, as a hop in the LSP path hop definition. If the hop is strict and corresponds to the router-id of the node, the CSPF path can use any TE enabled link to the downstream node, based on best cost. If the hop is strict and does not correspond to the router-id of the node, then CSPF fails.

2.5.2 LSP path change

The **tools perform router mpls update-path** {**lsp** *lsp-name* **path** *current-path-name* **new-path** *new-path-name*} command instructs MPLS to replace the path of the primary or secondary LSP.

The primary or secondary LSP path is indirectly identified via the current-path-name value. In existing implementation, the same path name cannot be used more than once in a specific LSP name.

This command is also supported on an SNMP interface.

This command applies to both CSPF LSP and to a non-CSPF LSP. However, it is only honored when the specified current-path-name has the adaptive option enabled. The adaptive option can be enabled the LSP level or at the path level.

The new path must be first configured in CLI or provided via SNMP. The **configure >router>mpls>path** *path-name* command is used to enter the path.

The command fails if any of the following conditions are satisfied:

- The specified current-path-name of this LSP does not have the adaptive option enabled.
- The specified new-path-name value does not correspond to a previously defined path.
- The specified new-path-name value exists but is being used by any path of the same LSP, including this one.

When the command is executed, MPLS performs a single MBB attempt to move the LSP path to the new path.

- If the MBB is successful, MPLS updates the new path.
  - MPLS writes the corresponding NHLFE in the datapath if this path is the current backup path for the primary.
  - If the current path is the active LSP path, it updates the path, writes the new NHLFE in the data path, which causes traffic to switch to the new path.
- If the MBB is not successful, the path retains its current value.
- The update-path MBB has the same priority as the manual resignal MBB.

2.5.3 Manual LSP path switch

This feature provides a new command to move the path of an LSP from a standby secondary to another standby secondary.

The base version of the command allows the path of the LSP to move from a standby (or an active secondary) to another standby of the same priority. If a new standby path with a higher priority or a primary path comes up after the **tools perform** command is executed, the path re-evaluation command runs and the path is moved to the path specified by the outcome of the re-evaluation.

The CLI command for the base version is:

tools>perform>router>mpls>switch-path>lsp *lsp-name* **path** *path-name*

The sticky version of the command can be used to move from a standby path to any other standby path regardless of priority. The LSP remains in the specified path until this path goes down or the user performs the no form of the **tools perform** command.

The CLI commands for the sticky version are:

tools>perform>router>mpls>force-switch-path>lsp *lsp-name* **path** *path-name*

tools>perform>router>mpls>no force-switch-path lsp *lsp-name*

2.5.4 MBB procedures for LSP/path parameter configuration change

When an LSP is switched from an existing working path to a new path, it is desirable to perform this in a hitless fashion. The Make-Before-Break (MBB) procedure consist of first signaling the new path when it is up, and having the ingress LER move the traffic to the new path. Only then the ingress LER tears down the original path.

MBB procedure is invoked during the following operations:

1. timer based and manual resignal of an LSP path
2. Fast-ReRoute (FRR) global revertive procedures
3. soft preemption of an LSP path
4. Traffic-Engineering (TE) graceful shutdown procedures
5. update of secondary path because of an update to primary path SRLG
6. LSP primary or secondary path name change
7. LSP or path configuration parameter change

In a prior implementation, item7 covers the following parameters:

1. changing the primary or secondary path **bandwidth** parameter on the fly
2. enabling the **frr** option for an LSP

This feature extends the coverage of the MBB procedure to most of the other LSP level and Path level parameters as follows:

- changes to include/exclude of admin groups at LSP and path levels
- enabling/disabling LSP level path-computation local-cspf option
- enabling/disabling LSP level metric-type parameter
- enabling/disabling LSP level propagate-admin-group option
- enabling/disabling LSP level hop-limit option in the fast-reroute context
- enabling the LSP level least-fill option
- enabling/disabling LSP level adspec option
- changing between node-protect and "no node-protect" (link-protect) values in the LSP level fast-reroute option
- changing LSP primary or secondary path priority values (setup-priority and hold-priority)
- changing LSP primary or secondary path class-type value and primary path backup-class-type value
- changing LSP level and path level hop-limit parameter value
- enabling/disabling primary or secondary path record and record-label options

This feature is not supported on a manual bypass LSP.

P2MP Tree Level Make-before-break operation is supported if changes are made to the following parameters on LSP-Template:

- changing bandwidth on P2MP LSP-Template

- enabling Fast Re-Route on P2MP LSP-Template

2.5.5 Automatic creation of RSVP-TE LSP mesh

This feature enables the automatic creation of an RSVP point-to-point LSP to a destination node whose router-id matches a prefix in the specified peer prefix policy. This LSP type is referred to as auto-LSP of type mesh.

The user can associate multiple templates with the same or different peer prefix policies. Each application of an LSP template with a specific prefix in the prefix list results in the instantiation of a single CSPF computed LSP primary path using the LSP template parameters as long as the prefix corresponds to a router-id for a node in the TE database. Each instantiated LSP has a unique LSP ID and a unique tunnel ID.

Up to five (5) peer prefix policies can be associated with a specific LSP template at all times. Each time the user executes the above command with the same or different prefix policy associations, or the user changes a prefix policy associated with an LSP template, the system re-evaluates the prefix policy. The outcome of the re-evaluation tells MPLS if an existing LSP needs to be torn down or if a new LSP needs to be signaled to a destination address that is already in the TE database.

If a /32 prefix is added to (removed from) or if a prefix range is expanded (shrunk) in a prefix list associated with an LSP template, the same prefix policy re-evaluation described above is performed.

The trigger to signal the LSP is when the router with a router-id the matching a prefix in the prefix list appears in the TE database. The signaled LSP is installed in the Tunnel Table Manager (TTM) and is available to applications such as LDP-over-RSVP, resolution of BGP labeled routes, resolution of BGP, IGP, and static routes. It is, however, not available to be used as a provisioned SDP for explicit binding or auto-binding by services.

If the **one-hop** option is specified instead of a prefix policy, this command enables the automatic signaling of one-hop point-to-point LSPs using the specified template to all directly connected neighbors. This LSP type is referred to as auto-LSP of type one-hop. Although the provisioning model and CLI syntax differ from that of a mesh LSP only by the absence of a prefix list, the actual behavior is quite different. When the above command is executed, the TE database keeps track of each TE link that comes up to a directly connected IGP neighbor whose router-id is discovered. It then instructs MPLS to signal an LSP with a destination address matching the router-id of the neighbor and with a strict hop consisting of the address of the interface used by the TE link. The **auto-lsp** command with the **one-hop** option results in one or more LSPs signaled to the neighboring router.

An auto-created mesh or one-hop LSP can have egress statistics collected at the ingress LER by adding the **egress-statistics** node configuration into the LSP template. The user can also have ingress statistics collected at the egress LER using the same **ingress-statistics** node in CLI used with a provisioned LSP. The user must specify the full LSP name as signaled by the ingress LER in the RSVP session name field of the Session Attribute object in the received Path message.

2.5.5.1 Automatic creation of RSVP mesh LSP: configuration and behavior

2.5.5.1.1 Feature configuration

The user first creates an LSP template of type mesh P2P:

config>router>mpls>lsp-template *template-name* **mesh-p2p**

Inside the template the user configures the common LSP and path level parameters or options shared by all LSPs using this template.

Then the user references the peer prefix list which is defined inside a policy statement defined in the global policy manager.

config>router>mpls>auto-lsp lsp-template *template-name* **policy** *peer-prefix-policy*

The user can associate multiple templates with same or different peer prefix policies. Each application of an LSP template with a specific prefix in the prefix list results in the instantiation of a single CSPF computed LSP primary path using the LSP template parameters as long as the prefix corresponds to a router-id for a node in the TE database. This feature does not support the automatic signaling of a secondary path for an LSP. If the user requires the signaling of multiple LSPs to the same destination node, he/she must apply a separate LSP template to the same or different prefix list which contains the same destination node. Each instantiated LSP has a unique LSP-id and a unique tunnel-ID. This feature also does not support the signaling of a non-CSPF LSP. The selection of the **no cspf** option in the LSP template is therefore blocked.

Up to 5 peer prefix policies can be associated with an LSP template at all times. Each time the user executes the above command, with the same or different prefix policy associations, or the user changes a prefix policy associated with an LSP template, the system re-evaluates the prefix policy. The outcome of the re-evaluation tells MPLS if an existing LSP needs to be torn down or a new LSP needs to be signaled to a destination address which is already in the TE database.

If a /32 prefix is added to (removed from) or if a prefix range is expanded (shrunk) in a prefix list associated with an LSP template, the same prefix policy re-evaluation described above is performed.

The user must perform a **no shutdown** command of the template before it takes effect. When a template is in use, the user must shutdown the template before effecting any changes to the parameters except for those LSP parameters for which the change can be handled with the Make-Before-Break (MBB) procedures. These parameters are **bandwidth** and enabling **fast-reroute** with or without the **hop-limit** or **node-protect** options. For all other parameters, the user shuts down the template and after it is added, removed or modified, the existing instances of the LSP using this template are torn down and re-signaled.

Finally the auto-created mesh LSP can be signaled over both numbered and unnumbered RSVP interfaces.

2.5.5.1.2 Feature behavior

Whether the prefix list contains one or more specific /32 addresses or a range of addresses, an external trigger is required to indicate to MPLS to instantiate an LSP to a node which address matches an entry in the prefix list. The objective of the feature is to provide an automatic creation of a mesh of RSVP LSP to achieve automatic tunneling of LDP-over-RSVP. The external trigger is when the router with the router-id matching an address in the prefix list appears in the TE database. In the latter case, the TE database provides the trigger to MPLS which means this feature operates with CSPF LSP only.

Each instantiation of an LSP template results in RSVP signaling and installing state of a primary path for the LSP to the destination router. The auto- LSP is installed in the Tunnel Table Manager (TTM) and is available to applications such as LDP-over-RSVP, resolution of BGP labeled routes, resolution of BGP, IGP, and static routes. The auto-LSP can also be used for auto-binding by a VPRN service. The auto-LSP is however not available to be used in a provisioned SDP for explicit binding by services. Therefore, an auto-LSP can also not be used directly for auto-binding of a PW template with the **use-provisioned-sdp** option in BGP-AD VPLS or FEC129 VLL service. However, an auto-binding of a PW template to an LDP LSP, which is then tunneled over an RSVP auto-LSP is supported.

If the user changes the **bandwidth** parameter in the LSP template, an MBB is performed for all LSPs using the template. If however the **auto-bandwidth** option was enabled in the template, the **bandwidth** parameter change is saved but only takes effect at the next time the LSP bounces or is re-signaled.

Except for the MBB limitations to the configuration parameter change in the LSP template, MBB procedures for manual and timer based re-signaling of the LSP, for TE Graceful Shutdown and for soft pre-emption are supported.

Note that the use of the **tools perform router mpls update-path** command with a mesh LSP is not supported.

The **one-to-one** option under **fast-reroute** is also not supported.

If while the LSP is UP, with the bypass backup path activated or not, the TE database loses the router-id, it performs an update to MPLS module which states router-id is no longer in TE database. This causes MPLS to tear down all mesh LSPs to this router-id. Note however that if the destination router is not a neighbor of the ingress LER and the user shuts down the IGP instance in the destination router, the router-id corresponding to the IGP instance is only deleted from the TE database in the ingress LER after the LSA/LSP ages out. If the user brought back up the IGP instance before the LSA/LSP aged out, the ingress LER deletes and re-installs the same router-id at the receipt of the updated LSA/LSP. In other words, the RSVP LSPs destined for this router-id gets deleted and re-established. All other failure conditions cause the LSP to activate the bypass backup LSP or to go down without being deleted.

2.5.5.1.3 Multi-area and multi-instance support

A router which does not have TE links within a specific IGP area/level does not have its router-id discovered in the TE database by other routers in this area/level. In other words, an auto-LSP of type P2P mesh cannot be signaled to a router which does not participate in the area/level of the ingress LER.

A mesh LSP can however be signaled using TE links all belonging to the same IGP area even if the router-id of the ingress and egress routers are interfaces reachable in a different area. In this case, the LSP is considered to be an intra-area LSP.

If multiple instances of ISIS or OSPF are configured on a router, each with its own router-id value, the TE database in other routers are able to discover TE links advertised by each instance. In such a case, an instance of an LSP can be signaled to each router-id with a CSPF path computed using TE links within each instance.

Finally, if multiple instances of ISIS or OSPF are configured on a destination router each with the same router-id value, a single instance of LSP is signaled from other routers. If the user shuts down one IGP instance, this is **no op** as long as the other IGP instances remain up. The LSP remains up and forwards traffic using the same TE links. The same behavior exists with a provisioned LSP.

2.5.5.1.4 Mesh LSP name encoding and statistics

When the ingress LER signals the path of a mesh auto-LSP, it includes the name of the LSP and that of the path in the Session Name field of the Session Attribute object in the Path message. The encoding is as follows:

Session Name: <lsp-name::path-name>, where lsp-name component is encoded as follows:

TemplateName-DestIpv4Address-TunnelId

Where *DestIpv4Address* is the address of the destination of the auto-created LSP.

At ingress LER, the user can enable egress statistics for the auto-created mesh LSP by adding the following configuration to the LSP template:

```
config
    router
        [no] mpls
             lsp-template template-name mesh-p2p]
             no lsp-template template-name
                  [no] egress-statistics
                       accounting-policy policy-id
                       no accounting-policy
                       no] collect-stats
```

If there are no stat indexes available when an LSP is instantiated, the assignment is failed and the egress-statistics field in the show command for the LSP path is in the operational DOWN state but in admin UP state.

An auto-created mesh LSP can also have ingress statistics enabled on the egress LER as long as the user specifies the full LSP name following the above syntax.

config>router>mpls>ingress-statistics>lsp *lsp-name* **sender** *ip-address*

2.5.5.2 Automatic creation of RSVP one-hop LSP: configuration and behavior

2.5.5.2.1 Feature configuration

The user first creates an LSP template of type one-hop:

config>router>mpls>lsp-template *template-name* **one-hop-p2p**

Then the user enables the automatic signaling of one-hop LSP to all direct neighbors using the following command:

config>router>mpls>auto-lsp lsp-template *template-name* **one-hop**

The LSP and path parameters and options supported in an LSP template of type **one-hop-p2p** are that same as in the LSP template of type **mesh-p2p** except for the parameter **from** which is not allowed in a template of type **one-hop-p2p**. The show command for the auto-LSP displays the actual outgoing interface address in the 'from' field.

Finally the auto-created one-hop LSP can be signaled over both numbered and unnumbered RSVP interfaces.

2.5.5.2.2 Feature behavior

Although the provisioning model and CLI syntax differ from that of a mesh LSP only by the absence of a prefix list, the actual behavior is quite different. When the above command is executed, the TE database keeps track of each TE link which comes up to a directly connected IGP neighbor which router-id is discovered. It then instructs MPLS to signals an LSP with a destination address matching the router-id of the neighbor and with a strict hop consisting of the address of the interface used by the TE link. Therefore, the **auto-lsp** command with the **one-hop** option results in one or more LSPs signaled to the IGP neighbor.

Only the router-id of the first IGP instance of the neighbor which advertises a TE link causes the LSP to be signaled. If subsequently another IGP instance with a different router-id advertises the same TE link,

no action is taken and the existing LSP is kept up. If the router-id originally used disappears from the TE database, the LSP is kept up and is associated now with the other router-id.

The state of a one-hop LSP when signaled follows the following behavior:

- If the interface used by the TE link goes down or BFD times out and the RSVP interface registered with BFD, the LSP path moves to the bypass backup LSP if the primary path is associated with one.
- If while the one-hop LSP is UP, with the bypass backup path activated or not, the association of the TE-link with a router-id is removed in the TE databases, the one-hop LSP is torn down. This would be the case if the interface used by the TE link is deleted or if the interface is shutdown in the context of RSVP.
- If while the LSP is UP, with the bypass backup path activated or not, the TE database loses the router-id, it performs two separate updates to MPLS module. The first one updates the loss of the TE link association which causes action (B) above for the one-hop LSP. The other update states router-id is no longer in TE database which causes MPLS to tear down all mesh LSPs to this router-id. A shutdown at the neighbor of the IGP instance which advertised the router-id causes the router-id to be removed from the ingress LER node immediately after the last IGP adjacency is lost and is not subject to age-out as for a non-directly connected destination router.

All other feature behavior, limitations, and statistics support are the same as for an auto-LSP of type **mesh-p2p**.

2.5.6 IGP shortcut and forwarding adjacency

The RSVP-TE LSP or SR-TE LSP shortcut for IGP route resolution supports packet forwarding to IGP learned routes using an RSVP-TE LSP. This is also referred to as IGP shortcut. This feature instructs IGP to include RSVP-TE LSPs and SR-TE LSPs that originate on this node and terminate on the router ID of a remote node as direct links with a metric equal to the metric provided by MPLS. During the IP reach to determine the reachability of nodes and prefixes, LSPs are overlaid and the LSP metric is used to determine the subset of paths that are equal to the lowest cost to reach a node or a prefix. When computing the cost of a prefix that is resolved to the LSP, if the user enables the relative-metric option for this LSP, the IGP applies the shortest IGP cost between the endpoints of the LSP, plus the value of the offset, instead of using the LSP operational metric.

Note: Dijkstra always uses the IGP link metric to build the SPF tree and the LSP metric value does not update the SPF tree calculation.

When a prefix is resolved to a tunnel next hop, the packet is sent labeled with the label stack corresponding to the NHLFE of the RSVP LSP and the explicit-null IPv6 label at the bottom of the stack in the case of an IPv6 prefix. Any network event causing an RSVP LSP to go down triggers a full SPF computation which may result in installing a new route over another RSVP LSP shortcut as tunnel next hop or over a regular IP next hop.

When **igp-shortcut** is enabled at the IGP instance level, all RSVP-TE and SR-TE LSPs originating on this node are eligible by default as long as the destination address of the LSP, as configured in **config>router>mpls>lsp>to**, corresponds to a router-id of a remote node. LSPs with a destination corresponding to an interface address or any other loopback interface address of a remote node are automatically not considered by IS-IS or OSPF. The user can, however, exclude a specific RSVP-TE LSP or a SR-TE LSP from being used as a shortcut for resolving IGP routes as described in IGP shortcut feature configuration.

Nokia recommends disabling the **igp-shortcut** option on RSVP LSP which has the cspf option disabled unless the full explicit path of the LSP is provided in the path definition. MPLS tracks in RTM the

destination or the first loose-hop in the path of a non CSPF LSP and, therefore, this can cause bouncing when used within IGP shortcuts.

The SPF in OSPF or IS-IS only uses RSVP LSPs as forwarding adjacencies, IGP shortcuts, or as endpoints for LDP-over-RSVP. These applications of RSVP LSPs are mutually exclusive at the IGP instance level. If two or more options are enabled in the same IGP instance, forwarding adjacency takes precedence over the shortcut application, which takes precedence over the LDP-over-RSVP application. The SPF in IGP uses SR-TE LSPs as IGP shortcuts only.

Table 13: RSVP LSP role as outcome of LSP level and IGP level configuration options summarizes the RSVP LSP role as an outcome of mixing these configuration options.

Table 13: RSVP LSP role as outcome of LSP level and IGP level configuration options

	IGP instance level configurations					
LSP level configuration	advertise-tunnel-link enabled / igp-shortcut enabled / ldp-over-rsvp enabled	advertise-tunnel-link enabled / igp-shortcut enabled / ldp-over-rsvp disabled	advertise-tunnel-link enabled / igp-shortcut disabled / ldp-over-rsvp disabled	advertise-tunnel-link disabled / igp-shortcut disabled / ldp-over-rsvp disabled	advertise-tunnel-link disabled / igp-shortcut enabled / ldp-over-rsvp enabled	advertise-tunnel-link disabled / igp-shortcut disabled / ldp-over-rsvp enabled
igp-shortcut enabled / ldp-over-rsvp enabled	Forwarding adjacency	Forwarding adjacency	Forwarding adjacency	None	IGP shortcut	LDP-over-RSVP
igp-shortcut enabled / ldp-over-rsvp disabled	Forwarding adjacency	Forwarding adjacency	Forwarding adjacency	None	IGP shortcut	None
igp-shortcut disabled / ldp-over-rsvp enabled	None	None	None	None	None	LDP-over-RSVP
igp-shortcut disabled / ldp-over-rsvp disabled	None	None	None	None	None	None

The **igp-shortcut shutdown** command disables the resolution of IGP routes using IGP shortcuts.

2.5.6.1 IGP shortcut feature configuration

The following CLI objects enable the resolution over IGP IPv4 shortcuts of IPv4 and IPv6 prefixes within an ISIS instance, of IPv6 prefixes within an OSPFv3 instance, and of IPv4 prefixes within an OSPFv2 instance.

```
A:Reno 194# configure router isis
           igp-shortcut
                 [no] shutdown
                 tunnel-next-hop
                      family {ipv4, ipv6}
                             resolution {any|disabled|filter|match-family-ip}
```

```
                              resolution-filter
                                    [no] rsvp
                                    exit
                               exit
                         exit
                   exit
```

```
A:Reno 194# configure router ospf
            igp-shortcut
                  [no] shutdown
                  tunnel-next-hop
                       family {ipv4}
                              resolution {any|disabled|filter|match-family-ip}
                              resolution-filter
                                    [no] rsvp
                                    exit
                               exit
                         exit
                   exit
```

```
A:Reno 194# configure router ospf3#
            igp-shortcut
                  [no] shutdown
                  tunnel-next-hop
                       family {ipv6}
                              resolution {any|disabled|filter}
                              resolution-filter
                                    [no] rsvp
                                    exit
                               exit
                         exit
                   exit
```

The new resolution node **igp-shortcut** is introduced to provide flexibility in the selection of the IP next hops or the tunnel types for each of the IPv4 and IPv6 prefix families.

When the IPv4 **family** option is enabled, the IS-IS or OSPF SPF includes the IPv4 IGP shortcuts in the IP reach calculation of IPv4 nodes and prefixes. RSVP-TE LSPs terminating on a node identified by its router ID can be used to reach IPv4 prefixes owned by this node or for which this node is the IPv4 next hop.

When the IPv6 **family** option is enabled, the IS-IS or OSPFv3 SPF includes the IPv4 IGP shortcuts in the IP reach calculation of IPv6 nodes and prefixes. RSVP-TE LSPs terminating on a node identified by its router ID can be used to reach IPv6 prefixes owned by this node or for which this node is the IPv6 next hop. The IPv6 option is supported in both ISIS MT=0 and MT=2.

The IS-IS or OSPFv3 IPv6 routes resolved to IPv4 IGP shortcuts are used to forward packets of IS-IS or OSPFv3 prefixes matching these routes but are also used to resolve the BGP next hop of BGP IPv6 prefixes, resolve the indirect next hop of static IPv6 routes, and forward CPM-originated IPv6 packets.

In the datapath, a packet for an IPv6 prefix contains a label stack that consists of the IPv6 Explicit-Null label value of 2 at the bottom of the label stack followed by the label of the IPv4 RSVP-TE LSP.

The following commands control the use of an RSVP-TE LSP in IGP shortcuts:

- **config**>**router**>**mpls**>**lsp# [no] igp-shortcut lfa-protect | lfa-only]**
- **config**>**router**>**mpls**>**lsp# igp-shortcut relative-metric** *offset*

An LSP can be excluded from being used as an IGP shortcut for forwarding IPv4 and IPv6 prefixes, or the LSP in the LFA SPF can be used to protect the primary IP next hop of an IPv4 or IPv6 prefix. For tunneling

LDP FECs over IGP shortcuts, the user must enable the **tunneling** option on the T-LDP sessions to the destinations of the RSVP-TE LSPs used as IGP shortcuts.

2.5.6.1.1 IGP shortcut binding construct

The SR OS **tunnel-next-hop** construct binds IP prefixes to IPv4 IGP shortcuts on a per-prefix family basis.

The following details the behavior of the construct:

- The construct supports the IPv4 and IPv6 families. It allows each family to resolve independently to either an IGP shortcut next hop using the unicast RTM or to the IP next hop using the multicast RTM.
- The **advertise-tunnel-link** (forwarding adjacency) takes priority over **igp-shortcut** if both CLI options are enabled. This is overall and not per family.
- The following commands are enabled based on the following relative priorities (from highest to lowest):
  - **advertise-tunnel-link** (IPv4 family with OSPFv2, IPv4, and IPv6 families with IS-IS MT=0 and IPv6 family in MT=2, no support in OSPFv3)
  - **igp-shortcut** (IPv4 family in OSPFv2, IPv6 family in OSPFv3, IPv4 and IPv6 families in IS-IS MT=0 and IPv6 family in MT=2)
  - **ldp-over-rsvp** (IPv4 FECs only)

  See Table 13: RSVP LSP role as outcome of LSP level and IGP level configuration options.
- No default behavior exists for IPv4 prefixes to automatically resolve to RSVP LSPs used as IGP shortcut by enabling the **igp-shortcut** context only. The IPv4 family must be enabled and the **resolution-filter** set to the value of **rsvp** which selects the RSVP-TE tunnel type.
- A [**no**] **shutdown** command under the **igp-shortcut** context enforces that the IGP shortcut context cannot be enabled unless at least one family is configured under the tunnel-next-hop node to a value other than **resolution disabled**, which is the default value for all families, and that a tunnel type is selected if the **resolution** is set to **filter**.
- To disable IGP shortcuts globally, shutdown the **igp-shortcut** context.
- When computing the backup next hop of an IPv4 or IPv6 prefix, LFA considers the IP links and tunnels of the selected tunnel type which are the result of the configuration of the **tunnel-next-hop** for the IPv4 or IPv6 prefix family.

The resolution outcome for each of the IPv4 and IPv6 prefix families is summarized in Table 14: IGP shortcut binding resolution outcome. The description and behavior of the SRv4 and SRv6 families are described in SR shortest path tunnel over RSVP-TE IGP shortcut feature configuration. See IPv4 IGP shortcuts using SR-TE LSP feature configuration for information about the description and behavior of the sr-te resolution option using SR-TE IGP shortcuts are described in .

Table 14: IGP shortcut binding resolution outcome

igp-shortcut CLI context	IP family (v4/v6) CLI config	SR family (v4/v6) CLI config	IPv4 ECMP NH SET computed	SRv4 ECMP NH SET computed	IPv6 ECMP NH SET computed	SRv6 ECMP NH SET computed
shutdown	—	—	IP (unicast RTM)	IP (mcast RTM)	IP (unicast RTM)	IP (mcast RTM)

igp-shortcut CLI context	IP family (v4/v6) CLI config	SR family (v4/v6) CLI config	IPv4 ECMP NH SET computed	SRv4 ECMP NH SET computed	IPv6 ECMP NH SET computed	SRv6 ECMP NH SET computed
no shutdown	resolution disabled	resolution disabled	IP (mcast RTM)	IP (mcast RTM)	IP (mcast RTM)	IP (mcast RTM)
		resolution match-family-ip	IP (mcast RTM)	IP (mcast RTM)	IP (mcast RTM)	IP (mcast RTM)
no shutdown	resolution-filter {rsvp}	resolution disabled	RSVP+IP	IP (mcast RTM)	RSVP+IP	IP (mcast RTM)
		resolution match-family-ip	RSVP+IP	RSVP+IP	RSVP+IP	RSVP+IP
no shutdown	resolution-filter {sr-te}	resolution disabled	SR-TE+IP	IP (mcast RTM)	SR-TE+IP	IP (mcast RTM)
		resolution match-family-ip	SR-TE+IP	IP (mcast RTM)	SR-TE+IP	IP (mcast RTM)
no shutdown	resolution {any}/ resolution-filter {rsvp,sr-te}	resolution disabled	RSVP+IP	IP (mcast RTM)	RSVP+IP	IP (mcast RTM)
			SR-TE+IP	IP (mcast RTM)	SR-TE+IP	IP (mcast RTM)
		resolution match-family-ip	RSVP+IP	RSVP+IP	RSVP+IP	RSVP+IP
			SR-TE+IP	IP (mcast RTM)	SR-TE+IP	IP (mcast RTM)

2.5.6.2 IPv4 IGP shortcuts using SR-TE LSP feature configuration

The configuration value of **sr-te** is added to the **resolution-filter** context of the **igp-shortcut** construct. When enabled, this value allows IGP to resolve IPv4 prefixes, IPv6 prefixes, and LDP IPv4 prefix FECs over SR-TE LSPs used as IGP shortcuts.

In addition, the value of **any** in the **resolution-filter** context allows the user to resolve IP prefixes and LDP FECs to either RSVP-TE or SR-TE LSPs used as IGP shortcuts.

```
A:Reno 194# configure router isis
           igp-shortcut
                 [no] shutdown
                 tunnel-next-hop
                      family {ipv4, ipv6}
                             resolution {any|disabled|filter|match-family-ip}
                             resolution-filter
                                   [no] rsvp
                                   [no] sr-te
```

```
                                    exit
                              exit
                        exit
                  exit
```

```
A:Reno 194# configure router ospf
           igp-shortcut
                 [no] shutdown
                 tunnel-next-hop
                       family {ipv4}
                              resolution {any|disabled|filter|match-family-ip}
                              resolution-filter
                                    [no] rsvp
                                    [no] sr-te
                                    exit
                              exit
                        exit
                  exit
```

```
A:Reno 194# configure router ospf3
           igp-shortcut
                 [no] shutdown
                 tunnel-next-hop
                       family {ipv6}
                              resolution {any|disabled|filter}
                              resolution-filter
                                    [no] rsvp
                                    [no] sr-te
                                    exit
                              exit
                        exit
                  exit
```

For tunneling LDP FECs over IGP shortcuts, the user must enable the **tunneling** option on the T-LDP sessions to the destinations of the SR-TE LSPs used as IGP shortcuts. See Family prefix resolution and tunnel selection rules for an explanation of the rules for the resolution of IPv4 prefixes, IPv6 prefixes, and LDP FECs, and for the selection of the tunnel types on a per family basis.

2.5.6.2.1 Family prefix resolution and tunnel selection rules

The IGP instance SPF routine performs the Dijkstra tree calculation on the topology with IP links only and saves the information in both the unicast and multicast routing tables. It then performs the IP reach calculation in the multicast routing table for each prefix family that disabled IGP shortcuts. Concurrently, it lays the tunnels on the tree and performs the IP reach calculation in the unicast routing table for each prefix family that enabled IGP shortcuts.

The following are the details of the resolution of prefix families in the unicast or multicast routing tables:

1. OSPF supports IPv4 prefixes by configuring **family ipv4**. IPv4 prefix resolution in the unicast routing table can mix IP and tunnel next hops with the preference given to tunnel next hops. A maximum of 64 ECMP tunnel and IP next hops can be programmed for an IPv4 prefix.
2. OSPFv3 supports IPv6 prefixes by configuring **family ipv6**. IPv6 prefix resolution in the unicast routing table can mix IP and tunnel next hops with the preference given to tunnel next hops. A maximum of 64 ECMP tunnel and IP next hops can be programmed for an IPv6 prefix.
3. IS-IS supports IPv4 prefixes in MT=0 by configuring **family ipv4** and **ipv6** prefixes in both MT=0 and MT=2 by enabling **family ipv6**. IPv4 and IPv6 prefix resolution in the unicast routing table can mix IP

and tunnel next hops with the preference given to tunnel next hops. A maximum of 64 ECMP tunnel and IP next hops can be programmed for an IPv4 or IPv6 prefix.

4. **family ipv4** also enables the resolution in the unicast routing table of LDP IPv4 prefix FEC in OSPF or IS-IS. When prefer-tunnel-in-tunnel is enabled (disabled) in LDP, an LDP FEC selects tunnel next hops (IP next hops) only and does not mix these next hop types when both are eligible in the unicast routing table.

   A maximum of 32 ECMP tunnels next hops can be programmed for an LDP FEC.

   LDP IPv6 prefix FECs are not supported over IPv4 IGP shortcuts when configuring **family ipv6**. Consequently, if the corresponding IPv6 prefix resolves to tunnel next hops only, the LDP IPv6 prefix FEC remains unresolved. For LDP IPv6 prefix FECs resolution (once family IPv6 is configured), the **config>router>ldp>targeted-session>resolve-v6-prefix-over-shortcut** command needs enabling.

5. In all cases, the IP reach calculation in the unicast routing table first follows the ECMP tunnel and IP next hop selection rules, described in ECMP considerations, when resolving a prefix over IGP shortcuts. After the set of ECMP tunnel and IP next hops have been selected, the preference of tunnel type is then applied based on the user setting of the resolution of the prefix family. If the user-enabled resolution of the prefix family to both RSVP-TE and SR-TE tunnel types, the TTM tunnel preference value is used to select one type for the prefix. That is, the RSVP-TE LSP type is preferred to a SR-TE LSP type on a per-prefix basis.

6. One or more SR-TE LSPs can be selected in the unicast routing table if **resolution** is set to **filter** and the **resolution-filter** is set to **sr-te**.

7. One or more SR-TE LSPs can also be selected in the unicast routing table if **resolution** is set to **any** and one or more SR-TE LSPs are available but no RSVP-TE LSPs are available for resolving the prefix by IGP.

8. An intra-area IP prefix of **family ipv4**, or **family ipv6**, or an LDP IPv4 prefix FEC always resolves to a single type of tunnel **rsvp-te** or **sr-te**. **rsvp-te** type is preferred if both types are allowed by the prefix family resolution and both types exist in the set of tunnel next hops of the prefix. The feature does not support mixing tunnel types per prefix.

9. An inter-area IP prefix of **family ipv4**, or **family ipv6**, or an LDP IPv4 prefix FECs always resolves to a single tunnel type and selects the tunnel next hops to the advertising ABR node from the most preferred tunnel type if the prefix family resolution allowed both types. If the prefix resolves to multiple ABR next hops, ABR nodes with the preferred tunnel type are selected. In other words, if RSVP-TE LSPs exist to at least one ABR node, ABR nodes that are the tail-end of only SR-TE LSPs are not used in the set of ECMP tunnel next hops for the inter-area prefix.

10. The feature does not support configuring a different tunnel type per prefix family in **resolution-filter**. The **no shutdown** command within the **igp-shortcut** context fails if the user configured **family ipv4** to resolve to **sr-te** and **family ipv6** to **rsvp-te** or the other way around. This is true for both inter-area and intra-area prefixes.

    The feature does, however, support selecting the best tunnel-type per prefix within each family as described in (5). For instance, **family ipv4** and **family ipv6** can both be configured in conjunction with **resolution any**. On a per prefix-basis, the best tunnel type is selected, therefore allowing both tunnel types to be deployed in the network.

11. The user can set **resolution** to **disabled** for each family independently, which disables IGP shortcuts for the corresponding prefix family in this IGP instance. IP Prefixes and LDP FECs of this family resolve over IP links in the multicast routing table.

2.5.6.2.2 Application support

The use of SR-TE IGP shortcuts is supported in the following applications:

1. **family ipv4** resolves IPv4 prefixes in RTM for the following:
   - IGP routes
   - indirect next hop of static routes
   - BGP next hop of BGP routes
   - LDP IPv4 prefix FEC
2. **family ipv6** resolves IPv6 prefixes in RTM for the following:
   - IGP routes
   - indirect next hop of static routes
   - BGP next hop of BGP routes
3. When an LDP IPv4 FEC prefix is resolved to one or more SR-TE LSPs, the following applications can resolve to LDP in TTM:
   - L2 service FECs
   - BGP next hop of VPN IPv4 and IPv6 prefixes
   - BGP next hop of EVPN routes
   - BGP next hop of IPv4 prefixes
   - BGP next hop of IPv6 prefixes (6PE)
   - IGP IPv4 routes (LDP shortcut feature)
   - indirect next hop of IPv4 static routes
4. When an LDP IPv4 FEC prefix is resolved to one or more SR-TE LSPs, next hops of BGP LU routes cannot resolve to LDP in TTM.

Note: SR OS supports a 3-level hierarchy in the datapath. Because SR-TE LSP is a hierarchical LSP already, this makes the BGP-over-LDP-over-SR-TE a 4-level hierarchy. Consequently, BGP keeps these BGP-LU routes unresolved.

2.5.6.2.3 LFA protection support

The following are the details of the Loop-free Alternate (LFA) protection support:

- Prefixes that use one or more SR-TE LSPs as their primary next hops are automatically protected by one of the LFA features, base LFA, remote LFA, or TI-LFA, when enabled on any of the SR-TE LSPs.
- If the user enables the **lfa-only** option for a specified SR-TE LSP, and the application prefix has a single IP primary next hop (no ECMP next hops), it can be protected by an LFA backup that uses an SR-TE LSP.

Note: The LFA SPF calculation cannot check whether the outgoing interface of the protecting SR-TE LSP is different from the primary next hop of the prefix. The prefix is still protected by either the ECMP next hops or the LFA backup next hop of the first segment of the protecting

SR-TE LSP. However, in the case where an RSVP-TE LSP is used with the **lfa-only** option, such an LSP is excluded from being used as an LFA backup next hop.

- Application prefixes that resolve in TTM to an LDP IPv4 prefix FEC, which itself is resolved to one or more SR-TE LSPs, are equally protected either by the SR-TE LSP FRR (1) or the LDP LFA backup using an SR-TE LSP (2).
- Assume **resolution** is set to **disabled** for one prefix family (for example, IPv6) while it is enabled to sr-te for the other (for example, IPv4). Also, assume a node is resolving an IPv6 and IPv4 prefix, both of which share the same downstream parent node in the Dijkstra tree. If the IPv4 prefix is protected by the LFA of one or more SR-TE LSP primary next hops (1), the feature supports computing an LFA IP backup next hop for the IPv6 prefix, which is resolved to a IP primary next hop. This behavior aligns with the behavior over RSVP-TE LSP used as IGP shortcut for IPv6 and IPv4 prefixes.
- Assume **resolution** is set to **disabled** for one prefix family (for example, IPv6) while it is enabled to sr-te for the other (for example, IPv4). Also, assume a node is resolving an IPv6 and IPv4 prefix, both of which share the same downstream parent node in the Dijkstra tree. If the IPv4 prefix resolves to a single primary IP next hop but is protected by the LFA backup next hop that uses an SR-TE LSP (2), the feature does not support computing an LFA IP backup next hop for IPv6 prefix, which then remains unprotected. This is a limitation of the feature that also exists with RSVP-TE LSP used as IGP shortcut for IPv6 and IPv4 prefixes.

  This behavior also applies if the configuration of the resolution command for IPv4 and IPv6 families are reversed.

  If the user enables the remote LFA or the TI-LFA feature and also enables the use of SR IPv6 or SR IPv6 tunnels as an LFA backup next hop by the LDP IPv6 or IPv4 FEC prefix (using the LDP **fast-reroute backup-sr-tunnel** option), the LDP FEC is protected if such a backup SR tunnel is found.

2.5.6.3 SR shortest path tunnel over RSVP-TE IGP shortcut feature configuration

Two prefix family values of **srv4** and **srv6** are added to the **igp-shortcut** construct.

When enabled, the **srv4** value allows IGP to resolve SR-ISIS IPv4 tunnels in MT=0 or SR-OSPF IPv4 tunnels over RSVP-TE LSPs used as IGP shortcuts.

When enabled, the **srv6** value allows IGP to resolve SR-ISIS IPv6 tunnels in MT=0 over RSVP-TE LSPs used as IGP shortcuts.

```
A:Reno 194# configure router isis
           igp-shortcut
                 [no] shutdown
                 tunnel-next-hop
                      family {srv4, srv6}
                             resolution {disabled | match-family-ip}
                             exit
                      exit
                 exit
```

```
A:Reno 194# configure router ospf
           igp-shortcut
                 [no] shutdown
                 tunnel-next-hop
                      family {srv4}
                             resolution {disabled | match-family-ip}
                             exit
                      exit
```

```
                exit
```

See Family prefix resolution and tunnel selection rules for applicable rules for the resolution of SR-ISIS IPv4 tunnels, SR-ISIS IPv6 tunnels, and SR-OSPF IPV4 tunnels, and the selection of tunnel types on a per-family basis.

2.5.6.3.1 Family prefix resolution and tunnel selection rules

The following are the details of the resolution of prefix families in the unicast and multicast routing tables:

- **family srv4** enables the resolution of SR-OSPF IPv4 tunnels and SR-ISIS IPv4 tunnels in MT=0 over RSVP-TE IPv4 IGP shortcuts. A maximum of 32 ECMP tunnel next hops can be programmed for an SR-OSPF or an SR-ISIS IPv4 tunnel.
- **family srv6** enables the resolution of SR-ISIS IPv6 tunnels in MT=0 over RSVP-TE IPv4 IGP shortcuts. A maximum of 32 ECMP tunnel next hops can be programmed for an SR-ISIS IPv6 tunnel.

  Note: Segment routing is not supported in IS-IS MT=2.

- One or more RSVP-TE LSPs can be selected if **resolution** is set to **match-family-ip** and the corresponding IPv4 or IPv6 prefix is resolved to RSVP-TE LSPs.
- An SR tunnel cannot resolve to SR-TE IGP shortcuts. If **resolution** is set to **match-family-ip** and the corresponding IPv4 or IPv6 prefix is resolved to SR-TE LSPs, the SR tunnel is resolved to IP next hops in the multicast routing table.
- For an SR tunnel corresponding to an inter-area prefix with best routes via multiple ABRs, setting **resolution** to **match-family-ip** means the SR tunnel can resolve to RSVP-TE LSPs to one or more ABR nodes. If, however, only SR-TE LSPs exist to any of the ABR nodes, IGP does not include this ABR in the selection of ECMP next hops for the tunnel. If there exists no RSVP-TE LSPs to all ABR nodes, the inter-area prefix is resolved to IP next hops in the multicast routing table.

  Note: While this feature is intended to tunnel SR-ISIS IPv4 and IPv6 tunnels and SR-OSPF IPv4 tunnels over RSVP-TE IPv4 IGP shortcuts, an SR-TE LSP that has its first segment (ingress LER role) or its next segment (LSR role) correspond to one of these SR-ISIS or SR-OSPF tunnels is also tunneled over RSVP-TE LSP.

- **resolution disabled** is the default value for the **srv4** and **srv6** families and means that SR-ISIS and SR-OSPF tunnels are resolved to IP links in the multicast routing table.

2.5.6.3.2 Application support

The following describes how SR-ISIS IPv4 or IPv6 or a SR-OSPF IPv4 tunnels are resolved.

1. When an SR-ISIS IPv4 or an SR-OSPF IPv4 tunnel is resolved to one or more RSVP-TE LSPs, the following applications can resolve to the SR-ISIS or SR-OSPF tunnel in TTM:
   - L2 service FECs
   - BGP next hop of VPN IPv4/IPv6 prefixes
   - BGP next hop of EVPN routes
   - BGP next hop of IPv4 prefixes

- BGP next hop of IPv6 prefixes (6PE)
- next hop of a BGP LU IPv4 route
- indirect next hop of IPv4 static routes

2. When an SR-ISIS IPv6 tunnel is resolved to one or more RSVP-TE LSPs, the following applications can resolve to the SR-ISIS tunnel in TTM:
   - L2 service FECs
   - next hop of VPN-IPv4 and VPN-IPv6 over a spoke-SDP interface using the SR tunnel
   - indirect next hop of IPv6 static routes
3. When an SR-ISIS IPv4 or an SR-OSPF IPv4 tunnel is resolved to one or more RSVP-TE LSPs, next hops of BGP LU routes cannot resolve in TTM to a SR-TE LSP that is using an SR-ISIS or SR-OSPF segment.

Note: Next hops of BGP LU routes cannot resolve to LDP in TTM to a SR-TE LSP that is using an SR-ISIS or SR-OSPF segment because SR OS supports a 3-level hierarchy in the datapath and, because SR-TE LSP is a hierarchical LSP already, this makes the BGP-over-SRTE-over-RSVPTE a 4-level hierarchy. BGP keeps these BGP-LU routes unresolved.

2.5.6.3.3 LFA protection support

The following are the details of the LFA protection support:

1. Prefixes that resolve to one or more RSVP-TE LSPs as their primary next hops are automatically protected by RSVP-TE LSP FRR if enabled.
2. If the user enables the **lfa-only** option for a specified RSVP-TE LSP, and the SR-ISIS or SR-OSPF tunnel has a single IP primary next hop (no ECMP next hops), it can be protected by a FRR backup that uses a RSVP-TE LSP.
3. Applications that resolve in TTM to an SR-ISIS or SR-OSPF tunnel, which itself is resolved to one or more RSVP-TE LSPs, are equally be protected either by the RSVP-TE LSP FRR (1) or the SR LFA using a RSVP-TE LSP (2).
4. Assume **family ipv4** resolves to RSVP-TE in the unicast routing table while **family srv4** resolves to IP links in the multicast routing table. If the IP prefix of an SR tunnel is resolved to a RSVP-TE LSP primary next hop, and is protected by RSVP-TE LSP FRR (1), this feature supports computing an LFA next hop for the SR IPv4 tunnel of the same prefix using IP next hops.
5. Assume **family ipv4** or **family ipv6** resolves to RSVP-TE in the unicast routing table while **family srv4** or **family srv6** resolves to IP links in the multicast routing table. If the IP prefix of an SR IPv4 or SR IPv6 tunnel is resolved to a single IP primary next hop and is protected by an SR LFA backup using an RSVP-TE LSP FRR (2), the feature does not support computing a LFA next hop for the SR IPv4 or SR IPv6 tunnel and remains unprotected.

   If, however, the user enabled the remote LFA or the TI-LFA feature, an SR backup next hop may be found for the SR IPv4 or SR IPv6 tunnel, which then becomes protected.

2.5.6.4 Using LSP relative metric with IGP shortcut

By default, the absolute metric of the LSP is used to compute the contribution of an IGP shortcut to the total cost of a prefix or a node after the SPF is complete. The absolute metric is the operational metric of the LSP populated by MPLS in the TTM. This corresponds to the cumulative IGP-metric of the LSP path returned by CSPF or the static administrative metric value of the LSP if the user configured one using the **config>router>mpls>lsp>metric** command. Note that MPLS populates the TTM with the maximum metric value of 16777215 in the case of a CSPF LSP using the TE-metric and a non-CSPF LSP with a loose or strict hop in the path. A non-CSPF LSP with an empty hop in the path definition returns the IGP cost for the destination of the LSP.

The user enables the use of the relative metric for an IGP shortcut with the following CLI command:

config>router>mpls>lsp>igp-shortcut relative-metric [*offset*]

IGP applies the shortest IGP cost between the endpoints of the LSP plus the value of the offset, instead of the LSP operational metric, when computing the cost of a prefix that is resolved to the LSP.

The offset value is optional and it defaults to zero. An offset value of zero is used when the **relative-metric** option is enabled without specifying the offset parameter value.

The minimum net cost for a prefix is capped to the value of one (1) after applying the offset:

```
Prefix cost = max(1, IGP cost + relative metric offset)
```

Note that the TTM continues to show the LSP operational metric as provided by MPLS, which allows applications such as LDP-over-RSVP (when IGP shortcut is disabled) and BGP and static route shortcuts to continue to use the LSP operational metric.

The **relative-metric** option, **lfa-protect**, and the **lfa-only** options are mutually exclusive. That is, an LSP with the **relative-metric** option enabled cannot be included in the LFA SPF and the other way around when the **igp-shortcut** option is enabled in the IGP.

Finally, it should be noted that the **relative-metric** option is ignored when forwarding adjacency is enabled in IS-IS or OSPF by configuring the **advertise-tunnel-link** option. In this case, IGP advertises the LSP as a point-to-point unnumbered link along with the LSP operational metric capped to the maximum link metric allowed in that IGP.

2.5.6.5 ECMP considerations

When ECMP is enabled on the system and multiple equal-cost paths exist for a prefix, the following selection criteria are used to select the set of next hops to program in the datapath:

- for a destination = tunnel-endpoint (including external prefixes with tunnel-endpoint as the next hop), select tunnel with lowest tunnel-index (ip next hop is never used in this case).
- for a destination != tunnel-endpoint:
  - exclude LSPs with metric higher than underlying IGP cost between the endpoint of the LSP
  - prefer tunnel next hop over ip next hop
  - within tunnel next hops:
    - select lowest endpoint to destination cost
    - if same endpoint to destination cost, select lowest endpoint node router-id
    - if same router-id, select lowest tunnel-index

  - within ip next hops:
    - select lowest downstream router-id
    - if same downstream router-id, select lowest interface-index
- Although no ECMP is performed across both the IP and tunnel next hops, the tunnel endpoint lies in one of the shortest IGP paths for that prefix. As a result, the tunnel next hop is always selected as long as the prefix cost using the tunnel is equal or lower than the IGP cost.

The ingress IOM sprays the packets for a prefix over the set of tunnel next hops and IP next hops based on the hashing routine currently supported for IPv4 packets.

2.5.6.6 Handling of control packets

All control plane packets that require an RTM lookup and whose destination is reachable over the RSVP shortcut are forwarded over the shortcut. This is because RTM keeps a single route entry for each prefix unless there is ECMP over different outgoing interfaces.

Interface bound control packets are not impacted by the RSVP shortcut because RSVP LSPs with a destination address different than the router-id are not included by IGP in its SPF calculation.

2.5.6.7 Forwarding adjacency

The forwarding adjacency feature can be enabled independently from the IGP shortcut feature in CLI. Use the following commands to enable forwarding adjacency in IS-IS or OSPF:

- **config>router>isis>advertise-tunnel-link**
- **config>router>ospf>advertise-tunnel-link**

If both **igp-shortcut** and **advertise-tunnel-link** options are enabled for a specific IGP instance, the **advertise-tunnel-link** wins. With this feature, ISIS or OSPF advertises an RSVP LSP as a link so that other routers in the network can include it in their SPF computations. An SR-TE LSP is not supported with forwarding adjacency. The RSVP LSP is advertised as an unnumbered point-to-point link and the link LSP/LSA has no TE opaque sub-TLVs, as described in RFC 3906 *Calculating Interior Gateway Protocol (IGP) Routes Over Traffic Engineering Tunnels*.

When the forwarding adjacency feature is enabled, each node advertises a P2P unnumbered link for each best metric tunnel to the router ID of any endpoint node. The node does not include the tunnels as IGP shortcuts in SPF computation directly. Instead, when the LSA or LSP advertising the corresponding P2P unnumbered link is installed in the local routing database, the node performs an SPF and uses it like any other link LSA or LSP. The link bidirectional check requires that a link, regular or tunnel link, exists in the reverse direction for the tunnel to be used in SPF.

The forwarding adjacency feature supports forwarding of both IPv4 and IPv6 prefixes. Specifically, it supports family IPv4 in OSPFv2, family IPv6 in OSPFv3, families IPv4 and IPv6 in ISIS MT=0, and family IPv6 in ISIS MT=2. Note that the **igp-shortcut** option under the LSP name governs the use of the LSP with both the **igp-shortcut** and the **advertise-tunnel-link** options in IGP. Table 15: Impact of LSP level configuration on IGP shortcut and forwarding adjacency features describes the interactions of the forwarding adjacency feature.

Table 15: Impact of LSP level configuration on IGP shortcut and forwarding adjacency features

LSP level configuration	Actions with IGP shortcut feature	Actions with forwarding adjacency feature
igp-shortcut	Tunnel is used in main SPF, but not in LFA SPF	Tunnel is advertised as a P2P link if it has the best LSP metric, is used in the main SPF if advertised, but is not used in LFA SPF
igp-shortcut lfa-protect	Tunnel is used in main SPF and in LFA SPF	Tunnel is advertised as a P2P link if it has the best LSP metric, is used in the main SPF if advertised, and is used in LFA SPF regardless of whether it is advertised or not
igp-shortcut lfa-only	Tunnel is not used in main SPF, but used in LFA SPF	Tunnel is not advertised as a P2P link, if not used in main SPF, but is used in LFA SPF

2.5.6.8 SR shortest path tunnel over RSVP-TE forwarding adjacency

This feature is enabled by configuring both the segment routing and forwarding adjacency features within an IS-IS instance in a multitopology MT=0.

Both IPv4 and IPv6 SR-ISIS tunnels can be resolved and further tunneled over one or more RSVP-TE LSPs used as forwarding adjacencies.

This feature uses the following procedures:

- The forwarding adjacency feature only advertises into IS-IS RSVP-TE LSPs. SR-TE LSPs are not supported.
- An SR-ISIS tunnel (node SID) can have up to 32 next hops, some of which can resolve to a forwarding adjacency and some to a direct IP link. When the router **ecmp** value is configured lower than the number of next hops for the SR-ISIS tunnel, the subset of next hops selected prefers a forwarding adjacency over an IP link.
- In SR OS, ECMP and LFA are mutually exclusive on a per-prefix basis. This is not specific to SR-ISIS but also applies to IP FRR, LDP FRR, and SR-ISIS FRR. If an SR-ISIS tunnel has one or more next hops that resolve to forwarding adjacencies, each next hop is protected by the FRR mechanism of the RSVP-TE LSP through which it is tunneled. In this case, LFA backup is not programmed by IS-IS.
- If an SR-ISIS tunnel has a single primary next hop that resolves to a direct link (not to a forwarding adjacency), base LFA may protect it if a loop-free alternate path exists. The LFA path may or may not use a forwarding adjacency.
- IS-IS does not compute a remote LFA or a TI-LFA backup for an SR-ISIS tunnel when forwarding adjacency is enabled in the IS-IS instance, even if these two types of LFAs are enabled in the configuration of that same IS-IS instance.

2.5.6.9 LDP forwarding over IGP shortcut

The configuration in IGP shortcut feature configuration enables IGP shortcuts for resolving IGP routes, indirect next hop of static routes, and BGP next hop of BGP routes. The user can enable LDP FECs over IGP shortcuts by further configuring T-LDP sessions, with the **tunneling** option, to the destination of the

RSVP LSP. In this case, LDP FEC is tunneled over the RSVP LSP, effectively implementing LDP-over-RSVP without having to enable the **ldp-over-rsvp** option in OSPF or IS-IS. The **ldp-over-rsvp** and **igp-shortcut** options are mutually exclusive under OSPF or IS-IS.

Similarly, LDP FECs can be tunneled over SR-TE LSPs as detailed in IPv4 IGP shortcuts using SR-TE LSP feature configuration.

2.5.6.10 LDP forwarding over static route shortcut tunnels

Similar to LDP forwarding over IGP shortcut tunnels, the user can enable the resolution of LDP FECs over static route shortcuts by configuring T-LDP sessions and a static route that provides tunneled next hops corresponding to RSVP LSPs. In this case, indirect tunneled next hops in a static route are preferred over IP indirect next hops. For more information, see the *7450 ESS, 7750 SR, 7950 XRS, and VSR Router Configuration Guide*.

2.5.6.11 Handling of multicast packets

This feature supports multicast Reverse-Path Check (RPF) in the presence of IGP shortcuts. When the multicast source for a packet is reachable via an IGP shortcut, the RPF check fails because PIM requires a bidirectional path to the source but IGP shortcuts are unidirectional.

The IGP shortcut feature provides IGP with the capability to populate the multicast RTM with the prefix IP next hop when both the **igp-shortcut** option and the **multicast-import** option are enabled in IGP.

This change is made possible with the enhancement introduced by which SPF keeps track of both the direct first hop and the tunneled first hop of a node that is added to the Dijkstra tree.

Note that IGP does not pass LFA next-hop information to the mcast RTM in this case. Only ECMP next-hops are passed. As a consequence, features such as PIM Multicast-Only FRR (MoFRR) only work with ECMP next-hops when IGP shortcuts are enabled.

Finally, note that the concurrent enabling of the **advertise-tunnel-link** option and the **multicast-import** option results a multicast RTM that is a copy of the unicast RTM and is populated with mix of IP and tunnel NHs. RPF succeeds for a prefix resolved to a IP NH, but fails for a prefix resolved to a tunnel NH. Table 16: Impact of IGP shortcut and forwarding adjacency on unicast and multicast RTM summarizes the interaction of the **igp-shortcut** and **advertise-tunnel-link** options with unicast and multicast RTMs.

Table 16: Impact of IGP shortcut and forwarding adjacency on unicast and multicast RTM

		Unicast RTM (primary SPF)	Multicast RTM (primary SPF)	Unicast RTM (LFA SPF)	Multicast RTM (LFA SPF)
OSPF	igp-shortcut	✓	✓[2]	✓	X[3]

[2] Multicast RTM is different from unicast RTM as it is populated with IP NHs only, including ECMP IP NHs. RPF check can be performed for all prefixes.

[3] LFA NH is not computed for the IP primary next-hop of a prefix passed to multicast RTM even if the same IP primary next-hop ends up being installed in the unicast RTM. The LFA next-hop, however, is computed and installed in the unicast RTM for a primary IP next-hop of a prefix.

		Unicast RTM (primary SPF)	Multicast RTM (primary SPF)	Unicast RTM (LFA SPF)	Multicast RTM (LFA SPF)
	advertise-tunnel-link	✓	✓[4]	✓	✓[5]
IS-IS	igp-shortcut	✓	✓[2]	✓	X[3]
	advertise-tunnel-link	✓	✓[4]	✓	✓[5]

2.5.6.12 MPLS entropy label on shortcut tunnels

The router supports the MPLS entropy label (RFC 6790) on RSVP-TE LSPs used for IGP and BGP shortcuts. LSR nodes in a network can load-balance labeled packets in a more granular way than by hashing on the standard label stack. See MPLS entropy label and hash label for more information.

To configure insertion of the entropy label on IGP or BGP shortcuts, use the **entropy-label** command under the **configure>router** context.

2.5.7 Disabling TTL propagation in an LSP shortcut

This feature provides the option for disabling TTL propagation from a transit or a locally generated IP packet header into the LSP label stack when an RSVP LSP is used as a shortcut for BGP next-hop resolution, a static-route-entry next-hop resolution, or for an IGP route resolution.

A transit packet is a packet received from an IP interface and forwarded over the LSP shortcut at ingress LER.

A locally-generated IP packet is any control plane packet generated from the CPM and forwarded over the LSP shortcut at ingress LER.

TTL handling can be configured for all RSVP LSP shortcuts originating on an ingress LER using the following global commands:

config>router>mpls>[no] shortcut-transit-ttl-propagate config>router>mpls>[no] shortcut-local-ttl-propagate

These commands apply to all RSVP LSPs which are used to resolve static routes, BGP routes, and IGP routes.

When the **no** form of the above command is enabled for local packets, TTL propagation is disabled on all locally generated IP packets, including ICMP Ping, trace route, and OAM packets that are destined for a route that is resolved to the LSP shortcut. In this case, a TTL of 255 is programmed onto the pushed label stack. This is referred to as pipe mode.

Similarly, when the **no** form is enabled for transit packets, TTL propagation is disabled on all IP packets received on any IES interface and destined for a route that is resolved to the LSP shortcut. In this case, a TTL of 255 is programmed onto the pushed label stack.

---

4 Multicast RTM is a copy of the unicast RTM and, so, is populated with mix of IP and tunnel NHs. RPF succeeds for a prefix resolved to a IP NH but fails for a prefix resolved to a tunnel NH.

5 Multicast RTM is a copy of the unicast RTM and, so, is populated with mix of IP and tunnel LFA NHs. RPF succeeds for a prefix resolved to a primary or LFA IP NH but fails for a prefix resolved to a primary or LFA tunnel NH.

2.5.8 RSVP-TE LSP signaling using LSP template

An LSP template can be used for signaling RSVP-TE LSP to far-end PE node that is detected based on auto-discovery method by a client application. RSVP-TE P2MP LSP signaling based on LSP template is supported for Multicast VPN application on SR OS platform. LSP template avoids an explicit LSP or LSP S2L configuration for a node that is dynamically added as a receiver.

An LSP template has the option to configure TE parameters that apply to LSP that is set up using the template. TE options that are currently supported are:

- adaptive
- admin-group
- bandwidth
- CSPF calculation
- fast-reroute
- hop-limit
- record-label
- retry-timer

2.5.9 Shared Risk Link Groups

Shared Risk Link Groups (SRLGs) is a feature that allows the user to establish a backup secondary LSP path or a FRR LSP path which is disjoint from the path of the primary LSP. Links that are members of the same SRLG represent resources sharing the same risk, for example, fiber links sharing the same conduit or multiple wavelengths sharing the same fiber.

When SRLGs are applied to MPLS interfaces, Constraint-based Shortest Path First (CSPF) at an LER excludes the SRLGs of interfaces used by the LSP primary path when computing the path of the secondary path. CSPF at an LER or LSR also excludes the SRLGs of the outgoing interface of the primary LSP path in the computation of the path of the Fast Reroute (FRR) backup LSP. This provides path disjointedness between the primary path and the secondary path or FRR backup path of an LSP.

When the SRLG option is enabled on a secondary path, CSPF includes the SRLG constraint in the computation of the secondary LSP path. CSPF would return the list of SRLG groups along with the ERO during primary path CSPF computation. At a subsequent establishment of a secondary path with the SRLG constraint, the MPLS task queries again CSPF providing the list of SRLG group numbers to be avoided. If the primary path was not successfully computed, MPLS assumes an empty SRLG list for the primary. CSPF prunes all links with interfaces which belong to the same SRLGs as the interfaces included in the ERO of the primary path. If CSPF finds a path, the secondary is setup. If not, MPLS keeps retrying the requests to CSPF.

When the SRLG option is enabled on FRR, CSPF includes the SRLG constraint in the computation of a FRR detour or bypass for protecting the primary LSP path. CSPF prunes all links with interfaces which belong to the same SRLG as the interface, which is being protected, that is, the outgoing interface at the PLR the primary path is using. If one or more paths are found, the MPLS task selects one based on best cost and signals the bypass/detour. If not and the user included the strict option, the bypass/detour is not setup and the MPLS task keeps retrying the request to CSPF. Otherwise, if a path exists which meets the other TE constraints, other than the SRLG one, the bypass/detour is setup.

A bypass or a detour LSP is not intended to be SRLG disjoint from the entire primary path. This is because only the SRLGs of the outgoing interface at the PLR the primary path is using are avoided.

When SRLGs are applied to IES, VPRN, or network IP interfaces, they are evaluated in the route next-hop selection by adding the SRLG option in a route next-hop policy template applied to an interface or a set of prefixes. For instance, the user can enable the SRLG constraint to select an LFA next-hop for a prefix that avoids all interfaces that share the outcome of the primary next hop.

During provisioning, the system rejects the creation of an SRLG if it reuses the same name with a different group value from an existing group, or if it reuses the same group value with a different name.

Only the SRLGs bound to an MPLS interface are advertised area-wide in TE link TLVs and sub-TLVs when the traffic-engineering option is enabled in IS-IS or OSPF. IES and VPRN interfaces do not have their attributes advertised in TE TLVs.

A user can specify a penalty weight associated with an SRLG. This controls the likelihood of bypass or detour LSP using paths with links that share SRLG values with a primary path. The higher the penalty weight, the less preferred it is to use the link with the SRLG.

Use the following command to specify a penalty weight associated with an SRLG:

- **MD-CLI**

```
configure routing-options if-attribute srlg-group penalty-weight
```

- **classic CLI**

```
configure router if-attribute srlg-group value penalty-weight
```

2.5.9.1 Enabling disjoint backup paths

A typical application of the SRLG feature is to provide for an automatic placement of secondary backup LSPs or FRR bypass/detour LSPs that minimizes the probability of fate sharing with the path of the primary LSP (Figure 30: Shared Risk Link Groups).

The following details the steps necessary to create shared risk link groups:

- For primary/standby SRLG disjoint configuration:
  1. Create an SRLG-group, similar to admin groups.
  2. Link the SRLG-group to MPLS interfaces.
  3. Configure primary and secondary LSP paths and enable SRLG on the secondary LSP path. Note that the SRLG secondary LSP paths always perform a strict CSPF query. The **srlg-frr** command is irrelevant in this case.
- For FRR detours/bypass SRLG disjoint configuration:
  1. Create an SRLG group, similar to admin groups.
  2. Link the SRLG group to MPLS interfaces.
  3. Enable the **srlg-frr** (strict/non-strict) option, which is a system-wide parameter, and it force every LSP path CSPF calculation, to take the configured SRLG memberships (and propagated through the IGP opaque-te-database) into account.
  4. Configure primary FRR (one-to-one/facility) LSP paths. Consider that each PLR creates a detour/bypass that only avoids the SRLG memberships configured on the primary LSP path egress interface. In a one-to-one case, detour-detour merging is out of the control of the PLR. As such, the

latter does not ensure that its detour is prohibited to merge with a colliding one. For facility bypass, with the presence of several bypass type to bind to, priority is given in the following order:

a. manual bypass disjoint

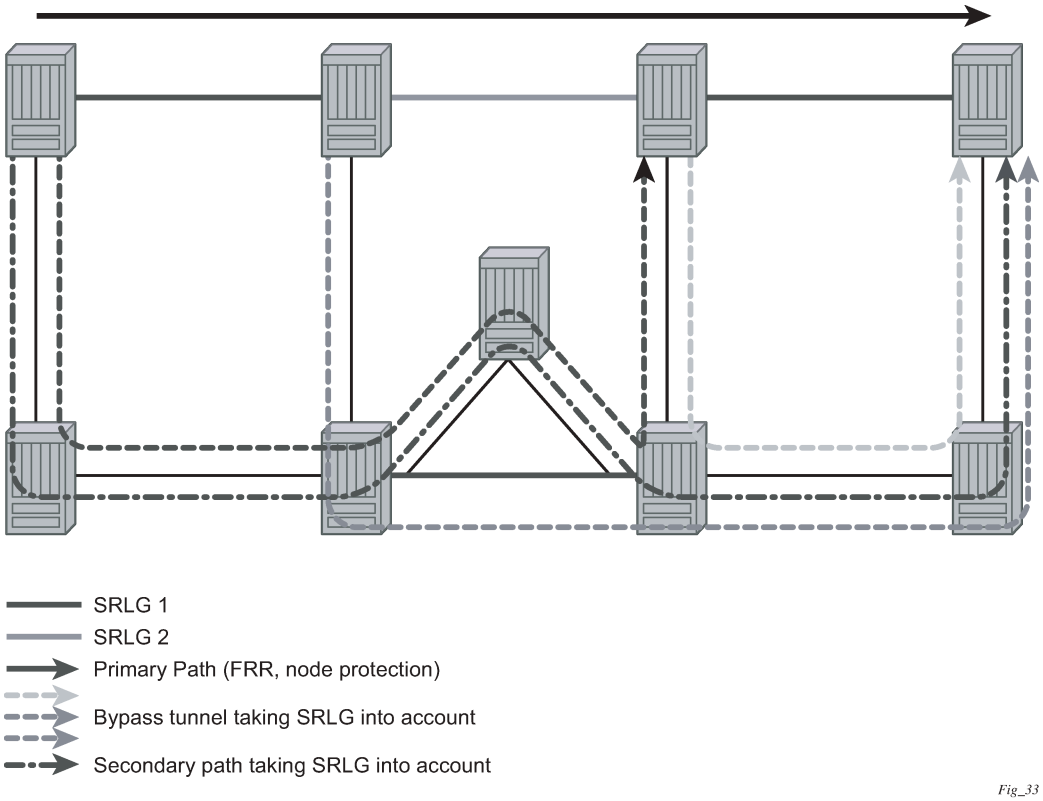
b. manual bypass non-disjoint (eligible only if srlg-frr is non-strict)

c. dynamic disjoint

d. dynamic non-disjoint (eligible only if srlg-frr is non-strict)

Note: Non-CSPF manual bypass is not considered.

Figure 30: Shared Risk Link Groups



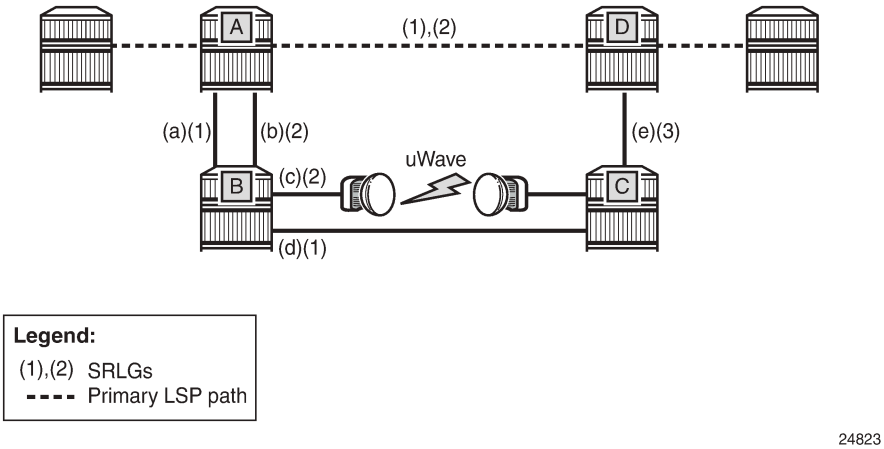
This feature is supported on OSPF and IS-IS interfaces on which RSVP is enabled.

2.5.9.2 SRLG penalty weights for detour and bypass LSPs

The likelihood of paths with links sharing SRLG values with a primary path being used by a bypass or detour LSP can be configured if a penalty weight is specified for the link. The higher the penalty weight, the less desirable it is to use the link with a specific SRLG.

Figure 31: SRLG penalty weight operation illustrates the operation of SRLG penalty weights.

Figure 31: SRLG penalty weight operation



The primary LSP path includes a link between A and D with SRLG (1) and (2). The bypass around this link through nodes B and C includes links (a) and (d), which are members of SRLG (1), and links (b) and (c), which are members of SRLG 2. If the link metrics are equal, then this gives four ECMP paths from A to D via B and C:

- (a), (d), (e)
- (a), (c), (e)
- (b), (c), (e)
- (b), (d), (e)

Two of these paths include undesirable (from a reliability perspective) link (c). SRLG penalty weights or costs can be used to provide a tiebreaker between these paths so that the path including (c) is less likely to be chosen. For example, if the penalty associated with SRLG (1) is 5, and the penalty associated with SRLG (2) is 10, and the penalty associated with SRLG (3) is 1, then the cumulative penalty of each of the paths above is calculated by summing the penalty weights for each SRLG that a path has in common with the primary path:

- (a), (d), (e) = 10
- (a), (c), (e) = 15
- (b), (c), (e) = 20
- (b), (d), (e) = 15

Therefore path (a), (d), (e) is chosen because it has the lowest cumulative penalty.

Penalties are applied by summing the values for SRLGs in common with the protected part of the primary path.

A user can define a penalty weight value associate with an SRLG group using the **penalty-weight** parameter of the **srlg-group** command under the **configure**>**router-if-attribute** context. If an SRLG penalty weight is configured, then CSPF includes the SRLG penalty weight in the computation of an FRR detour or bypass for protecting the primary LSP path at a PLR node. Links with a higher SRLG penalty should be more likely to be pruned than links with a lower SRLG penalty.

Note that the configured penalty weight is not advertised in the IGP.

An SRLG penalty weight is applicable whenever an SRLG group is applied to an interface, including in the static SRLG database. However, penalty weights are used in bypass and detour path computation only when the srlg-frr (loose) flag is enabled.

2.5.9.3 Static configurations of SRLG memberships

This feature provides operations with the ability to manually enter the link members of SRLG groups for the entire network at any SR OS which needs to signal LSP paths (for example, a head-end node).

The operator may explicitly enable the use by CSPF of the SRLG database. In that case, CSPF does not query the TE database for IGP advertised interface SRLG information.

Note, however, that the SRLG secondary path computation and FRR bypass/detour path computation remains unchanged.

There are deployments where the SR OS interoperates with routers that do not implement the SRLG membership advertisement via IGP SRLG TLV or sub-TLV.

In these situations, the user is provided with the ability to enter manually the link members of SRLG groups for the entire network at any SR OS which needs to signal LSP paths, for example, a head-end node.

The user enters the SRLG membership information for any link in the network by using the **interface** *ip-int-name* **srlg-group** *group-name* command in the **config>router>mpls> srlg-database>router-id** context. An interface can be associated with up to 5 SRLG groups for each execution of this command. The user can associate an interface with up to 64 SRLG groups by executing the command multiple times. The user must also use this command to enter the local interface SRLG membership into the user SRLG database. The user deletes a specific interface entry in this database by executing the **no** form of this command.

The *group-name* must have been previously defined in the **srlg-group** *group-name* **value** *group-value* command in the **config**>**router**>**if-attribute**. The maximum number of distinct SRLG groups the user can configure on the system is 1024.

The parameter value for *router-id* must correspond to the router ID configured under the base router instance, the base OSPF instance or the base IS-IS instance of a specific node. Note however that a single user SRLG database is maintained per node regardless if the listed interfaces participate in static routing, OSPF, IS-IS, or both routing protocols. The user can temporarily disable the use by CSPF of all interface membership information of a specific router ID by executing the **shutdown** command in the **config>router>mpls> srlg-database> router-id** context. In this case, CSPF assumes these interfaces have no SRLG membership association. The operator can delete all interface entries of a specific router ID entry in this database by executing the **no router-id** *router-address* command in the **config>router>mpls> srlg-database** context.

CSPF does not use entered SRLG membership if an interface is not listed as part of a router ID in the TE database. If an interface was not entered into the user SRLG database, it is assumed that it does not have any SRLG membership. CSPF does not query the TE database for IGP advertised interface SRLG information.

The operator enables the use by CSPF of the user SRLG database by entering the user-srlg-db enable command in the **config>router>mpls** context. When the MPLS module makes a request to CSPF for the computation of an SRLG secondary path, CSPF queries the local SRLG and computes a path after pruning links which are members of the SRLG IDs of the associated primary path. Similarly, when MPLS makes a request to CSPF for a FRR bypass or detour path to associate with the primary path, CSPF queries the user SRLG database and computes a path after pruning links which are members of the SRLG IDs of the PLR outgoing interface.

The operator can disable the use of the user SRLG database by entering the user-srlg-db disable in command in the **config>router>mpls** context. CSPF then resumes queries into the TE database for SRLG membership information. However, the user SRLG database is maintained

The operator can delete the entire SRLG database by entering the **no srlg-database** command in the **config>router>mpls** context. In this case, CSPF assumes all interfaces have no SRLG membership association if the user has not disabled the use of this database.

2.5.10 TE graceful shutdown

Graceful shutdown provides a method to bulk re-route transit LSPs away from the node during software upgrade of a node. A solution is described in RFC 5817, *Graceful Shutdown in MPLS and Generalized MPLS Traffic Engineering Networks*. This is achieved in this RFC by using a PathErr message with a specific error code Local Maintenance on TE link required flag. When a LER gets this message, it performs a make-before-break on the LSP path to move the LSP away from the links/nodes which IP addresses were indicated in the PathErr message.

Graceful shutdown can flag the affected link/node resources in the TE database so other routers signal LSPs using the affected resources only as a last resort. This is achieved by flooding an IGP TE LSA/ LSP containing link TLV for the links under graceful shutdown with the TE metric set to 0xffffffff and 0 as unreserved bandwidth.

2.5.11 Soft preemption of DiffServ RSVP LSP

A DiffServ LSP can preempt another LSP of the same or of a different CT if its setup priority is strictly higher (numerically lower) than the holding priority of that other LSP.

2.5.12 Least-fill bandwidth rule in CSPF ECMP selection

When multiples equal-cost paths satisfy the constraints of a specific RSVP LSP path, CSPF in the router head-end node selects a path so that LSP bandwidth is balanced across the network links. In releases before R7.0, CSPF used a random number generator to select the path and returned it to MPLS. In the course of time, this method actually balances the number of LSP paths over the links in the network; it does not necessarily balance the bandwidth across those links.

The least-fill path selection algorithm identifies the single link in each of the equal cost paths which has the least available bandwidth in proportion to its maximum reserved bandwidth. It then selects the path which has the largest value of this figure. The net effect of this algorithm is that LSP paths are spread over the network links over time such that percentage link utilization is balanced. When the least-fill option is enabled on an LSP, during a manual reset CSPF applies this method to all path calculations of the LSP, also at the time of the initial configuration.

2.5.13 Inter-area TE LSP (ERO expansion method)

Inter-area contiguous LSP scheme provides end-to-end TE path. Each transit node in an area can set up a TE path LSP based on TE information available within its local area.

A PE node initiating an inter-area contiguous TE LSP does partial CSPF calculation to include its local area border router as a loose node.

Area border router on receiving a PATH message with loose hop ERO does a partial CSPF calculation to the next domain border router as loose hop or CSPF to reach the final destination.

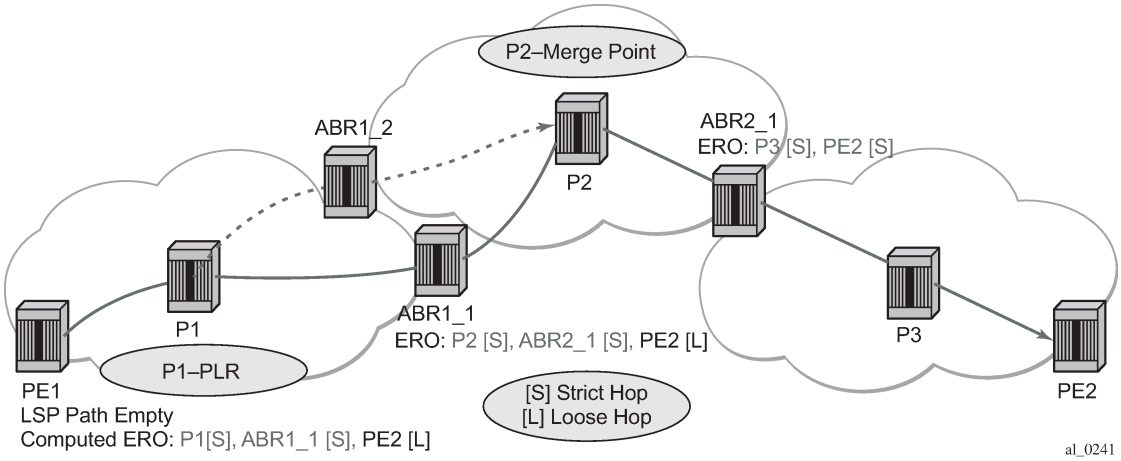
2.5.13.1 Area border node FRR protection for inter-area LSP

This feature enhances the prior implementation of an inter-area RSVP P2P LSP by making the ABR selection automatic at the ingress LER. The user does not need to include the ABR as a loose-hop in the LSP path definition.

CSPF adds the capability to compute all segments of a multisegment intra-area or inter-area LSP path in one operation.

Figure 32: Automatic ABR node selection for inter-area LSP illustrates the role of each node in the signaling of an inter-area LSP with automatic ABR node selection.

Figure 32: Automatic ABR node selection for inter-area LSP



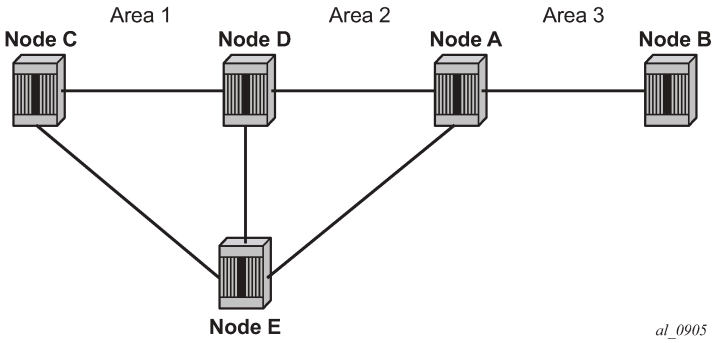
CSPF for an inter-area LSP operates as follows:

- CSPF in the Ingress LER node determines that an LSP is inter-area by doing a route lookup with the destination address of a P2P LSP (that is the address in the to field of the LSP configuration). If there is no intra-area route to the destination address, the LSP is considered as inter-area.
- When the path of the LSP is empty, CSPF computes a single-segment intra-area path to an ABR node that advertised a prefix matching with the destination address of the LSP.
- When the path of the LSP contains one or more hops, CSPF computes a multisegment intra-area path including the hops that are in the area of the Ingress LER node.
- When all hops are in the area of the ingress LER node, the calculated path ends on an ABR node that advertised a prefix matching with the destination address of the LSP.
- When there are one or more hops that are not in the area of the ingress LER node, the calculated path ends on an ABR node that advertised a prefix matching with the first hop-address that is not in the area of the ingress LER node.
- Note the following special case of a multisegment inter-area LSP. If CSPF hits a hop that can be reached via an intra-area path but that resides on an ABR, CSPF only calculates a path up to that ABR. This is because there is a better chance to reach the destination of the LSP by first signaling the LSP up

to that ABR and continuing the path calculation from there on by having the ABR expand the remaining hops in the ERO.

This behavior can be illustrated in the Figure 33: CSPF for an inter-area LSP. The TE link between ABR nodes D and E is in area 0. When node C computes the path for LSP from C to B which path specified nodes C and D as loose hops, it would fail the path computation if CSPF attempted a path all the way to the last hop in the local area, node E. Instead, CSPF stops the path at node A which further expands the ERO by including link D-E as part of the path in area 0.

Figure 33: CSPF for an inter-area LSP



- If there is more than 1 ABR that advertised a prefix, CSPF calculates a path for all ABRs. Only the shortest path is withheld. If more than one path has the shortest path, CSPF picks a path randomly or based on the least-fill criterion if enabled. If more than one ABR satisfies the least-fill criterion, CSPF also picks one path randomly.
- The path for an intra-area LSP path is not able to exit and re-enter the local area of the ingress LER. This behavior was possible in prior implementation when the user specified a loose hop outside of the local area or when the only available path was via TE links outside of the local area.

2.5.13.1.1 Rerouting of inter-area LSP

In prior implementation, an inter-area LSP path would have been re-routed if a failure or a topology change occurred in the local or a remote area while the ABR loose-hop in the path definition was still up. If the exit ABR node went down, went into IS-IS overload, or was put into node TE graceful shutdown, the LSP path remains down at the ingress LER.

One new behavior introduced by the automatic selection of ABR is the ability of the ingress LER to reroute an inter-area LSP primary path via a different ABR in the following situations:

- When the local exit ABR node fails, There are two cases to consider:
  - The primary path is not protected at the ABR and, so, is torn down by the previous hop in the path. In this case the ingress LER retries the LSP primary path via the ABR which currently has the best path for the destination prefix of the LSP.
  - The primary path is protected at the ABR with a manual or dynamic bypass LSP. In this case the ingress LER receives a Path Error message with a notification of a protection becoming active downstream and a RESV with a *Local-Protection-In-Use* flag set. At the receipt of first of these two messages, the ingress LER then performs a Global Revertive Make-Before-Break (MBB) to re-optimize the LSP primary path via the ABR which currently has the best path for the destination prefix of the LSP.

- When the local exit ABR node goes into IS-IS overload or is put into node TE Graceful Shutdown. In this case, the ingress LER performs a MBB to re-optimize the LSP primary path via the ABR which currently has the best path for the destination prefix of the LSP. The MBB is performed at the receipt of the PathErr message for the node TE shutdown or at the next timer or manual re-optimization of the LSP path in the case of the receipt of the IS-IS overload bit.

2.5.13.1.2 Behavior of MPLS options in inter-area LSP

The automatic ABR selection for an inter-area LSP does not change prior implementation inter-area LSP behavior of many of the LSP and path level options. There is, however, a number of enhancements introduced by the automatic ABR selection feature as described in the following.

- Features such as path bandwidth reservation and admin-groups continue to operate within the scope of all areas because they rely on propagating the parameter information in the Path message across the area boundary.
- The TE graceful shutdown and soft preemption features continues to support MBB of the LSP path to avoid the link or node that originated the PathErr message as long as the link or node is in the local area of the ingress LER. If the PathErr originated in a remote area, the ingress LER is not able to avoid the link or node when it performs the MBB because it computes the path to the local ABR exit router only. There is, however, an exception to this for the TE graceful shutdown case only. An enhancement has been added to cause the upstream ABR nodes in the current path of the LSP to record the link or node to avoid and use it in subsequent ERO expansions. This means that if the ingress LER computes a new MBB path which goes via the same exit ABR router as the current path and all ABR upstream nodes of the node or link which originated the PathErr message are also selected in the new MBB path when the ERO is expanded, the new path indeed avoids this link or node. The latter is a new behavior introduced with the automatic ABR selection feature.
- The support of MBB to avoid the ABR node when the node is put into TE Graceful Shutdown is a new behavior introduced with the automatic ABR selection feature.
- The **metric-type te** option in CSPF cannot be propagated across the area boundary and operates within the scope of the local area of the ingress LER node. This is a new behavior introduced with the automatic ABR selection feature.
- The **srlg** option on bypass LSP continues to operate locally at each PLR within each area. The PLR node protecting the ABR checks the SRLG constraint for the path of the bypass within the local area.
- The **srlg** option on secondary path is allowed to operate within the scope of the local area of the ingress LER node with the automatic ABR selection feature.
- The **least-fill** option support with an inter-area LSP is introduced with the automatic ABR selection feature. When this option is enabled, CSPF applies the least-fill criterion to select the path segment to the exit ABR node in the local area.
- The PLR node must indicate to CSPF that a request to one-to-one detour LSP path must remain within the local area. If the destination for the detour, which is the same as that of the LSP, is outside of the area, CSPF must return no path.
- The **propagate-admin-group** option under the LSP still needs to be enabled on the inter-area LSP if the user wants to have admin-groups propagated across the areas.
- With the automatic ABR selection feature, timer based re-signal of the inter-area LSP path is supported and re-signals the path if the cost of the path segment to the local exit ABR changed. The cost shown for the inter-area LSP at ingress LER is the cost of the path segments to the ABR node.

2.5.13.2 Inter-area LSP support of OSPF virtual links

The OSPF virtual link extends area 0 for a router that is not connected to area 0. As a result, it makes all prefixes in area 0 reachable via an intra-area path but in reality, they are not because the path crosses the transit area through which the virtual link is set up to reach the area 0 remote nodes.

The TE database in a router learns all of the remote TE links in area 0 from the ABR connected to the transit area, but an intra-area LSP path using these TE links cannot be signaled within area 0 because none of these links is directly connected to this node.

This inter-area LSP feature can identify when the destination of an LSP is reachable via a virtual link. In that case, CSPF automatically computes and signals an inter-area LSP via the ABR nodes that is connected to the transit area.

However, when the ingress LER for the LSP is the ABR connected to the transit area and the destination of the LSP is the address corresponding to another ABR router-id in that same transit area, CSPF computes and signals an intra-area LSP using the transit area TE links, even when the destination router-id is only part of area 0.

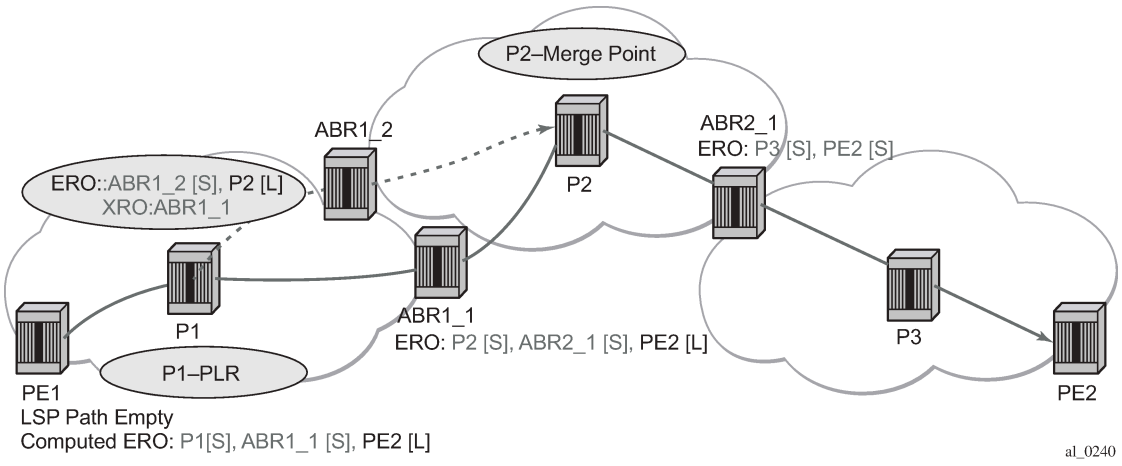
2.5.13.3 Area border node FRR protection for inter-area LSP

For protection of the area border router, the upstream node of the area border router acts as a point-of-local-repair (PLR), and the next-hop node to the protected domain border router is the merge-point (MP). Both manual and dynamic bypass are available to protect area border node.

Manual bypass protection works only when a correct completely strict path is provisioned that avoids the area border node.

Dynamic bypass protection provides for the automatic computation, signaling, and association with the primary path of an inter-area P2P LSP to provide ABR node protection. Figure 34: ABR node protection using dynamic bypass LSP illustrates the role of each node in the ABR node protection using a dynamic bypass LSP.

Figure 34: ABR node protection using dynamic bypass LSP



In order for a PLR node within the local area of the ingress LER to provide ABR node protection, it must dynamically signal a bypass LSP and associate it with the primary path of the inter-area LSP using the following new procedures:

- The PLR node must inspect the node-id RRO of the LSP primary path to determine the address of the node immediately downstream of the ABR in the other area.
- The PLR signals an inter-area bypass LSP with a destination address set to the address downstream of the ABR node and with the XRO set to exclude the node-id of the protected ABR node.
- The request to CSPF is for a path to the merge-point (that is the next-next-hop in the RRO received in the RESV for the primary path) along with the constraint to exclude the protected ABR node and the include/exclude admin-groups of the primary path. If CSPF returns a path that can only go to an intermediate hop, then the PLR node signals the dynamic bypass and automatically includes the XRO with the address of the protected ABR node and propagate the admin-group constraints of the primary path into the Session Attribute object of the bypass LSP. Otherwise, the PLR signals the dynamic bypass directly to the merge-point node with no XRO object in the Path message.
- If a node-protect dynamic bypass cannot be found or signaled, the PLR node attempts a link-protect dynamic bypass LSP. As in existing implementation of dynamic bypass within the same area, the PLR attempts in the background to signal a node-protect bypass at the receipt of every third Resv refresh message for the primary path.
- Refresh reduction over dynamic bypass only works if the node-id RRO also contains the interface address. Otherwise the neighbor is not created when the bypass is activated by the PLR node. The Path state then times out after three refreshes following the activation of the bypass backup LSP.

Note that a one-to-one detour backup LSP cannot be used at the PLR for the protection of the ABR node. As a result, a PLR node does not signal a one-to-one detour LSP for ABR protection. In addition, an ABR node rejects a Path message, received from a third party implementation, with a detour object and with the ERO having the next-hop loose. This is performed regardless if the **cspf-on-loose-hop** option is enabled or not on the node. In other words, the router as a transit ABR for the detour path rejects the signaling of an inter-area detour backup LSP.

2.5.14 Timer-based reversion for RSVP-TE LSPs

The following secondary to primary path reversion is supported for RSVP-TE LSPs:

- configurable timer-based reversion for primary LSP path
- manual reversion from secondary to primary path

Normally, an RSVP-TE LSP automatically switches back from using a secondary path to the primary path as soon as the primary path recovers. In some deployments, it is useful to delay reversion or allow manual reversion, instead of allowing an LSP to revert to the primary path as soon as it is available. This feature provides a method to manage fail-overs in the network.

If manual reversion is used, a fall-back timer-based mechanism is required in case a human operator fails to execute the switch back to the primary path. This function is also useful to stagger reversion for large numbers of LSPs.

A reversion timer for an LSP is configured using the CLI as follows:

```
config
   router
      [no] mpls
                lsp
                  [no] revert-timer <timer-value>
```

When configured, the revert timer is started as soon as a primary path recovers. The LSP does not revert from the currently used secondary path to the primary path until the timer expires. When configured, the revert-timer is used instead of the existing hold timer.

The timer value can be configured in one minute increments, up to 4320 minutes (72 hours). After a timer has started, it can be modified using this command. If a new value is entered, then the current timer is canceled (without reverting the LSP) and then restarted using the new value. The revert timer should always be configured to a higher value than the hold timer. This prevents the router from reverting to the primary path and sending traffic before the downstream LSRs have programmed their datapath.

The **no** form of the command cancels any currently outstanding revert timer and causes the LSP to revert to the primary path if it is up.

If the LSP secondary path fails while the revert timer is still running, the system cancels the revert-timer and the LSP reverts to the primary path immediately. A user can manually force an LSP to revert to the primary path while the revert-timer is still running, using the following tools command:

tools>perform>router>mpls revert lsp *lsp-name*

This command forces the early expiry of the revert timer for the LSP. The primary path must be up in order for this command to work.

2.5.15 LSP tagging and auto-bind using tag information

RSVP and SR-TE LSPs can be configured with an administrative tag.

The primary application of LSP tagging is to enable the system to resolve to specific transport tunnels (or groups of eligible transport tunnels) for BGP routes for applications such as BGP labeled unicast, VPRN, or EVPN. Additionally, LSP tagging specifies a finer level of granularity on the next-hop or the far-end prefix associated with a BGP labeled unicast route or unlabeled BGP route shortcut tunnels.

LSP tagging is supported using the following capabilities in SR OS:

- The ability to associate a color with an exported BGP route. This is signaled using the BGP Color Extended Community described in Section 4.3 of *draft-ietf-idr-tunnel-encaps-03*. This provides additional context associated with a route that an upstream router can use to help select a distinct transport for traffic associated with that route.
- The ability to define a set of administrative tags on a node for locally-coloring imported routes and consequent use in transport tunnel selection. Up to 256 discrete tag values are supported.
- The ability to configure a set of administrative tags on an RSVP or SR-TE LSP. This tag is used by applications to refer to the LSP (or set of LSPs with the same tag) for the purposes of transport tunnel selection. Up to four tags are supported per LSP.
- The ability to apply one or more administrative tags to include or exclude as an action to a matching route in a BGP route policy. Different admin-tag values can be applied to different VPRN routes, such that different VPRNs can ultimately share the same set of tunnels by having the same admin-tags associated with their VPN routes via matching on RT extended community values.
- The ability to match an administrative tag in a route policy for the following service types to the list of available RSVP or SR-TE tunnels (potentially filtered by the resolution filter):
  - BGP labeled unicast and BGP shortcuts
  - VPRN with auto-bind-tunnel
  - EVPN with auto-bind-tunnel

The following provides an overview of how the feature is intended to operate:

1. Configure a nodal database of admin-tags. Each tag is automatically assigned an internal color. The nodal admin tag database is configured under **config**>**router**>**admin-tags** in the CLI.
2. Optionally, configure export route policies associating routes with a color extended community. The color extended community allows for a color to be advertised along with specific routes, intended to indicate some property of a transport that a route can be associated with.
3. Configure a named **route-admin-tag-policy** containing a list of admin-tags to include or exclude. The **route-admin-tag-policy** is configured under **config**>**router**>**admin-tags** in the CLI. Up to eight include and exclude statements are supported per policy.
4. Configure a named **route-admin-tag-policy** as an action against matching routes in a route policy. An internal route color is applied to matching routes. Examples of a match are on a BGP next-hop or an extended community; for example, the color extended community specified in Section 4.3 of *draft-ietf-idr-tunnel-encaps-03*. That is, if that policy is later used as an import policy by a service, routes received from, for example, a matching BGP next hop or color-extended community in the policy is given the associated internal color.
5. Configure admin-tags on RSVP or SR-TE LSPs so that different groups of LSPs can be treated differently by applications that intend to use them. More than one admin-tag can be configured against a specified LSP. Admin-tags are configured using the **admin-tag** command under **config**>**router**>**mpls**>**lsp** in the CLI.
6. Apply a route policy to a service or other object as an import policy. The system then matches the internal color policy of a route against corresponding LSP internal colors in the tunnel table. That set of LSPs can subsequently be limited by a resolution filter. For BGP-LU and BGP shortcut routes, the resolution filter can optionally be restricted to only those LSPs matching the pattern of admin-tags in the **route-admin-tag-policy** (otherwise the resolution fails) using the **enforce-strict-tunnel-tagging** option. If **enforce-strict-tunnel-tagging** is not specified, then the router falls back to untagged LSPs. The tunnels that VPRN and EVPN services can auto-bind to can also be restricted using the **enforce-strict-tunnel-tagging** option in the **auto-bind-tunnel** configuration for the service. The following subsections provide more details about how the matching algorithm works.

2.5.15.1 Internal route color to LSP color matching algorithm

This section describes how the matrix of **include** or **exclude** colors in a **route-admin-tag-policy** *policy-name*, which is assigned to a route, are matched against LSP internal colors. This is a generic algorithm. The following sections provide further details of how this applies to specific use cases.

Internal color matching occurs before any resolution filter is applied.

The following selection process assumes the system starts with a set of eligible RSVP and SR-TE LSPs to the appropriate BGP next hop.

1. Prune the following RSVP and SR-TE LSPs from the eligible set:
   - uncolored LSPs
   - LSPs where none of the internal colors match any "include" color for the route
   - LSPs where any of the internal colors match any "exclude" color for the route
2. If none of the LSPs match, then the default behavior is that the route does not resolve. Depending on the context, configure a fall-back method, as described in LSP admin tag use in tunnel selection for VPRN and EVPN auto-bind.

3. If a route does not have an admin-tag policy, it is assumed that the operator does not want to express a preference for the LSP to use. Therefore, routes with no admin-tag policy can still resolve to any tagged or untagged LSP.

This selection process results in a set of one or more ECMP LSPs, which may be further reduced by a resolution filter.

2.5.15.2 LSP admin tag use in tunnel selection for VPRN and EVPN auto-bind

For VPRN, EVPN-VPLS, and EVPN-VPWS, routes may be imported via peer route import policies that contain route admin-tag policies or via VRF import for VPRN and VSI import for EVPN VPLS or Epipe used for auto-bind-tunnel.

VRF import and VSI import policies take precedence over the peer route import policy.

For policies that contain route admin-tag policies, the set of available RSVP and SR-TE LSPs in TTM are first pruned as described in Internal route color to LSP color matching algorithm. This set may then be further reduced by a resolution filter. If **weighted-ecmp** is configured, then this is applied across the resulting set.

Routes with no admin-tag, or a tag that is not explicitly excluded by the route admin tag policy, can still resolve to any tagged or untagged LSP but matching tagged LSPs are used in preference to any other. It is possible that following the resolution filter no eligible RSVP or SR-TE LSP exists. By default, the system falls back to regular auto-bind behavior using LDP, SR-ISIS, SR-OSPF, or any other lower priority configured tunnel type, otherwise the resolution fails. That is, matching admin-tagged RSVP or SR-TE LSPs are used in preference to other LSP types, whether tagged or untagged. However, it is possible on a per-service basis to enforce that only specific tagged tunnels should be considered, otherwise resolution fails, using the **enforce-strict-tunnel-tagging** command in the **auto-bind-tunnel** context.

2.5.15.3 LSP admin tag use for BGP next hop or BGP prefix for labeled and unlabeled unicast routes

A specific LSP can be selected as transport to a specified BGP next hop for BGP labeled unicast and unlabeled BGP routes tunneled over RSVP and SR-TE LSPs.

Routes are imported via import route policies. Named routing policies may contain route admin-tag policies. For route import policies that contain route admin-tag policies, the set of available RSVP and SR-TE LSPs in TTM are first pruned as described in Internal route color to LSP color matching algorithm.

This set may then be further reduced by a resolution filter.

If **weighted-ecmp** is configured, then this is applied across the resulting set.

Routes with no admin-tag can still resolve to any tagged or untagged LSP. It is possible that, following the resolution filter, no eligible RSVP or SR-TE LSP exists. By default, the system falls back to using LDP, SR-ISIS, SR-OSPF, or any other lower-priority tunnel type; otherwise the resolution fails. That is, matching admin-tagged RSVP or SR-TE LSPs are preferred to other LSP types. On a per-address family basis, the **enforce-strict-tunnel-tagging** command in the **next-hop-resolution** filter for BGP labeled routes or shortcut tunnels can be used to enforce that only tagged tunnels are considered; otherwise, resolution fails.

2.5.16 LSP Self-ping

LSP Self-ping is specified in RFC 7746, *Label Switched Path (LSP) Self-Ping*. LSP Self-ping provides a lightweight, periodic connectivity check by the head-end LER of an LSP with no session state in the tail-end LER. LSP Self-ping checks that an LSP datapath has been programmed following the receipt of the RESV message for the path. LSP Self-ping defines a new OAM packet with a locally unique session ID. The IP source address of this packet is set to the address of the egress LER, and the destination address is set to that of the ingress LER, such that when the packet exits the egress LER the packet is simply forwarded back to the ingress LER. LSP Self-ping is a distinct OAM mechanism from LSP ping, despite the similar name.

SR OS supports LSP Self-ping for point-to-point RSVP-TE LSPs and point-to-point RSVP auto-LSPs, including PCC-initiated and PCC-controlled LSPs, and PCC-initiated and PCE-controlled LSPs.

An SR OS router can use LSP Self-ping to test that the datapath of an LSP has been fully programmed along its length before moving traffic onto it. When enabled, LSP Self-ping packets are periodically sent on a candidate path that the router intends to switch to, for example, during primary or secondary switching (with FRR on the primary) or MBB of a path, following the receipt of the RESV message, until a reply is received from the far end. When a reply is received, the system determines that the datapath of the LSP must have been programmed. LSP Self-ping is used instead of the LSP hold timer (**config**>**router**>**mpls**>**hold-timer**). This is particularly useful in multivendor networks where specific nodes may take unexpectedly long times to program their datapath.

LSP BFD is not supported if LSP Self-ping is enabled. The router ignores the LSP Self Ping configuration if **configure**>**router**>**mpls**>**lsp**>**bfd**>**failure-action failover-or-down** is configured for an LSP.

LSP Self-ping is configured under the MPLS context using the **lsp-self-ping** command.

```
configure
   router
      mpls
         [no] lsp-self-ping
           interval <seconds>
           timeout <seconds>
           timeout-action {retry | switch}
           rsvp-te {enable | disable}
```

LSP Self-ping is enabled for all RSVP-TE LSPs using the **rsvp-te enable** command. However, it is possible to enable or disable LSP Self-ping for a specific LSP or LSP template regardless of the setting at the MPLS level.

The **interval** command sets the interval, in seconds, that periodic LSP Self-ping packets are sent. The **timeout** command configures a timer that is started when the first LSP Self-ping packet for a specific event is sent on an LSP path. The **timeout-action** specifies what action to take if no LSP Self-ping reply is received before the timer expires. If **timeout-action** is set to **retry**, then the router tries to signal a new path and the process repeats (see Detailed behavior of LSP Self-ping for more information). If **timeout-action** is set to **switch**, then the router uses the new path regardless and stops the LSP Self-ping cycle.

LSP Self-ping can also be enabled or disabled for a specific LSP or LSP template:

```
configure router mpls
   lsp
     lsp-self-ping {enable | disable | inherit}

configure router mpls
   lsp-template
      lsp-self-ping {enable | disable | inherit}
```

By default, LSPs and LSP templates inherit the configuration at the MPLS level. However, LSP Self-ping may be enabled for a specific LSP or LSP template using the **lsp-self-ping enable** command. LSP Self-ping may be explicitly disabled for a specific LSP or LSP template, even if enabled at the MPLS level, using the **lsp-self-ping disable** command.

2.5.16.1 Detailed behavior of LSP Self-ping

When LSP Self-ping is enabled, destination UDP port 8503 is opened and a unique session ID is allocated for each RSVP LSP path. When an RESV message is received following a resignaling event, LSP Self-ping packets are sent at configurable periodic intervals until a reply is received from the far end for that session ID.

LSP Self-ping applies in cases where the active path is changed, while the previous active path remains up, whether it is FRR/MBB or pre-empted. These cases are as follows:

- primary in degraded state -> standby or secondary path
- standby or secondary path -> primary path (reversion)
- standby or secondary path -> another standby or secondary path (**tools**>**perform**>**router**>**mpls**>**switch-path** command or path preference change)
- degraded standby/secondary path -> degraded primary path (degraded primary is preferred to degraded standby/secondary path)
- MBB on active path

A path can go to a degraded state either because of FRR active (only on the primary path), soft pre-emption, or LSP BFD down (when the failure action is failover).

The system does not activate a candidate path until the first LSP Self-ping reply is received, subject to the timeout. The LSP Self-ping timer is started when the RESV message is received. The system then periodically sends LSP Self-ping packets until the timer expires or the first LSP Self-ping reply is received, whichever comes first. If the timeout expires before an LSP Self-ping reply has been received and the **timeout-action** is set to **retry**, then the system tears down the candidate path (in the case of switching between paths) and go back to CSPF for a new path. The system then starts the LSP Self-ping cycle again after a new path is obtained. In the case of switching between paths, the system retries immediately and increments the retry counter. In the case of MBB, the system retries immediately, but does not increment the retry counter, which has the effect of continuously repeating the retry/LSP Self-ping cycle until a new path is successfully established.

Note: If the configured timeout value is changed for an LSP with an in-progress LSP Self-ping session, the previous timer completes, and the new value is not used until the next lsp-self-ping session.

If no timeout is configured, then the default value is used.

2.5.16.2 Considerations for scaled scenarios

The router can send LSP Self-ping packets at a combined rate across all sessions of 125 packets per second. This means that it takes 10 seconds to detect that the data plane is forwarding for 1250 LSPs. If the number of currently in-progress LSP Self-ping sessions reaches 125 PPS with no response, then the system continues with these LSP Self-ping sessions until the timeout is reached and is not able to test additional LSP paths. In scaled scenarios, it is recommended that the lsp-self-ping interval and timeout values be configured so that LSP Self-ping sessions are completed (either successfully or

through timing out) so that all required LSP paths are tested within an acceptable time frame. A count of the number of LSP Self-ping and OAM resource exhaustion timeouts is shown in the output of the **show>router>mpls>lsp detail** and **show>router>mpls>lsp-self-ping** commands.

2.5.17 Accounting for dark bandwidth

In traffic engineered networks, IGP-TE advertisements are used to distribute bandwidth availability on each link. This bandwidth availability information only accounts for RSVP-TE LSP set-ups and tear-downs. However, network deployments often have labeled traffic (other than RSVP-TE LSP) flowing on the same links as these RSVP-TE LSPs, in particular when MPLS Segment Routing (MPLS-SR) is deployed. The bandwidth consumed by this labeled traffic is often referred to as dark bandwidth.

The bandwidth consumed by, for example, MPLS-SR traffic is not accounted for in IGP-TE advertisements. This unaccounted-for traffic may result in suboptimal constrained routing decisions or contention for the access to the bandwidth resource. SR OS enables accounting for dark bandwidth in IGP-TE advertisement and provides the means to control the behavior of this accounting.

To configure dark bandwidth accounting:

1. Enable collection of traffic statistics for dark bandwidth, using the command **configure>router>mpls>aux-stats sr**

   Note: Only one keyword parameter is available (**sr**) for this command, so only MPLS-SR is considered as contributing to dark bandwidth.

2. Enable dark bandwidth accounting on each SE, using the command **configure>router>rsvp>dbw-accounting**

   Note: After dark bandwidth has been enabled, auxiliary statistics collection cannot be disabled. Dark bandwidth accounting must be disabled (**no dbw-accounting**) before auxiliary statistics collection can be disabled.

3. Configure the dark bandwidth accounting parameters to control the behavior of the system.

When dark bandwidth accounting is enabled, the system samples dark bandwidth at the end of every sample interval and computes an average after *sample-multiplier* samples. The system applies a multiplier (*dbw-multiplier*) to the computed average dark bandwidth and then determines whether an IGP-TE update is required based on whether one of the thresholds (*up-threshold* or *down-threshold*) has been crossed. If an IGP-TE advertisement is required, the bandwidth information is updated, considering that dark bandwidth has the highest priority among the eight available priorities. These thresholds represent a change of Maximum Reservable Bandwidth (OSPF) or Maximum Reservable Link Bandwidth (IS-IS) compared to the previously advertised bandwidth. These parameters are generally global parameters, but it is possible to override the global value of some parameters on a per-interface basis.

The **show>router>rsvp>status** command allows the user to view, on a global or per-interface basis, key values associated with the dark bandwidth accounting process.

2.6 P2MP RSVP LSP

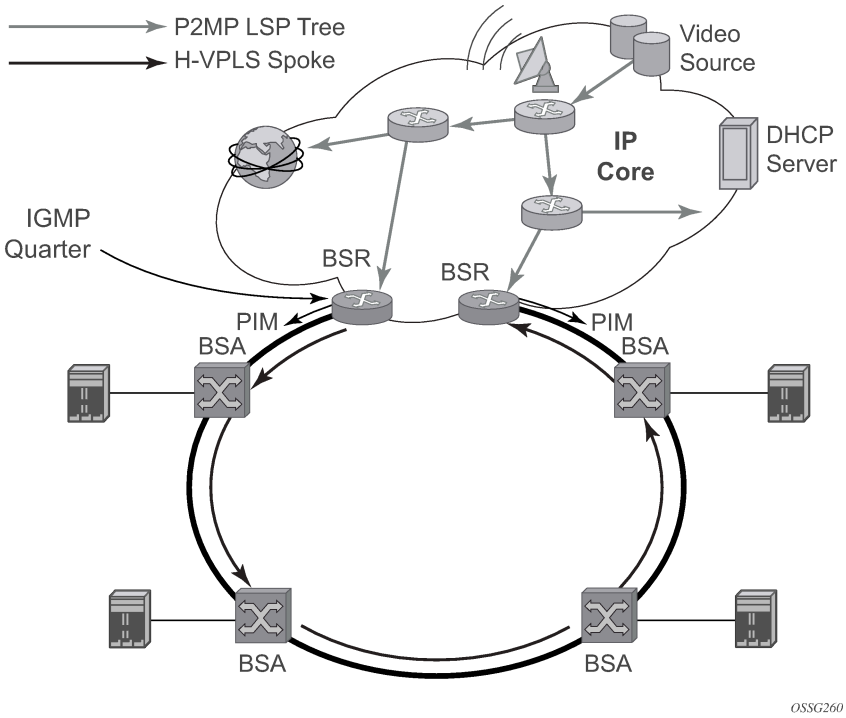
Point-to-multipoint (P2MP) RSVP LSP allows the source of multicast traffic to forward packets to one or many multicast receivers over a network without requiring a multicast protocol, such as PIM, to be

configured in the network core routers. A P2MP LSP tree is established in the control plane which path consists of a head-end node, one or many branch nodes, and the leaf nodes. Packets injected by the head-end node are replicated in the data plane at the branching nodes before they are delivered to the leaf nodes.

2.6.1 Application in video broadcast

Figure 35: Application of P2MP LSP in video broadcast illustrates the use of the 7450 ESS, 7750 SR, 7950 XRS, and VSR in triple play application (TPSDA). The Broadband Service Router (BSR) is a 7750 SR and the Broadband Service Aggregator (BSA) is the 7450 ESS.

Figure 35: Application of P2MP LSP in video broadcast



A PIM-free core network can be achieved by deploying P2MP LSPs using other core routers. The router can act as the ingress LER receiving the multicast packets from the multicast source and forwarding them over the P2MP LSP.

A router can act as a leaf for the P2MP LSP tree initiated from the head-end router co-located with the video source. The router can also act as a branch node serving other leaf nodes and supports the replication of multicast packets over P2MP LSPs.

2.6.2 P2MP LSP data plane

A P2MP LSP is a unidirectional label switched path (LSP) which inserts packets at the root (ingress LER) and forwards the exact same replication of the packet to one or more leaf nodes (egress LER). The packet can be replicated at the root of P2MP LSP tree or at a transit LSR, or both, which acts as a branch node for the P2MP LSP tree.

Note that the data link layer code-point, for example Ethertype when Ethernet is the network port, continues to use the unicast codepoint defined in RFC 3032, *MPLS Label Stack Encoding*, and which is used on P2P LSP. This change is specified in *draft-ietf-mpls-multicast-encaps*, *MPLS Multicast Encapsulations*.

When a router sends a packet over a P2MP LSP which egresses on an Ethernet-based network interface, the Ethernet frame uses a MAC unicast destination address when sending the packet over the primary P2MP LSP instance or over a P2P bypass LSP). Note that a MAC multicast destination address is also allowed in the *draft-ietf-mpls-multicast-encaps*. Therefore, at the ingress network interface on an Ethernet port, the router can accept both types of Ethernet destination addresses.

2.6.2.1 Ingress LER node

At the root of the P2MP LSP (head-end or ingress LER node):

1. First, the P2MP LSP state is established via the control plane. Each leaf of the P2MP LSP has a next-hop label forwarding entry (NHLFE) configured in the forwarding plane for each outgoing interface.
2. The user maps a specific multicast destination group address to the P2MP LSP in the base router instance by configuring a static multicast group under a tunnel interface representing the P2MP LSP.
3. An FTN entry is programmed at the ingress of the head-end node that maps the FEC of a received user IP multicast packet to a list of outgoing interfaces (OIF) and corresponding NHLFEs.
4. The head-end node replicates the received IP multicast packet to each NHLFE. Replication is performed at ingress toward the fabric, or at egress forwarding engine, or both, depending on the location of the OIF.
5. At ingress, the head-end node performs a PUSH operation on each of the replicated packets.

2.6.2.2 LSR node

At an LSR node that is not a branch node, the LSR performs a label swapping operation on a leaf of the P2MP LSP. This is a conventional operation of an LSR in a P2P LSP. An ILM entry is programmed at the ingress of the LSR to map an incoming label to a NHLFE.

For control packets received on an ILM in an LSR, packets that arrive with the TTL in the outer label expiring are sent to the CPM for further processing and are not forwarded to the egress NHLFE.

2.6.2.3 Branch LSR node

At an LSR node that is a branch node, the LSR performs a replication and a label swapping for each leaf of the P2MP LSP. An ILM entry is programmed at the ingress of the LSR to map an incoming label to a list of OIF and corresponding NHLFEs. There is a limit of 127 OIF/NHLFEs per ILM entry.

The following is an exception handling procedure for control packets received on an ILM in a branch LSR, packets that arrive with the TTL in the outer label expiring are sent to the CPM for further processing and not copied to the LSP branches.

2.6.2.4 Egress LER node

At the leaf node of the P2MP LSP, (egress LER) the egress LER performs a pop operation. An ILM entry is programmed at the ingress of the egress LER to map an incoming label to a list of next-hop/OIF.

For control packets received on an ILM in an egress LER, the packet is sent to the CPM for further processing if there is any of the IP header exception handling conditions set after the label is popped: 127/8 destination address, router alert option set, or any other options set.

2.6.2.5 BUD LSR node

At an LSR node which is both a branch node and an egress leaf node, (bud node) the bud LSR performs a pop operation on one or many replications of the received packet and a swap operation of the remaining replications. An ILM entry is programmed at ingress of the LSR to map the incoming label to list of NHLFE/OIF and next-hop/OIF. Note however, the exact same packets are replicated to an LSP leaf and to a local interface.

The following are the exception handling procedures for control packets received on an ILM in a bud LSR, packets which arrive with the TTL in the outer label expiring are sent to the CPM and are not copied to the LSP branches. Packets whose TTL does not expire are copied to all branches of the LSP. The local copy of the packet is sent to the CPM for further processing if there is any of the IP header exception handling conditions set after the label is popped: 127/8 destination address, router alert option set, or any other options set.

2.6.3 Ingress path management for P2MP LSP packets

The SR OS provides the ingress multicast path management (IMPM) capability that allows users to manage the way IP multicast streams are forwarded over the router’s fabric and to maximize the use of the fabric multicast path capacity.

IMPM consists of two components, a bandwidth policy and a multicast information policy. The bandwidth policy configures the parameters of the multicast paths to the fabric. This includes the multicast queue parameters of each path. The multicast information policy configures the bandwidth and preference parameters of individual multicast flows corresponding to a channel, for example, a <*,G> or a <S,G>, or a bundle of channels.

By default, the XCM (on the 7950 XRS) and the IOM/IMM (on the 7750 SR and 7450 ESS) ingress data paths provides two multicast paths through the fabric referred to as high-priority path and low-priority path respectively. When a multicast packet is received on an ingress network or access interface or on a VPLS SAP, the packet’s classification determines its forwarding class and priority or profile as per the ingress QoS policy. This then determines which of the SAP or interface multicast queues it must be stored in. By default SAP and interface expedited forwarding class queues forward over the high-priority multicast path and the non-expedited forwarding class queues forward over the low-priority multicast path.

When IMPM on the ingress FP is enabled on the 7950 XRS, 7750 SR, or 7450 ESS, one or more multicast paths are enabled depending on the hardware in use. In addition, for all routers, multicast flows managed by IMPM are stored in a separate shared multicast queue for each multicast path. These queues are configured in the bandwidth policy.

IMPM maps a packet to one of the paths dynamically based on monitoring the bandwidth usage of each packet flow matching a <*,G> or <S,G> record. The multicast bandwidth manager also assigns multicast flows to a primary path based on the flow preference until the rate limits of each path is reached. At that point in time, a multicast flow is mapped to the secondary flow. If a path congests, the bandwidth manager

removes and black-hole lower preference flows to guarantee bandwidth to higher preference flows. The preference of a multicast flow is configured in the multicast info policy.

A packet received on a P2MP LSP ILM is managed by IMPM when IMPM is enabled on the ingress XMA or the ingress FP and the packet matches a specific multicast record. When IMPM is enabled but the packet does not match a multicast record, or when IMPM is disabled, a packet received on a P2MP LSP ILM is mapped to a multicast path.

2.6.3.1 Ingress P2MP path management on XCM/IOM/IMMs

On an ingress XCM or IOM/IMM, there are multiple multicast paths available to forward multicast packets, depending on the hardware being used. Each path has a set of multicast queues and associated with it. Two paths are enabled by default, a primary path and a secondary path, and represent the high-priority and low-priority paths respectively. Each VPLS SAP, access interface, and network interface have a set of per forwarding class multicast or broadcast queues, or both, which are defined in the ingress QoS policy associated with them. The expedited queues are attached to the primary path while the non-expedited queues are attached to secondary path.

When IMPM is enabled or when a P2MP LSP ILM exists on the ingress XCM or IOM/IMM or both, the remaining multicast paths are also enabled. 16 multicast paths are supported by default with 28 on 7950 XRS systems and 7750 SR-12e systems, with the latter having the **tools** perform **system set-fabric-speed fabric-speed-b**. One path remains as a secondary path and the rest are primary paths.

A separate pair of shared multicast queues is created on each of the primary paths, one for IMPM managed packets and one for P2MP LSP packets not managed by IMPM. The secondary path does not forward IMPM managed packets or P2MP LSP packets. These queues have a default rate (PIR=CIR) and CBS/MBS/low-drop-tail thresholds, but these can be changed under the bandwidth policy.

A VPLS snooped packet, a PIM routed packet, or a P2MP LSP packet is managed by IMPM if it matches a <*,G> or a <S,G> multicast record in the ingress forwarding table and IMPM is enabled on the ingress XMA or the FP where the packet is received. The user enables IMPM on the ingress XMA datapath or the FP datapath using the **config>card>fp>ingress>mcast-path-management** command.

A packet received on an IP interface and to be forwarded to a P2MP LSP NHLFE or a packet received on a P2MP LSP ILM is not managed by IMPM when IMPM is disabled on the ingress XMA or the FP where the packet is received or when IMPM is enabled but the packet does not match any multicast record. A P2MP LSP packet duplicated at a branch LSR node is an example of a packet not managed by IMPM even when IMPM is enabled on the ingress XMA or the FP where the P2MP LSP ILM exists. A packet forwarded over a P2MP LSP at an ingress LER and which matches a <*,G> or a <S,G> is an example of a packet which is not managed by IMPM if IMPM is disabled on the ingress XMA or the FP where the packet is received.

When a P2MP LSP packet is not managed by IMPM, it is stored in the unmanaged P2MP shared queue of one of the primary multicast paths.

By default, non-managed P2MP LSP traffic is distributed across the IMPM primary paths using hash mechanisms. This can be optimized by enabling IMPM on any forwarding complex, which allows the system to redistribute this traffic on all forwarding complexes across the IMPM paths to achieve a more even capacity distribution. Be aware that enabling IMPM causes routed and VPLS (IGMP and PIM) snooped IP multicast groups to be managed by IMPM.

The above ingress datapath procedures apply to packets of a P2MP LSP at ingress LER, LSR, branch LSR, bud LSR, and egress LER. Note that in the presence of both IMPM managed traffic and unmanaged P2MP LSP traffic on the same ingress forwarding plane, the user must account for the presence of the unmanaged traffic on the same path when setting the rate limit for an IMPM path in the bandwidth policy.

2.6.4 RSVP control plane in a P2MP LSP

P2MP RSVP LSP is specified in RFC 4875, *Extensions to Resource Reservation Protocol - Traffic Engineering (RSVP-TE) for Point-to-Multipoint TE Label Switched Paths (LSPs).*

A P2MP LSP is modeled as a set of source-to-leaf (S2L) sub-LSPs. The source or root, for example the head-end node, triggers signaling using one or multiple path messages. A path message can contain the signaling information for one or more S2L sub-LSPs. The leaf sub-LSP paths are merged at branching points.

A P2MP LSP is identified by the combination of <P2MP ID, tunnel ID, extended tunnel ID> part of the P2MP session object, and <tunnel sender address, LSP ID> fields in the P2MP sender_template object.

A specific sub-LSP is identified by the <S2L sub-LSP destination address> part of the S2L_SUB_LSP object and an ERO and secondary ERO (SERO) objects.

The following are characteristics of this feature:

- Supports the de-aggregated method for signaling the P2MP RSVP LSP. Each root to leaf is modeled as a P2P LSP in the RSVP control plane. Only data plane merges the paths of the packets.
- Each S2L sub-LSP is signaled in a separate path message. Each leaf node responds with its own resv message. A branch LSR node forwards the path message of each S2L sub-LSP to the downstream LSR without replicating it. It also forwards the resv message of each S2L sub-LSP to the upstream LSR without merging it with the resv messages of other S2L sub-LSPs of the same P2MP LSP. The same is done for subsequent refreshes of the path and resv states.
- The node drops aggregated RSVP messages on the receive side if originated by another vendor’s implementation.
- The user configures a P2MP LSP by specifying the optional create-time parameter **p2mp-lsp** following the LSP name. Next, the user creates a primary P2MP instance using the keyword **primary-p2mp-instance**. Then a path name of each S2L sub-LSP must added to the P2MP instance using the keyword **s2l-path**. The paths can be empty paths or can specify a list of explicit hops. The path name must exist and must have been defined in the **config>router>mpls>path** context.
- The same path name can be re-used by more than one S2L of the primary P2MP instance. However the **to** keyword must have a unique argument per S2L as it corresponds to the address of the egress LER node.
- The user can configure a secondary instance of the P2MP LSP to backup the primary one. In this case, the user enters the name of the secondary P2MP LSP instance under the same LSP name. One or more secondary instances can be created. The trigger for the head-end node to switch the path of the LSP from the primary P2MP instance to the secondary P2MP instance is to be determined. This could be based on the number of leaf LSPs which went down at any specific time.
- The following parameters can be used with a P2MP LSP: adaptive, cspf, exclude, fast-reroute, from, hop-limit, include, metric, retry-limit, retry-timer, resignal-timer.
- The following parameters cannot be used with a P2MP LSP: adspec, primary, secondary, to.
- The node ingress LER does not inset an adspec object in the path message of an S2L sub-LSP. If received in the resv message, it is dropped. The operational MTU of an S2L path is derived from the MTU of the outgoing interface of that S2L path.
- The **to** parameter is not available at the LSP level but at the path level of each S2L sub-LSP of the primary or secondary instance of this P2MP LSP.

- The hold-timer configured in the **config>router>mpls>hold-timer** context applies when signaling or re-signaling an individual S2L sub-LSP path. It does not apply when the entire tree is signaled or re-signaled.
- The head-end node can add or remove, or both, a S2L sub-LSP of a specific leaf node without impacting forwarding over the already established S2L sub-LSPs of this P2MP LSP and without re-signaling them.
- The head-end node performs a make-before break (MBB) on an individual S2L path of a primary P2MP instance whenever it applies the FRR global revertive procedures to this path. If CSPF finds a new path, RSVP signals this S2L path with the same LSP-ID as the existing path.
- All other configuration changes, such as adaptive/no-adaptive (when an MBB is in progress), metric-type te, no-frr, path-computation-method/no path-computation-method, result in the tear-down and re-try of all affected S2L paths.
- MPLS requests CSPF to re-compute the whole set of S2L paths of a specific active P2MP instance each time the P2MP re-signal timer expires. The P2MP re-signal timer is configured separately from the P2P LSP. MPLS performs a global MBB and moves each S2L sub-LSP in the instance into its new path using a new P2MP LSP ID if the global MBB is successful. This is regardless of the cost of the new S2L path.
- MPLS requests CSPF to re-compute the whole set of S2L paths of a specific active P2MP instance each time the user performs a manual re-signal of the P2MP instance. MPLS then always performs a global MBB and moves each S2L sub-LSP in the instance into its new path using a new P2MP LSP ID if the global MBB is successful. This is regardless of the cost of the new S2L path. The user executes a manual re-signal of the P2MP LSP instance using the command: **tools>perform>router>mpls>resignal p2mp-lsp** *lsp-name* **p2mp-instance** *instance-name*.
- When performing global MBB, MPLS runs a separate MBB on each S2L in the P2MP LSP instance. If an S2L MBB does not succeed the first time, MPLS retries the S2L using the re-try timer and re-try count values inherited from P2MP LSP configuration. However, there is a global MBB timer set to 600 seconds and which is not configurable. If the global MBB succeeds, for example, all S2L MBBs have succeeded, before the global timer expires, MPLS moves all S2L sub-LSPs into their new path. Otherwise when this timer expires, MPLS checks if all S2L paths have at least tried once. If so, it then aborts the global MBB. If not, it continues until all S2Ls have re-tried once and then aborts the global MBB. After global MBB is aborted, MPLS moves all S2L sub-LSPs into the new paths only if the set of S2Ls with a new path found is a superset of the S2Ls which have a current path which is up.
- While make-before break is being performed on individual S2L sub-LSP paths, the P2MP LSP continues forwarding packets on S2L sub-LSP paths which are not being re-optimized and on the older S2L sub-LSP paths for which make-before-break operation was not successful. MBB therefore results in duplication of packets until the old path is torn down.
- The MPLS datapath of an LSR node, branch LSR node, and bud LSR node is able to re-merge S2L sub-LSP paths of the same P2MP LSP in case their ILM is on different incoming interfaces and their NHLFE is on the same or different outgoing interfaces. This could occur anytime there are equal cost paths through this node for the S2L sub-LSPs of this P2MP LSP.
- Link-protect FRR bypass using P2P LSPs is supported. In link protect, the PLR protecting an interface to a branch LSR only makes use of a single P2P bypass LSP to protect all S2L sub-LSPs traversing the protected interface.
- Refresh reduction on RSVP interface and on P2P bypass LSP protecting one or more S2L sub-LSPs.
- A manual bypass LSP cannot be used for protecting S2L paths of a P2MP LSP.
- The following MPLS features do operate with P2MP LSP:

  - BFD on RSVP interface
  - MD5 on RSVP interface
  - IGP metric and TE metric for computing the path of the P2MP LSP with CSPF
  - SRLG constraint for computing the path of the P2MP LSP with CSPF. SRLG is supported on FRR backup path only
  - TE graceful shutdown
  - Admin group constraint
- The following MPLS features are not operable with P2MP LSP:
  - Class based forwarding over P2MP RSVP LSP
  - LDP-over-RSVP where the RSVP LSP is a P2MP LSP
  - DiffServ TE
  - Soft preemption of RSVP P2MP LSP

2.6.5 P2MP RSVP-TE preemption behavior

P2MP S2Ls can be preempted by or preempt other P2P or P2MP LSPs. SR OS supports P2MP S2L soft preemption as described in Soft preemption and hard preemption as described in Hard preemption.

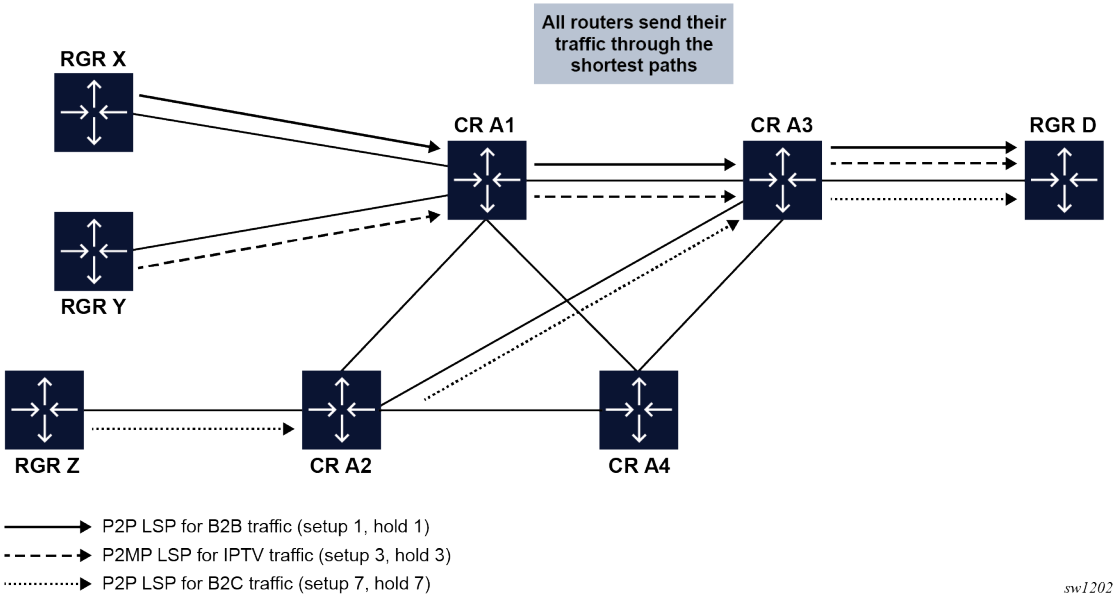
The P2P LSPs and P2MP S2L LSPs reserve the bandwidth they require throughout the network. The P2P and P2MP LSPs only compete for bandwidth if a link failure occurs and a single link is overloaded by additional P2P and S2L LSPs.

The user can configure the setup and hold priority on all LSP types to ensure the higher priority LSPs (P2P or S2L) can preempt lower priority LSPs.

Figure 36: LSP priority example illustrates a network example with three LSP types:

- gold P2P LSP, with setup 1 and hold 1
- silver P2MP LSP, with setup 3 and hold 3
- bronze P2P LSP, with setup 7 and hold 7

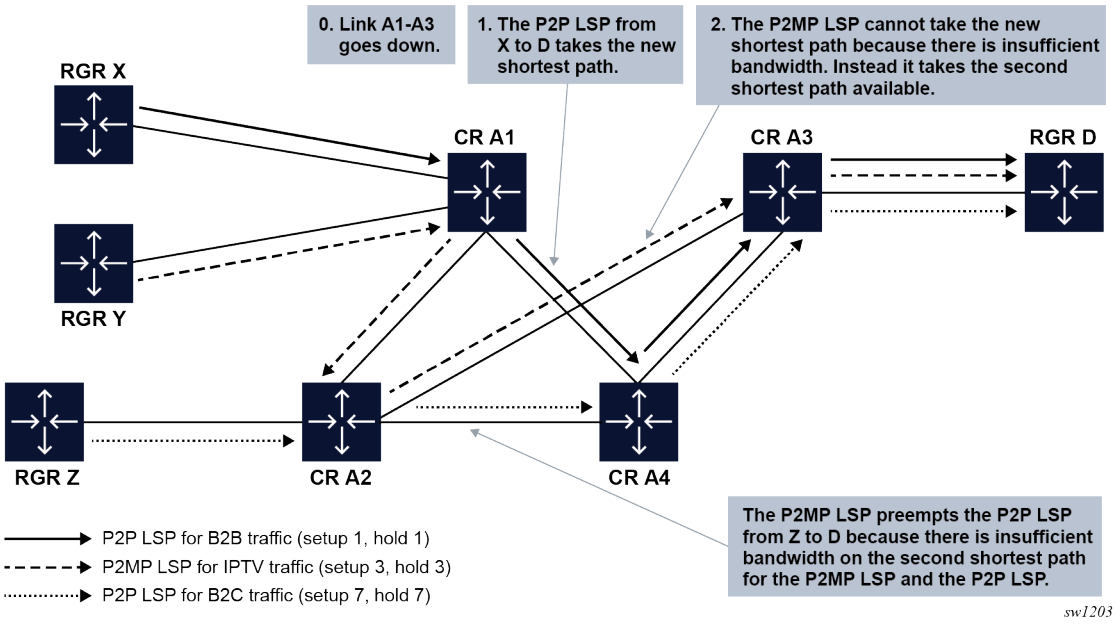
Figure 36: LSP priority example



If a link failure occurs between CR A1 and CR A3, as illustrated in Figure 37: Link failure example:

- The gold P2P LSPs take the shortest path and preempt all other P2P and P2MP LSPs that have lower hold values.
- The silver P2MP LSPs (S2L) take the second shortest path because there is insufficient bandwidth on the shortest path after the gold P2P LSPs reserve all the bandwidth. The bronze LSPs on this path are preempted.
- The bronze P2P LSPs take the longest path because there is insufficient bandwidth on the other two paths. They cannot preempt any other LSPs and can always be preempted by other LSPs that have higher priority values.

Figure 37: Link failure example



2.6.5.1 Soft preemption

When soft preemption is enabled for P2MP S2L LSPs, the S2L preemption is governed by the timer value configured using the **config>router>rsvp preemption-timer** classic CLI command or **configure router rsvp preemption-timer** MD-CLI command.

When the S2L is preempted at an LSR node, the preempting node sends to the head-end node an Resv refresh message with the "preemption pending" flag set or a PathErr message with error code=34 (Reroute) and a value=1 (Reroute request soft preemption). The preemption timer (configured as described above) starts. When the timer expires, the node performs MBB on the affected adaptive CSPF LSP. Both IGP metric and TE metric based CSPF LSPs are included. If an alternative path that excludes the flagged interface is not found, the LSP is placed on a retry list in a similar way to the global revertive procedure at a head-end node.

When the preemption timer expires, the preempting node tears down the S2L and sends a path error to the head-end node, and the head-end node places the S2L on the retry list.

2.6.5.2 Hard preemption

When soft preemption is not enabled for the P2MP LSP, the value of the preemption timer is hard coded as 0 for S2L LSPs. That is, S2Ls are hard preempted by higher priority LSPs. Make-before-break (MBB) is not performed at the root of the preempted S2L. That is, the S2L is immediately torn down to the root PE when it is preempted and must signal again.

When an S2L is preempted, it sends an RESVTEAR message to the root PE (head-end) indicating the lack of resources, and then the S2L is torn down throughout the network. After the P2MP S2L retry or fast retry timer expires, the S2L signals again by sending a new PATH message from the headend, based on the

newly calculated Constraint-based Shortest Path First (CSPF) path where the bandwidth resources are available.

S2Ls can preempt other P2P LSPs or other S2Ls based on the hold and setup priority.

2.6.6 Forwarding multicast packets over RSVP P2MP LSP in the base router

Multicast packets are forwarded over the P2MP LSP at the ingress LER based on a static join configuration of the multicast group against the tunnel interface associated with the originating P2MP LSP. At the egress LER, packets of a multicast group are received from the P2MP LSP via a static assignment of the specific <S,G> to the tunnel interface associated with a terminating LSP.

2.6.6.1 Procedures at ingress LER node

To forward multicast packets over a P2MP LSP, perform the following steps:

1. Create a tunnel interface associated with the P2MP LSP: **config>router>tunnel-interface rsvp-p2mp** *lsp-name*. (The config>router>pim>tunnel-interface command has been discontinued.)
2. Add static multicast group joins to the PIM interface, either as a specific <S,G> or as a <*,G>: **config>router>igmp>tunnel-if>static>group>source** *ip-address* and **config>router>igmp>tunnel-if>static>group>starg**.

The tunnel interface identifier consists of a string of characters representing the LSP name for the RSVP P2MP LSP. Note that MPLS actually passes to PIM a more structured tunnel interface identifier. The structure follows the one BGP uses to distribute the PMSI tunnel information in BGP multicast VPN as specified in *draft-ietf-l3vpn-2547bis-mcast-bgp*, *Multicast in MPLS/BGP IP VPNs*. The format is: <extended tunnel ID, reserved, tunnel ID, P2MP ID> as encoded in the RSVP-TE P2MP LSP session_attribute object in RFC 4875.

The user can create one or more tunnel interfaces in PIM and associate each to a different RSVP P2MP LSP. The user can then assign static multicast group joins to each tunnel interface. Note however that a specific <*,G> or <S,G> can only be associated with a single tunnel interface.

A multicast packet which is received on an interface and which succeeds the RPF check for the source address is replicated and forwarded to all OIFs which correspond to the branches of the P2MP LSP. The packet is sent on each OIF with the label stack indicated in the NHLFE of this OIF. The packets are also replicated and forwarded natively on all OIFs which have received IGMP or PIM joins for this <S,G>.

The multicast packet can be received over a PIM or IGMP interface which can be an IES interface, a spoke-SDP-terminated IES interface, or a network interface.

To duplicate a packet for a multicast group over the OIF of both P2MP LSP branches and the regular PIM or IGMP interfaces, the tap mask for the P2MP LSP and that of the PIM based interfaces needs to be combined into a superset MCID.

2.6.6.2 Procedures at egress LER node

2.6.6.2.1 Procedures with a primary tunnel interface

The user configures a tunnel interface and associates it with a terminating P2MP LSP leaf using the command: **config>router>tunnel-interface rsvp-p2mp lsp-name sender** *sender-address*. The **config>router>pim>tunnel-interface** command has been discontinued.

The tunnel interface identifier consists of a couple of string of characters representing the LSP name for the RSVP P2MP LSP followed by the system address of the ingress LER. The LSP name must correspond to a P2MP LSP name configured by the user at the ingress LER and must not contain the special character ":" Note that MPLS actually passes to PIM a more structured tunnel interface identifier. The structure follows the one BGP uses to distribute the PMSI tunnel information in BGP multicast VPN as specified in *draft-ietf-l3vpn-2547bis-mcast-bgp*. The format is: <extended tunnel ID, reserved, tunnel ID, P2MP ID> as encoded in the RSVP-TE P2MP LSP session_attribute object in RFC 4875.

The egress LER accepts multicast packets using the following methods:

- the regular RPF check on unlabeled IP multicast packets, which is based on routing table lookup
- the static assignment which specifies the receiving of a multicast group <*,G> or a specific <S,G> from a primary tunnel-interface associated with an RSVP P2MP LSP

One or more primary tunnel interfaces in the base router instance can be configured. In other words, the user is able to receive different multicast groups, <*,G> or specific <S,G>, from different P2MP LSPs. This assumes that the user configured static joins for the same multicast groups at the ingress LER to forward over a tunnel interface associated with the same P2MP LSP.

A multicast info policy CLI option allows the user to define a bundle and specify channels in the bundle that must be received from the primary tunnel interface. The user can apply the defined multicast info policy to the base router instance.

At any time, packets of the same multicast group can be accepted from either the primary tunnel interface associated with a P2MP LSP or from a PIM interface. These are mutually exclusive options. As soon as a multicast group is configured against a primary tunnel interface in the multicast info policy, it is blocked from other PIM interfaces.

However, if the user configured a multicast group to be received from a primary tunnel interface, there is nothing preventing packets of the same multicast group from being received and accepted from another primary tunnel interface. However, an ingress LER does not allow the same multicast group to be forwarded over two different P2MP LSPs. The only possible case is that of two ingress LERs forwarding the same multicast group over two P2MP LSPs toward the same egress LER.

A multicast packet received on a tunnel interface associated with a P2MP LSP can be forwarded over a PIM or IGMP interface which can be an IES interface, a spoke-SDP-terminated IES interface, or a network interface.

Note that packets received from a primary tunnel-interface associated with a terminating P2MP LSP cannot be forwarded over a tunnel interface associated with an originating P2MP LSP.

2.7 Pipe mode support for RSVP-TE MPLS trees

RSVP-TE P2MP LSPs can operate in uniform mode or pipe mode.

In uniform mode (default behavior), the multicast packet TTL value is copied to the P2MP LSP EXP field on the ingress label edge router (iLER). The MPLS TTL value is copied to the multicast PDU TTL on the egress label edge router (eLER), .

In pipe mode for P2MP LSPs, the iLER and LSR set the EXP value of the P2MP LSP header to 255 and the multicast PDU TTL value is not propagated to the MPLS header TTL. On the eLER, the behavior is the same as unicast, that is, the multicast PDU TTL = MIN{transport label stack TTL-1, service packet TTL-1}.

Use the following command to configure the pipe mode for iLER and eLER.

```
configure router mpls p2mp-ttl-propagate
```

The iLER and LSR default behavior is uniform mode.

2.7.1 Switching between uniform and pipe modes

When the **configure router mpls p2mp-ttl-propagate** configuration is modified, the new TTL mode applies to future P2MP LSPs only. The existing operational LSPs are not affected. If a new S2L is added to an existing P2MP tree at any node, the new S2L uses the same TTL mode as the rest of the tree. For the new configuration to take effect, the user must manually resignal the P2MP LSPs from the iLER. S2Ls cannot be resignaled from the eLER.

Use the following command at the iLER to resignal the specified P2MP LSP using Make-Before-Break (MBB).

```
tools perform router mpls resignal p2mp-lsp p2mp-lsp-name p2mp-instance p2mp-instance-name
```

Use the following command to make the P2MP resignal timer expire faster.

```
tools perform router mpls resignal p2mp-delay p2mp-minutes
```

Use the following command at the iLER to bounce the specified P2MP LSP.

```
clear router mpls lsp p2mp-lsp-name
```

When the **p2mp-ttl-propagate** configuration changes, an information message is displayed in the classic CLI indicating that the P2MP LSPs must be bounced for the change to take effect. In the MD-CLI, this information message is not supported currently.

2.8 MPLS service usage

Nokia routers enable service providers to deliver VPNs and Internet access using Generic Routing Encapsulation (GRE) or MPLS tunnels, or both, with Ethernet interfaces or SONET/SDH (on the 7750 SR and 7450 ESS) interfaces, or both.

2.8.1 Service distribution paths

A service distribution path (SDP) acts as a logical way of directing traffic from one router to another through a unidirectional (one-way) service tunnel. The SDP terminates at the far-end router which directs packets to the correct service egress service access point (SAP) on that device. All services mapped to an SDP use the same transport encapsulation type defined for the SDP (either GRE or MPLS).

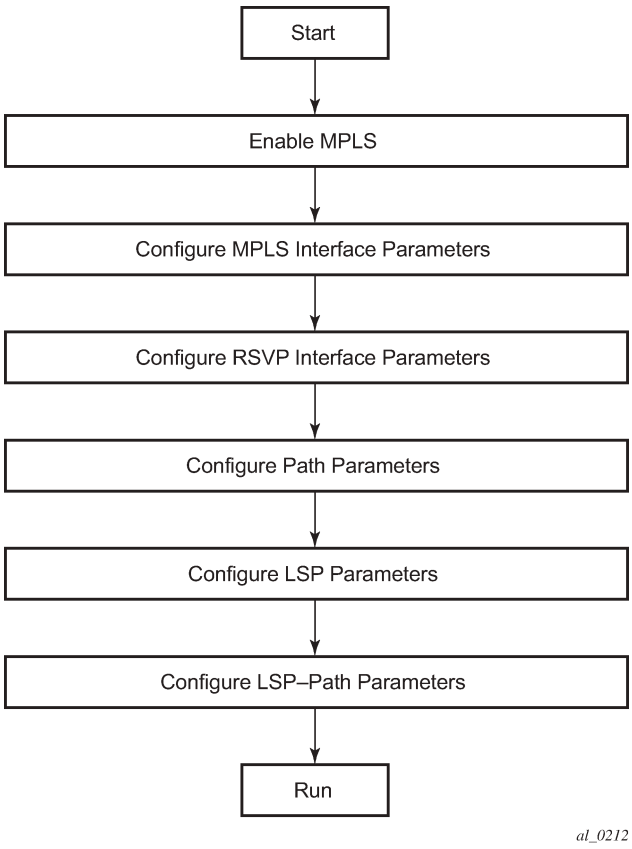
For information about service transport tunnels, see "Service Distribution Paths (SDPs)" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Services Overview Guide*. They can support up to eight forwarding classes

and can be used by multiple services. Multiple LSPs with the same destination can be used to load-balance traffic.

2.9 MPLS/RSVP configuration process overview

Figure 38: MPLS and RSVP configuration and implementation flow displays the process to configure MPLS and RSVP parameters.

Figure 38: MPLS and RSVP configuration and implementation flow



2.10 Configuration notes

This section describes MPLS and RSVP restrictions:

- Interfaces must already be configured in the **config**>**router**>**interface** context before they can be specified in MPLS and RSVP.
- A router interface must be specified in the **config**>**router**>**mpls** context to apply it or modify parameters in the **config**>**router**>**rsvp** context.
- A system interface must be configured and specified in the **config**>**router**>**mpls** context.
- Paths must be created before they can be applied to an LSP.

2.11 Configuring MPLS and RSVP with CLI

This section provides information to configure MPLS and RSVP using the command line interface.

2.11.1 MPLS configuration overview

Multiprotocol Label Switching (MPLS) enables routers to forward traffic based on a simple label embedded into the packet header. A router examines the label to determine the next hop for the packet, saving time for router address lookups to the next node when forwarding packets. MPLS is not enabled by default and must be explicitly enabled.

To implement MPLS, the following entities must be configured:

2.11.1.1 LSPs

To configure MPLS-signaled label switched paths (LSPs), an LSP must run from an ingress router to an egress router. Configure only the ingress router and configure LSPs to allow the software to make the forwarding decisions or statically configure some or all routers in the path. The LSP is set up by Resource Reservation Protocol (RSVP), through RSVP signaling messages. The router automatically manages label values. Labels that are automatically assigned have values ranging from 1,024 through 1,048,575 (see Label values).

A static LSP is a manually set up LSP where the nexthop IP address and the outgoing label are explicitly specified.

2.11.1.2 Paths

To configure signaled LSPs, you must first create one or more named paths on the ingress router. For each path, the transit routers (hops) in the path are specified.

2.11.1.3 Router interface

At least one router interface and one system interface must be defined in the **config**>**router**>**interface** context to configure MPLS on an interface.

2.11.1.4 Choosing the signaling protocol

To configure a static or a RSVP signaled LSP, you must enable MPLS on the router, which automatically enables RSVP and adds the system interface into both contexts. Any other network IP interface, other than loopbacks, added to MPLS is also automatically enabled in RSVP and becomes a TE link. When the interface is enabled in RSVP, the IGP instance advertises the Traffic Engineering (TE) information for the link to other routers in the network to build their TE database and compute CSPF paths. Operators must enable the traffic-engineering option in the ISIS or OSPF instance for this. Operators can also configure under the RSVP context of the interface the RSVP protocol parameters for that interface.

If only static label switched paths are used in your configurations, operators must manually define the paths through the MPLS network. Label mappings and actions configured at each hop must be specified.

Operators can disable RSVP on the interface if it is used only for incoming or outgoing static LSP label by shutting down the interface in the RSVP context. The latter causes IGP to withdraw the TE link from its advertisement which removes it from its local and neighbors TE database.

If dynamic LSP signaling is implemented in an operator's network then they must keep RSVP enabled on the interfaces they want to use for explicitly defined or CSPF calculated LSP path.

2.11.2 Basic MPLS configuration

This section provides information to configure MPLS and configuration examples of common configuration tasks. To enable MPLS, you must configure at least one MPLS interface. The other MPLS configuration parameters are optional. This follow displays an example of an MPLS configuration.

```
ALA-1>config>router>if-attr# info
----------------------------------------------
admin-group "green" 15
admin-group "yellow" value 20
admin-group "red" value 25
----------------------------------------------
A:ALA-1>config>router>mpls# info
----------------------------------------
            interface "system"
            exit
            interface "StaticLabelPop"
                admin-group "green"
                label-map 50
                    pop
                    no shutdown
                exit
            exit
            interface "StaticLabelPop"
                label-map 35
                    swap 36 nexthop 10.10.10.91
                    no shutdown
                exit
            exit
            path "secondary-path"
                no shutdown
            exit
            path "to-NYC"
                hop 1 10.10.10.104  strict
                no shutdown
            exit
            lsp "lsp-to-eastcoast"
                to 10.10.10.104
                from 10.10.10.103
                fast-reroute one-to-one
                exit
                primary "to-NYC"
                exit
                secondary "secondary-path"
                exit
                no shutdown
            exit
            static-lsp "StaticLabelPush"
                to 10.10.11.105
                push 60 nexthop 10.10.11.105
                no shutdown
            exit
            no shutdown
```

```
-----------------------------------------------
A:ALA-1>config>router>mpls#
```

2.11.3 Common configuration tasks

This section provides a brief overview of the tasks to configure MPLS and provides the CLI commands.

The following protocols must be enabled on each participating router:

- MPLS
- RSVP (for RSVP-signaled MPLS only), which is automatically enabled when MPLS is enabled

In order for MPLS to run, you must configure at least one MPLS interface in the **configure router mpls** context.

- An interface must be created in the **configure router interface** context before it can be applied to MPLS.
- In the **configure router mpls** context, configure path command options for configuring LSP parameters. A path specifies some or all hops from ingress to egress. A path can be used by multiple LSPs.
- When an LSP is created, the egress router must be specified in the following command and at least one primary or secondary path must be specified.

  ```
  configure router mpls lsp to
  configure router mpls static-lsp to
  ```

  All other statements under the LSP hierarchy are optional.

2.11.4 Configuring MPLS components

Use the MPLS and RSVP CLI syntax in the following sections to configure MPLS components.

2.11.4.1 Configuring global MPLS parameters

Admin groups can signify link colors, such as red, yellow, or green. MPLS interfaces advertise the link colors it supports. CSPF uses the information when paths are computed for constrained-based LSPs. CSPF must be enabled in order for admin groups to be relevant.

To configure MPLS admin-group parameters, enter the following commands:

```
if-attribute
    – admin-group group-name value group-value
    – mpls
    – frr-object
    – resignal-timer minutes
```

The following displays an admin group configuration example:

```
ALA-1>config>router>if-attr# info
----------------------------------------------
admin-group "green" value 15
admin-group "yellow" value 20
```

```
admin-group "red" value 25
-------------------------------------------
A:ALA-1>config>router>mpls# info
-------------------------------------------
            resignal-timer 500
...
-------------------------------------------
A:ALA-1>config>router>mpls#
```

2.11.4.2 Configuring an MPLS interface

Configure the **label-map** parameters if the interface is used in a static LSP. To configure an MPLS interface on a router, enter the following commands:

```
config>router>mpls
    – interface
        – no shutdown
        – admin-group group-name [group-name...(up to 32 max)]
        – label-map
            – pop
            – swap
            – no shutdown
        – srlg-group group-name [group-name...(up to 5 max)]
        – te-metric value
```

The following displays an interface configuration example:

```
A:ALA-1>config>router>mpls# info
-------------------------------------------
...
            interface "to-104"
                admin-group "green"
                admin-group "red"
                admin-group "yellow"
                label-map 35
                    swap 36 nexthop 10.10.10.91
                    no shutdown
                exit
            exit
            no shutdown
...
-------------------------------------------
A:ALA-1>config>router>mpls#
```

2.11.4.3 Configuring MPLS paths

Configure an LSP path to use in MPLS. When configuring an LSP, the IP address of the hops that the LSP should traverse on its way to the egress router must be specified. The intermediate hops must be configured as either **strict** or **loose** meaning that the LSP must take either a direct path from the previous hop router to this router (**strict**) or can traverse through other routers (**loose**).

Use the following CLI syntax to configure a path:

```
config>router> mpls
    – path path-name
        – hop hop-index ip-address {strict | loose}
```

```
        — no shutdown
```

The following displays a path configuration example:

```
A:ALA-1>config>router>mpls# info
----------------------------------------
            interface "system"
            exit
            path "secondary-path"
                hop 1 10.10.0.121  strict
                hop 2 10.10.0.145  strict
                hop 3 10.10.0.1    strict
                no shutdown
            exit
            path "to-NYC"
                hop 1 10.10.10.103 strict
                hop 2 10.10.0.210  strict
                hop 3 10.10.0.215  loose
            exit
----------------------------------------
A:ALA-1>config>router>mpls#
```

2.11.4.4 Configuring an MPLS LSP

Configure an LSP path for MPLS. When configuring an LSP, you must specify the IP address of the egress router in the **to** statement. Specify the primary path to be used. Secondary paths can be explicitly configured or signaled upon the failure of the primary path. All other statements are optional.

The following displays an MPLS LSP configuration:

```
A:ALA-1>config>router>mplp# info
----------------------------------------------
...
            lsp "lsp-to-eastcoast"
                to 192.168.200.41
                rsvp-resv-style ff
                path-computation-method local-cspf
                include "red"
                exclude "green"
                adspec
                fast-reroute one-to-one
                exit
                primary "to-NYC"
                    hop-limit 10
                exit
                secondary "secondary-path"
                    bandwidth 50000
                exit
                no shutdown
            exit
            no shutdown
----------------------------------------------
A:ALA-1>config>router>mpls#
```

2.11.4.5 Configuring a static LSP

An LSP can be explicitly (statically) configured. Static LSPs are configured on every node along the path. The label's forwarding information includes the address of the next hop router.

Use the following CLI syntax to configure a static LSP:

```
config>router>mpls
    – static-lsp lsp-name
        – to ip-address
        – push out-label nexthop ip-addr
        – no shutdown
```

The following displays a static LSP configuration example:

```
A:ALA-1>config>router>mpls# info
----------------------------------------------
...
            static-lsp "static-LSP"
                to 10.10.10.124
                push 60 nexthop 10.10.42.3
                no shutdown
            exit
...
----------------------------------------------
A:ALA-1>config>router>mpls#
```

2.11.4.6 Configuring manual bypass tunnels

Consider the following network setup:

A----B----C----D

| |

E----F

The user first configures the option to disable the dynamic bypass tunnels on node B if required. The CLI for this configuration is:

config>router>mpls>dynamic-bypass [disable | enable]

By default, dynamic bypass tunnels are enabled.

Next, the user configures an LSP on node B, such as B-E-F-C to be used only as bypass. The user specifies each hop in the path, for example, the bypass LSP has a strict path.

Note that including the bypass-only keyword disables the following options under the LSP configuration:

- bandwidth
- fast-reroute
- secondary

The following LSP configuration options are allowed:

- adaptive
- adspec
- exclude

- hop-limit
- include
- metric-type
- path-computation-method local-cspf

The following example displays a bypass tunnel configuration:

```
A:ALA-48>config>router>mpls>path# info
----------------------------------------
...
            path "BEFC"
                hop 10 10.10.10.11  strict
                hop 20 10.10.10.12  strict
                hop 30 10.10.10.13  strict
                no shutdown
            exit


            lsp "bypass-BC"
                to 10.10.10.15
                primary "BEFC"
                exit
                no shutdown
...
----------------------------------------
A:ALA-48>config>router>mpls>path#
```

Next, the user configures an LSP from A to D and indicates fast-reroute bypass protection by selecting facility as the FRR method (**config>router>mpls>lsp>fast-reroute facility**). If the LSP goes through B, and bypass is requested, and the next hop is C, and there is a manually configured bypass-only tunnel from B to C, excluding link BC, then node B uses that.

2.11.4.7 Configuring RSVP parameters

RSVP is used to set up LSPs. RSVP must be enabled on the router interfaces that are participating in signaled LSPs. The **keep-multiplier** and **refresh-time** default values can be modified in the RSVP context.

Initially, interfaces are configured in the **config>router>mpls>interface** context. Only these existing (MPLS) interfaces are available to modify in the **config>router> rsvp** context. Interfaces cannot be directly added in the RSVP context.

The following example displays an RSVP configuration example:

```
A:ALA-1>config>router>rsvp# info
----------------------------------------------
interface "system"
             no shutdown
          exit
          interface to-104
             hello-interval 4000
             no shutdown
          exit
          no shutdown
----------------------------------------------
A:ALA-1>config>router>rsvp#
```

2.11.4.8 Configure RSVP message pacing parameters

RSVP message pacing maintains a count of the messages that were dropped because the output queue for the egress interface was full.

Use the following CLI syntax to configure RSVP parameters:

```
config>router>rsvp
    – no shutdown
    – msg-pacing
        – period milli-seconds
        – max-burst number
```

The following example displays a RSVP message pacing configuration example:

```
A:ALA-1>config>router>rsvp# info
----------------------------------------------
            keep-multiplier 5
            refresh-time 60
            msg-pacing
                period 400
                max-burst 400
            exit
            interface "system"
                no shutdown
            exit
            interface to-104
                hello-interval 4000
                no shutdown
            exit
            no shutdown
----------------------------------------------
A:ALA-1>config>router>rsvp#
```

2.11.4.9 Configuring graceful shutdown

TE graceful shutdown can be enabled on a specific interface using the **config**>**router**>**rsvp**>**if**>**graceful-shutdown** command. This interface is referred to as the maintenance interface.

Graceful shutdown can be disabled by executing the **no** form of the command at the RSVP interface level or at the RSVP level. In this case, the user configured TE parameters of the maintenance links are restored and the maintenance node floods them.

2.12 MPLS configuration management tasks

This section discusses MPLS configuration management tasks.

2.12.1 Deleting MPLS

Note: To remove the MPLS instance, MPLS must be disabled (shutdown) and all SDP bindings to LSPs removed. If MPLS is not shutdown first, when the **no mpls** command is executed, a warning message on the console displays indicating that MPLS is still administratively up.

When MPLS is shut down, the **no mpls** command deletes the protocol instance and removes all configuration parameters for the MPLS instance. To disable MPLS, use the **shutdown** command.

To remove MPLS on a router, enter the following command:

```
config>router# no mpls
```

2.12.2 Modifying MPLS parameters

Note: You must shut down MPLS entities to modify parameters. Re-enable (**no shutdown**) the entity for the change to take effect.

2.12.3 Modifying an MPLS LSP

Some MPLS LSP parameters such as primary and secondary, must be shut down before they can be edited or deleted from the configuration.

The following displays a MPLS LSP configuration example. See the LSP configuration in Configuring an MPLS LSP.

```
A:ALA-1>>config>router>mpls>lsp# info
----------------------------------------------
                shutdown
                to 10.10.10.104
                from 10.10.10.103
                rsvp-resv-style ff
                include "red"
                exclude "green"
                fast-reroute one-to-one
                exit
                primary "to-NYC"
                    hop-limit 50
                exit
                secondary "secondary-path"
                exit
----------------------------------------------
A:ALA-1>config>router>mpls#
```

2.12.4 Modifying MPLS path parameters

To modify path parameters, the **config>router>mpls>path** context must be shut down first.

The following displays a path configuration example. See Configuring MPLS paths.

```
A:ALA-1>config>router>mpls# info
#------------------------------------------
echo "MPLS"
```

```
#-----------------------------------------
...
            path "secondary-path"
                hop 1 10.10.0.111  strict
                hop 2 10.10.0.222  strict
                hop 3 10.10.0.123  strict
                no shutdown
            exit
            path "to-NYC"
                hop 1 10.10.10.104 strict
                hop 2 10.10.0.210  strict
                no shutdown
            exit
...
-----------------------------------------------
A:ALA-1>config>router>mpls#
```

2.12.5 Modifying MPLS static LSP parameters

To modify static LSP parameters, the **config>router>mpls>path** context must be shut down first.

The following displays a static LSP configuration example. See the static LSP configuration in Configuring a static LSP.

```
A:ALA-1>config>router>mpls# info
----------------------------------------------
...
            static-lsp "static-LSP"
                to 10.10.10.234
                push 102704 nexthop 10.10.8.114
                no shutdown
            exit
            no shutdown
----------------------------------------------
A:ALA-1>config>router>mpls#
```

2.12.6 Deleting an MPLS interface

To delete an interface from the MPLS configuration, the interface must be shut down first.

Use the following CLI syntax to delete an interface from the MPLS configuration:

```
mpls
    – [no] interface ip-int-name
        – shutdown
```

```
ALA-1>config>router>if-attr# info
----------------------------------------------
admin-group "green" value 15
admin-group "yellow" value 20
admin-group "red" value 25
----------------------------------------------
A:ALA-1>config>router>mpls# info
----------------------------------------------
...
            interface "system"
            exit
```

```
            no shutdown
-----------------------------------------------
A:ALA-1>config>router>mpls#
```

2.13 RSVP configuration management tasks

This section discusses RSVP configuration management tasks.

2.13.1 Modifying RSVP parameters

Only interfaces configured in the MPLS context can be modified in the RSVP context.

The **no rsvp** command deletes this RSVP protocol instance and removes all configuration parameters for this RSVP instance.

The **shutdown** command suspends the execution and maintains the existing configuration.

The following example displays a modified RSVP configuration example:

```
A:ALA-1>config>router>rsvp# info
-----------------------------------------------
            keep-multiplier 5
            refresh-time 60
            msg-pacing
                period 400
                max-burst 400
            exit
            interface "system"
            exit
            interface "test1"
                hello-interval 5000
            exit
            no shutdown
-----------------------------------------------
A:ALA-1>config>router>rsvp#
```

2.13.2 Modifying RSVP message pacing parameters

RSVP message pacing maintains a count of the messages that were dropped because the output queue for the egress interface was full.

The following example displays command usage to modify RSVP parameters:

The following example displays a modified RSVP message pacing configuration example. See Configure RSVP message pacing parameters.

```
A:ALA-1>config>router>rsvp# info
-----------------------------------------------
            keep-multiplier 5
            refresh-time 60
            msg-pacing
                period 200
                max-burst 200
            exit
            interface "system"
```

```
            exit
            interface "to-104"
            exit
            no shutdown
-----------------------------------------------
A:ALA-1>config>router>rsvp#
```

2.13.3 Deleting an interface from RSVP

Interfaces cannot be deleted directly from the RSVP configuration. An interface must have been configured in the MPLS context, which enables it automatically in the RSVP context. The interface must first be deleted from the MPLS context. This removes the association from RSVP.

See Deleting an MPLS interface for information about deleting an MPLS interface.

3 Label Distribution Protocol

3.1 Label Distribution Protocol

Label Distribution Protocol (LDP) is a protocol used to distribute labels in non-traffic-engineered applications. LDP allows routers to establish label switched paths (LSPs) through a network by mapping network-layer routing information directly to data link layer-switched paths.

An LSP is defined by the set of labels from the ingress Label Switching Router (LSR) to the egress LSR. LDP associates a Forwarding Equivalence Class (FEC) with each LSP it creates. A FEC is a collection of common actions associated with a class of packets. When an LSR assigns a label to a FEC, it must allow other LSRs in the path know about the label. LDP helps to establish the LSP by providing a set of procedures that LSRs can use to distribute labels.

The FEC associated with an LSP specifies which packets are mapped to that LSP. LSPs are extended through a network as each LSR splices incoming labels for a FEC to the outgoing label assigned to the next hop for the FEC. The next-hop for a FEC prefix is resolved in the routing table. LDP can only resolve FECs for IGP and static prefixes. LDP does not support resolving FECs of a BGP prefix.

LDP allows an LSR to request a label from a downstream LSR so it can bind the label to a specific FEC. The downstream LSR responds to the request from the upstream LSR by sending the requested label.

LSRs can distribute a FEC label binding in response to an explicit request from another LSR. This is known as Downstream On Demand (DOD) label distribution. LSRs can also distribute label bindings to LSRs that have not explicitly requested them. This is called Downstream Unsolicited (DU).

3.1.1 LDP and MPLS

LDP performs the label distribution only in MPLS environments. The LDP operation begins with a hello discovery process to find LDP peers in the network. LDP peers are two LSRs that use LDP to exchange label/FEC mapping information. An LDP session is created between LDP peers. A single LDP session allows each peer to learn the other's label mappings (LDP is bidirectional) and to exchange label binding information.

LDP signaling works with the MPLS label manager to manage the relationships between labels and the corresponding FEC. For service-based FECs, LDP works in tandem with the Service Manager to identify the virtual leased lines (VLLs) and Virtual Private LAN Services (VPLSs) to signal.

An MPLS label identifies a set of actions that the forwarding plane performs on an incoming packet before discarding it. The FEC is identified through the signaling protocol (in this case, LDP) and allocated a label. The mapping between the label and the FEC is communicated to the forwarding plane. In order for this processing on the packet to occur at high speeds, optimized tables are maintained in the forwarding plane that enable fast access and packet identification.

When an unlabeled packet ingresses the router, classification policies associate it with a FEC. The appropriate label is imposed on the packet, and the packet is forwarded. Other actions that can take place before a packet is forwarded are imposing additional labels, other encapsulations, learning actions, and so on When all actions associated with the packet are completed, the packet is forwarded.

When a labeled packet ingresses the router, the label or stack of labels indicates the set of actions associated with the FEC for that label or label stack. The actions are performed on the packet and then the packet is forwarded.

The LDP implementation provides DOD, DU, ordered control, liberal label retention mode support.

3.1.2 LDP architecture

LDP comprises a few processes that handle the protocol PDU transmission, timer-related issues, and protocol state machine. The number of processes is kept to a minimum to simplify the architecture and to allow for scalability. Scheduling within each process prevents starvation of any particular LDP session, while buffering alleviates TCP-related congestion issues.

The LDP subsystems and their relationships to other subsystems are illustrated in Figure 39: Subsystem interrelationships. This illustration shows the interaction of the LDP subsystem with other subsystems, including memory management, label management, service management, SNMP, interface management, and RTM. In addition, debugging capabilities are provided through the logger.

Communication within LDP tasks is typically done by inter-process communication through the event queue, as well as through updates to the various data structures. The primary data structures that LDP maintains are:

- **FEC/label database**

  This database contains all FEC to label mappings that include both sent and received. It also contains both address FECs (prefixes and host addresses) and service FECs (L2 VLLs and VPLS).

- **timer database**

  This database contains all timers for maintaining sessions and adjacencies.

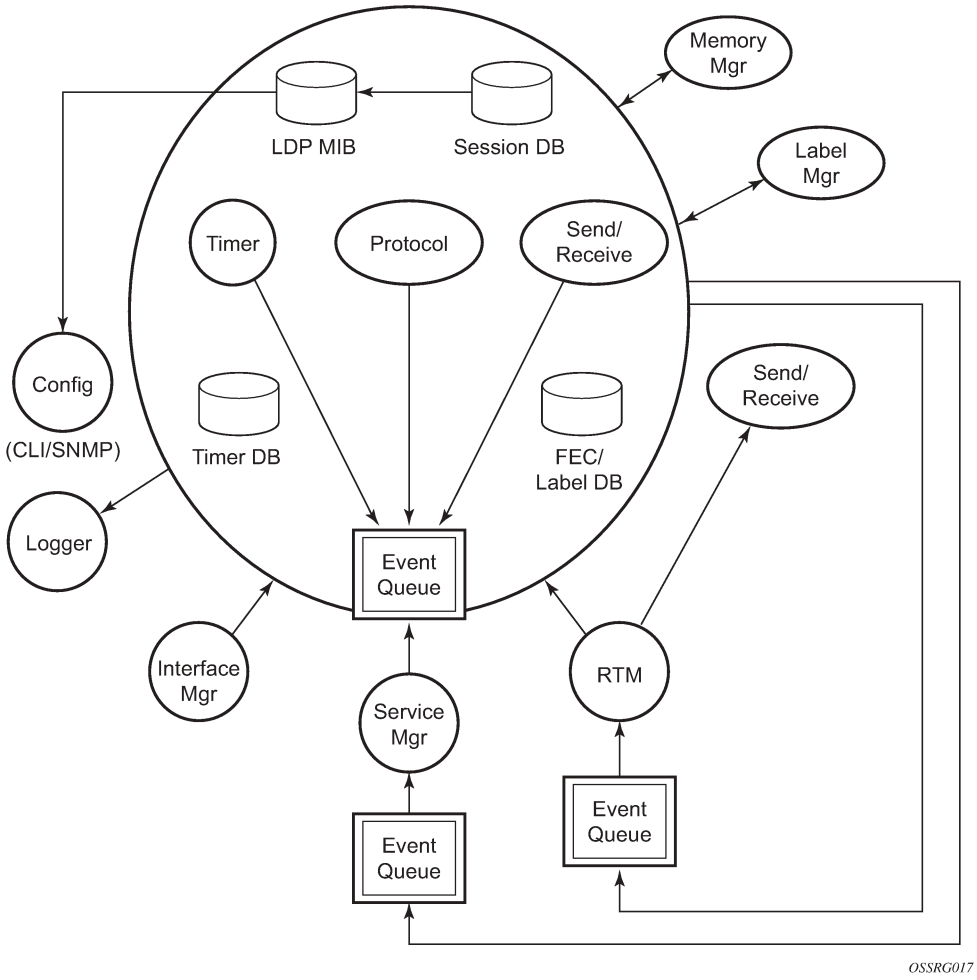
- **session database**

  This database contains all session and adjacency records and serves as a repository for the LDP MIB objects.

3.1.3 Subsystem interrelationships

The sections below describe how LDP and the other subsystems work to provide services. Figure 39: Subsystem interrelationships shows the interrelationships among the subsystems.

Figure 39: Subsystem interrelationships



3.1.3.1 Memory manager and LDP

LDP does not use any memory until it is instantiated. It pre-allocates some amount of fixed memory so that initial startup actions can be performed. Memory allocation for LDP comes out of a pool reserved for LDP that can grow dynamically as needed. Fragmentation is minimized by allocating memory in larger chunks and managing the memory internally to LDP. When LDP is shut down, it releases all memory allocated to it.

3.1.3.2 Label manager

LDP assumes that the label manager is up and running. LDP aborts initialization if the label manager is not running. The label manager is initialized at system boot up; therefore, anything that causes it to fail likely implies that the system is not functional. The router uses the dynamic label range to allocate all dynamic labels, including RSVP and BGP allocated labels and VC labels.

3.1.3.3 LDP configuration

The router uses a single consistent interface to configure all protocols and services. CLI commands are translated to SNMP requests and are handled through an agent-LDP interface. LDP can be instantiated or deleted through SNMP. Also, LDP targeted sessions can be set up to specific endpoints. Targeted-session parameters are configurable.

3.1.3.4 Logger

LDP uses the logger interface to generate debug information relating to session setup and teardown, LDP events, label exchanges, and packet dumps. Per-session tracing can be performed.

3.1.3.5 Service manager

All interaction occurs between LDP and the service manager, because LDP is used primarily to exchange labels for Layer 2 services. In this context, the service manager informs LDP when an LDP session is to be set up or torn down, and when labels are to be exchanged or withdrawn. In turn, LDP informs service manager of relevant LDP events, such as connection setups and failures, timeouts, labels signaled/withdrawn.

3.1.4 Execution flow

LDP activity in the operating system is limited to service-related signaling. Therefore, the configurable parameters are restricted to system-wide parameters, such as hello and keepalive timeouts.

3.1.4.1 Initialization

LDP makes sure that the various prerequisites, such as ensuring the system IP interface is operational, the label manager is operational, and there is memory available, are met. It then allocates itself a pool of memory and initializes its databases.

3.1.4.2 Session lifetime

In order for a targeted LDP (T-LDP) session to be established, an adjacency must be created. The LDP extended discovery mechanism requires Hello messages to be exchanged between two peers for session establishment. After the adjacency establishment, session setup is attempted.

3.1.4.2.1 Adjacency establishment

In the router, the adjacency management is done through the establishment of a Service Distribution Path (SDP) object, which is a service entity in the Nokia service model.

The Nokia service model uses logical entities that interact to provide a service. The service model requires the service provider to create configurations for four main entities:

- customers
- services

- Service Access Paths (SAPs) on the local routers
- Service Distribution Points (SDPs) that connect to one or more remote routers

An SDP is the network-side termination point for a tunnel to a remote router. An SDP defines a local entity that includes the system IP address of the remote routers and a path type. Each SDP comprises:

- the SDP ID
- the transport encapsulation type, either MPLS or GRE
- the far-end system IP address

If the SDP is identified as using LDP signaling, then an LDP extended Hello adjacency is attempted.

Note: If the **tldp** option is selected as the mechanism for exchanging service labels over an MPLS or GRE SDP and the T-LDP session is automatically established, an explicit T-LDP session that is subsequently configured takes precedence over the automatic T-LDP session. However, if the explicit, manually-configured session is then removed, the system does not revert to the automatic session and the automatic session is also deleted. To address this, recreate the T-LDP session by disabling and re-enabling the SDP using the **shutdown** and **no shutdown** commands. To address this in MD-CLI, recreate the T-LDP session by using the **admin-state** command to administratively disable and then enable the SDP.

If another SDP is created to the same remote destination, and if LDP signaling is enabled, no further action is taken, because only one adjacency and one LDP session exists between the pair of nodes.

An SDP is a unidirectional object, so a pair of SDPs pointing at each other must be configured in order for an LDP adjacency to be established. When an adjacency is established, it is maintained through periodic Hello messages.

3.1.4.2.2 Session establishment

When the LDP adjacency is established, the session setup follows as per the LDP specification. Initialization and keepalive messages complete the session setup, followed by address messages to exchange all interface IP addresses. Periodic keepalives or other session messages maintain the session liveliness.

Because TCP is back-pressured by the receiver, it is necessary to be able to push that back-pressure all the way into the protocol. Packets that cannot be sent are buffered on the session object and re-attempted as the back-pressure eases.

3.1.5 Label exchange

Label exchange is initiated by the service manager. When an SDP is attached to a service (for example, the service gets a transport tunnel), a message is sent from the service manager to LDP. This causes a label mapping message to be sent. Additionally, when the SDP binding is removed from the service, the VC label is withdrawn. The peer must send a label release to confirm that the label is not in use.

3.1.5.1 Other reasons for label actions

Other reasons for label actions include:

- **MTU changes**

LDP withdraws the previously assigned label and re-signals the FEC with the new MTU in the interface parameter.

- **clear labels**

  When a service manager command is issued to clear the labels, the labels are withdrawn, and new label mappings are issued.

- **SDP down**

  When an SDP goes administratively down, the VC label associated with that SDP for each service is withdrawn.

- **memory allocation failure**

  If there is no memory to store a received label, it is released.

- **VC type unsupported**

  When an unsupported VC type is received, the received label is released.

3.1.5.2 Cleanup

LDP closes all sockets, frees all memory, and shuts down all its tasks when it is deleted, so its memory usage is 0 when it is not running.

3.1.5.3 Configuring implicit null label

The implicit null label option allows an egress LER to receive MPLS packets from the previous hop without the outer LSP label. The user can configure to signal the implicit operation of the previous hop is referred to as penultimate hop popping (PHP). This option is signaled by the egress LER to the previous hop during the FEC signaling by the LDP control protocol.

Enable the use of the implicit null option, for all LDP FECs for which this node is the egress LER, using the following command:

config>**router**>**ldp**>**implicit-null-label**

When the user changes the implicit null configuration option, LDP withdraws all the FECs and re-advertises them using the new label value.

3.1.6 Global LDP filters

Both inbound and outbound LDP label binding filtering are supported.

Inbound filtering is performed by way of the configuration of an import policy to control the label bindings an LSR accepts from its peers. Label bindings can be filtered based on:

- prefix-list (match on bindings with the specified prefix/prefixes)
- neighbor (match on bindings received from the specified peer)

The default import policy is to accept all FECs received from peers.

Outbound filtering is performed by way of the configuration of an export policy. The Global LDP export policy can be used to explicitly originate label bindings for local interfaces. The Global LDP export policy

does not filter out or stop propagation of any FEC received from neighbors. Use the LDP peer export prefix policy for this purpose.

By default, the system does not interpret the presence or absence of the system IP in global policies, and as a result always exports a FEC for that system IP. The **consider-system-ip-in-gep** command causes the system to interpret the presence or absence of the system IP in global export policies in the same way as it does for the IP addresses of other interfaces.

Export policy enables configuration of a policy to advertise label bindings based on:

- direct (all local subnets)
- prefix-list (match on bindings with the specified prefix or prefixes)

The default export policy is to originate label bindings for system address only and to propagate all FECs received from other LDP peers.

Finally, the 'neighbor interface' statement inside a global import policy is not considered by LDP.

3.1.6.1 Per LDP peer FEC import and export policies

The FEC prefix export policy provides a way to control which FEC prefixes received from prefixes received from other LDP and T-LDP peers are re-distributed to this LDP peer.

The user configures the FEC prefix export policy using the following command:

config>router>ldp>session-params>peer>export-prefixes policy-name

By default, all FEC prefixes are exported to this peer.

The FEC prefix import policy provides a mean of controlling which FEC prefixes received from this LDP peer are imported and installed by LDP on this node. If resolved these FEC prefixes are then re-distributed to other LDP and T-LDP peers.

The user configures the FEC prefix export policy using the following command:

config>router>ldp>session-params>peer>import-prefixes policy-name

By default, all FEC prefixes are imported from this peer.

3.1.7 Configuring multiple LDP LSR ID

The multiple LDP LSR-ID feature provides the ability to configure and initiate multiple Targeted LDP (T-LDP) sessions on the same system using different LDP LSR-IDs. In the current implementation, all T-LDP sessions must have the LSR-ID match the system interface address. This feature continues to allow the use of the system interface by default, but also any other network interface, including a loopback, address on a per T-LDP session basis. The LDP control plane does not allow more than a single T-LDP session with different local LSR ID values to the same LSR-ID in a remote node.

An SDP of type LDP can use a provisioned targeted session with the local LSR-ID set to any network IP for the T-LDP session to the peer matching the SDP far-end address. If, however, no targeted session has been explicitly pre-provisioned to the far-end node under LDP, then the SDP auto-establishes one but uses the system interface address as the local LSR ID.

An SDP of type RSVP must use an RSVP LSP with the destination address matching the remote node LDP LSR-ID. An SDP of type GRE can only use a T-LDP session with a local LSR-ID set to the system interface.

The multiple LDP LSR-ID feature also provides the ability to use the address of the local LDP interface, or any other network IP interface configured on the system, as the LSR-ID to establish link LDP Hello adjacency and LDP session with directly connected LDP peers. The network interface can be a loopback or not.

Link LDP sessions to all peers discovered over a specific LDP interface share the same local LSR-ID. However, LDP sessions on different LDP interfaces can use different network interface addresses as their local LSR-ID.

By default, the link and targeted LDP sessions to a peer use the system interface address as the LSR-ID unless explicitly configured using this feature. The system interface must always be configured on the router or else the LDP protocol does not come up on the node. There is no requirement to include it in any routing protocol.

When an interface other than system is used as the LSR-ID, the transport connection (TCP) for the link or targeted LDP session also uses the address of that interface as the transport address.

3.1.7.1 Advertisement of FEC for local LSR ID

The FEC for a Local LSR ID is not advertised by default by the system, unless it is explicitly configured to do so. The advertisement of the local-lsr-id is configured using the **adv-local-lsr-id** commands in the session parameters for a specified peer or the targeted-session peer-template.

3.1.8 Extend LDP policies to mLDP

In addition to link LDP, a policy can be assigned to mLDP as an import policy. For example, if the following policy was assigned as an import policy to mLDP, any FEC arriving with an IP address of 100.0.1.21 is dropped.

```
*A:SwSim2>config>router>policy-options# info
----------------------------------------------
            prefix-list "100.0.1.21/32"
                prefix 100.0.1.21/32 exact
            exit
            policy-statement "policy1"
                entry 10
                    from
                        prefix-list "100.0.1.21/32"
                    exit
                    action drop
                    exit
                exit
                entry 20
                exit
                default-action accept
                exit
            exit
```

The policy can be assigned to mLDP using the **configure router ldp import-mcast-policy** *policy1* command. Based on this configuration, the prefix list matches the mLDP outer FEC and the action is executed.

Note: mLDP import policies are only supported for IPv4 FECs.

The mLDP import policy is useful for enforcing root only functionality on a network. For a PE to be a root only, enable the mLDP import policy to drop any arriving FEC on the P router.

3.1.8.1 Recursive FEC behavior

In the case of recursive FEC, the prefix list matches the outer root. For example, for recursive FEC <outerROOT, opaque <ActualRoot, opaque<lspID>> the import policy works on the outerROOT of the FEC.

The policy only matches to the outer root address of the FEC and no other field in the FEC.

3.1.8.2 Import policy

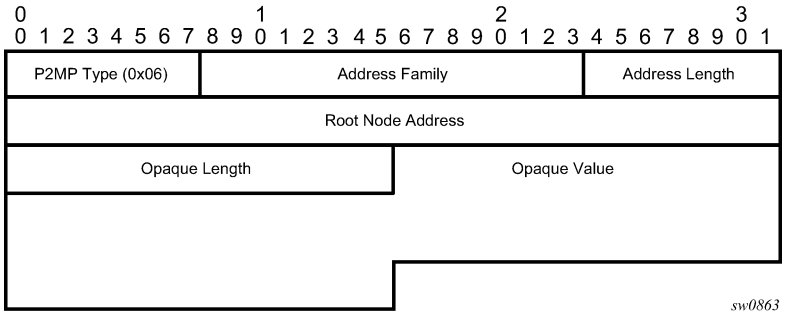
For mLDP, a policy can be assigned as an import policy only. Import policies only affect FECs arriving to the node, and do not affect the self-generated FECs on the node. The import policy causes the multicast FECs received from the peer to be rejected and stored in the LDP database but not resolved. Therefore, the **show router ldp binding** command displays the FEC but the FEC is not shown by the **show router ldp binding active** command. The FEC is not resolved if it is not allowed by the policy.

Only global import policies are supported for mLDP FEC. Per-peer import policies are not supported.

As defined in RFC 6388 for P2MP FEC, SR OS only matches the prefix against the root node address field of the FEC, and no other fields. This means that the policy works on all P2MP Opaque types.

The P2MP FEC Element is encoded as shown in Figure 40: P2MP FEC element encoding.

Figure 40: P2MP FEC element encoding



3.1.9 LDP FEC resolution per specified community

LDP communities provide separation between groups of FECs at the LDP session level. LDP sessions are assigned a community value and any FECs received or advertised over them are implicitly associated with that community.

Note: The community value only has local significance to a node. The user must therefore ensure that communities are assigned consistently to sessions across the network.

SR OS supports multiple targeted LDP sessions over a specified network IP interface between LDP peer systems, each with its own local LSR ID. This makes it especially suitable for building multiple LDP overlay topologies over a common IP infrastructure, each with their own community.

LDP FEC resolution per specified community is supported in combination with stitching to SR or BGP tunnels as follows:

- Although a FEC is only advertised within a specific LDP community, FEC can resolve to SR or BGP tunnels if those are the only available tunnels.
- If LDP has received a label from an LDP peer with an assigned community, that FEC is assigned the community of that session.
- If no LDP peer has advertised the label, LDP leaves the FEC with no community.
- The FEC may be resolvable over an SR or BGP tunnel, but the community it is assigned at the stitching node depends on whether LDP has also advertised that FEC to that node, and the community assigned to the LDP session over which the FEC was advertised.

3.1.9.1 Configuration

Note: The **no local-lsr-id** or **local-lsr-id system** commands are synonymous and mean that there is no local LSR ID for a session. These commands apply to classic CLI only.

A community is assigned to an LDP session by configuring a community string in the corresponding session parameters for the peer or the targeted session peer template. A community only applies to a local LSR ID for a session for the following commands.

```
configure router ldp interface-parameters interface ipv4 local-lsr-id
configure router ldp interface-parameters interface ipv6 local-lsr-id
configure router ldp targeted-session peer local-lsr-id
configure router ldp targeted-session peer-template local-lsr-id
```

It is never applied to a system FEC or local static FEC. A system FEC or static FEC cannot have a community associated with it and is therefore not advertised over an LDP session with a configured community. Only a single community string can be configured for a session toward a specified peer or within a specified targeted peer template. The FEC advertised by the following commands is automatically put in the community configured on the session.

```
configure router ldp session-parameters peer adv-local-lsr-id
configure router ldp targeted-session peer-template adv-local-lsr-id
```

The specified community is only associated with IPv4 and IPv6 address FECs incoming or outgoing on the relevant session, and not to IPv4/IPv6 P2MP FECs, or service FECs incoming/outgoing on the session.

Static FECs are treated as having no community associated with them, even if they are also received over another session with an assigned community. A mismatch is declared if this situation arises.

3.1.9.2 Operation

If a FEC is received over a session of a specified community, it is assumed to be associated with that community and is only broadcast to peers using sessions of that community. Likewise, a FEC received over a session with no community is only broadcast over other sessions with no community.

If a FEC is received over a session that does not have an assigned community, the FEC is treated as if it was received from a session with a differing assigned community. In other words, any particular FEC must only be received from sessions with a single, assigned community or no community. In any other

case (from sessions with differing communities, or from a combination of sessions with a community and sessions without a community), the FEC is considered to have a community mismatch.

The following procedures apply:

1. The system remembers the first community (including no community) of the session that a FEC is received on.
2. If the same FEC is subsequently received over a session with a differing community, the FEC is marked as mismatched and the system raises a trap indicating community mismatch.

   Note: Subsequent traps because of a mismatch for a FEC arriving over a session of the same community (or no community) are squelched for a period of 60 seconds after the first trap. The trap indicates the session and the community of the session, but does not need to indicate the FEC itself.

3. After a FEC has been marked as mismatched, the FEC is no longer advertised over sessions (or resolved to sessions) that differ either from the original community or in whether a community has been assigned. This can result in asymmetrical leaking of traffic between communities in specific cases, as illustrated by the following scenario. It is therefore recommended that FEC mismatches be resolved as soon as possible after they occur.

   Consider a triangle topology of Nodes A-B-C with iLDP sessions between them, using community=RED. At bootstrap, all the adv-local-lsrId FECs are exchanged, and the FECs are activated correctly as per routing. On each node, for each FEC there is a [local push] and a [local swap] as there is more than one peer advertising such a FEC. At this point all FECs are marked as being RED.

   - Focusing on Node C, consider:
     - Node A-owned RED FEC=X/32
     - Node B-owned RED FEC=Y/32
   - On Node C, the community of the session to node B is changed to BLUE. The consequence of this on Node C follows:
     - The [swap] operation for the remote Node A RED FEC=X/32 is de-programmed, as the Node B peer now BLUE, and therefore are not receiving Node A FEC=X/32 from B. Only the push is left programmed.
     - The [swap] operation for the remote Node B RED FEC=Y/32, is still programmed, even though this RED FEC is in mismatch, as it is received from both the BLUE peer Node B and the RED peer Node C.

4. When a session community changes, the session is flapped and the FEC community audited. If the original session is flapped, the FEC community changes as well. The following scenarios illustrate the operation of FEC community auditing:

   - **scenario A**
     - The FEC comes in on blue session A. The FEC is marked blue.
     - The FEC comes in on red session B. The FEC is marked "mismatched" and stays blue.
     - Session B is changed to green. Session B is bounced. The FEC community is audited, stays blue, and stays mismatched.
   - **scenario B**
     - The FEC comes in on blue session A. The FEC is marked blue.
     - The FEC comes in on red session B. The FEC is marked "mismatched" and stays blue.

  - Session A is changed to red. The FEC community audit occurs. The "mismatch" indication is cleared and the FEC is marked as red. The FEC remains red when session A comes back up.

- **scenario C**
  - The FEC comes in on blue session A. The FEC is marked blue.
  - The FEC comes in on red session B. The FEC is marked

    "mismatched" and stays blue.
  - Session A goes down. The FEC community audit occurs. The FEC is marked as red and the "mismatch" indication is cleared. The FEC is advertised over red session B.
  - Session A subsequently comes back up and it is still blue. The FEC remains red but is marked "mismatched". The FEC is no longer advertised over blue session A.

The community mismatch state for a prefix FEC is visible through the **show**>**router**>**ldp**>**bindings**>**prefixes** command output, while the community mismatch state is visible via a MIB flag (in the vRtrLdpNgAddrFecFlags object).

The fact that a FEC is marked "mismatched" has no bearing on its accounting with respect to the limit of the number of FECs that may be received over a session.

The ability of a policy to reject a FEC is independent of the FEC mismatch. A policy prevents the system from using the label for resolution, but if the corresponding session is sending community-mismatched FECs, there is a problem and it should be flagged. For example, the policy and community mismatch checks are independent, and a FEC should still be marked with a community mismatch, if needed, per the rules above

3.1.10 T-LDP hello reduction

This feature implements a new mechanism to suppress the transmission of the Hello messages following the establishment of a Targeted LDP session between two LDP peers. The Hello adjacency of the targeted session does not require periodic transmission of Hello messages as in the case of a link LDP session. In link LDP, one or more peers can be discovered over a specific network IP interface and therefore, the periodic transmission of Hello messages is required to discover new peers in addition to the periodic keepalive message transmission to maintain the existing LDP sessions. A Targeted LDP session is established to a single peer. Thus, after the Hello adjacency is established and the LDP session is brought up over a TCP connection, keepalive messages are sufficient to maintain the LDP session.

When this feature is enabled, the targeted Hello adjacency is brought up by advertising the Hold-Time value the user configured in the hello timeout parameter for the targeted session. The LSR node then starts advertising an exponentially increasing Hold-Time value in the Hello message as soon as the targeted LDP session to the peer is up. Each new incremented Hold-Time value is sent in a number of Hello messages equal to the value of the hello reduction factor before the next exponential value is advertised. This provides time for the two peers to settle on the new value. When the Hold-Time reaches the maximum value of 0xffff (binary 65535), the two peers send Hello messages at a frequency of every [(65535-1)/local helloFactor] seconds for the lifetime of the targeted-LDP session (for example, if the local hello factor is three (3), then Hello messages are sent every 21844 seconds).

Both LDP peers must be configured with this feature to bring gradually their advertised Hold-Time up to the maximum value. If one of the LDP peers does not, the frequency of the Hello messages of the targeted Hello adjacency continues to be governed by the smaller of the two Hold-Time values. This feature complies to *draft-pdutta-mpls-tldp-hello-reduce*.

3.1.11 Tracking a T-LDP peer with BFD

BFD tracking of an LDP session associated with a T-LDP adjacency allows for faster detection of the liveliness of the session by registering the peer transport address of a LDP session with a BFD session. The source or destination address of the BFD session is the local or remote transport address of the targeted or link (if peers are directly connected) Hello adjacency which triggered the LDP session.

By enabling BFD for a selected targeted session, the state of that session is tied to the state of the underneath BFD session between the two nodes. The parameters used for the BFD are set with the BFD command under the IP interface which has the source address of the TCP connection.

3.1.12 Link LDP hello adjacency tracking with BFD

LDP can only track an LDP peer using the Hello and keepalive timers. If an IGP protocol registered with BFD on an IP interface to track a neighbor, and the BFD session times out, the next-hop for prefixes advertised by the neighbor are no longer resolved. This however does not bring down the link LDP session to the peer because the LDP peer is not directly tracked by BFD.

To properly track the link LDP peer, LDP needs to track the Hello adjacency to its peer by registering with BFD.

The user effects Hello adjacency tracking with BFD by enabling BFD on an LDP interface:

config>**router**>**ldp**>**if-params**>**if**>**enable-bfd** [**ipv4**][**ipv6**]

The parameters used for the BFD session, that is, transmit-interval, receive-interval, and multiplier, are those configured under the IP interface:

config>**router**>**if**>**bfd**

The source or destination address of the BFD session is the local or remote address of link Hello adjacency. When multiple links exist to the same LDP peer, a Hello adjacency is established over each link. However, a single LDP session exists to the peer and uses a TCP connection over one of the link interfaces. Also, a separate BFD session should be enabled on each LDP interface. If a BFD session times out on a specific link, LDP immediately brings down the Hello adjacency on that link. In addition, if there are FECs that have their primary NHLFE over this link, LDP triggers the LDP FRR procedures by sending to IOM and line cards the neighbor/next-hop down message. This results in moving the traffic of the impacted FECs to an LFA next-hop on a different link to the same LDP peer or to an LFA backup next-hop on a different LDP peer depending on the lowest backup cost path selected by the IGP SPF.

As soon as the last Hello adjacency goes down as a result of the BFD timing out, the LDP session goes down and the LDP FRR procedures are triggered. This results in moving the traffic to an LFA backup next-hop on a different LDP peer.

3.1.13 LDP LSP statistics

RSVP-TE LSP statistics is extended to LDP to provide the following counters:

- per-forwarding-class forwarded in-profile packet count
- per-forwarding-class forwarded in-profile byte count
- per-forwarding-class forwarded out-of-profile packet count
- per-forwarding-class forwarded out-of-profile byte count

The counters are available for the egress datapath of an LDP FEC at ingress LER and at LSR. Because an ingress LER is also potentially an LSR for an LDP FEC, combined egress data path statistics is provided whenever applicable.

3.1.14 MPLS entropy label

The router supports the MPLS entropy label (RFC 6790) on LDP LSPs used for IGP and BGP shortcuts. This allows LSR nodes in a network to load-balance labeled packets in a much more granular fashion than allowed by simply hashing on the standard label stack.

To configure insertion of the entropy label on IGP or BGP shortcuts, use using the **entropy-label** command under the **configure router** context.

3.1.15 Importing LDP tunnels to non-host prefixes to TTM

When an LDP LSP is established, TTM is automatically populated with the corresponding tunnel. This automatic behavior does not apply to non-host prefixes. The **config**>**router**>**ldp**>**import-tunnel-table** command allows for TTM to be populated with LDP tunnels to such prefixes in a controlled manner for both IPv4 and IPv6.

3.2 TTL security for BGP and LDP

The BGP TTL Security Hack (BTSH) was originally designed to protect the BGP infrastructure from CPU utilization-based attacks. It is derived from the fact that the vast majority of ISP EBGP peerings are established between adjacent routers. Because TTL spoofing is considered nearly impossible, a mechanism based on an expected TTL value can provide a simple and reasonably robust defense from infrastructure attacks based on forged BGP packets.

While TTL Security Hack (TSH) is most effective in protecting directly connected peers, it can also provide a lower level of protection to multihop sessions. When a multihop BGP session is required, the expected TTL value can be set to 255 minus the configured range-of-hops. This approach can provide a qualitatively lower degree of security for BGP (such as a DoS attack could, theoretically, be launched by compromising a box in the path). However, BTSH catches a vast majority of observed distributed DoS (DDoS) attacks against EBGP.

TSH can be used to protect LDP peering sessions as well. For more information, see *draft-chen-ldp-ttl-xx.txt*, *TTL-Based Security Option for LDP Hello Message*.

The TSH implementation supports the ability to configure TTL security per BGP/LDP peer and evaluate (in hardware) the incoming TTL value against the configured TTL value. If the incoming TTL value is less than the configured TTL value, the packets are discarded and a log is generated.

3.3 ECMP support for LDP

ECMP support for LDP performs load balancing for LDP based LSPs by having multiple outgoing next-hops for a specific IP prefix on ingress and transit LSRs.

An LSR that has multiple equal cost paths to a specific IP prefix can receive an LDP label mapping for this prefix from each of the downstream next-hop peers. As the LDP implementation uses the liberal label retention mode, it retains all the labels for an IP prefix received from multiple next-hop peers.

Without ECMP support for LDP, only one of these next-hop peers is selected and installed in the forwarding plane. The algorithm used to determine the next-hop peer to be selected involves looking up the route information obtained from the RTM for this prefix and finding the first valid LDP next-hop peer (for example, the first neighbor in the RTM entry from which a label mapping was received). If, for some reason, the outgoing label to the installed next-hop is no longer valid, say the session to the peer is lost or the peer withdraws the label, a new valid LDP next-hop peer is selected out of the existing next-hop peers and LDP reprograms the forwarding plane to use the label sent by this peer.

With ECMP support, all the valid LDP next-hop peers, those that sent a label mapping for a specific IP prefix, are installed in the forwarding plane. In both cases, ingress LER and transit LSR, an ingress label are mapped to the next hops that are in the RTM and from which a valid mapping label has been received. The forwarding plane then uses an internal hashing algorithm to determine how the traffic is distributed amongst these multiple next-hops, assigning each "flow" to a particular next-hop.

The hash algorithm at LER and transit LSR are described in the "Traffic Load Balancing Options" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Interface Configuration Guide*.

LDP supports up to 64 ECMP next hops. LDP takes its maximum limit from the lower of **config**>**router**>**ecmp** and **config**>**router**>**ldp**>**max-ecmp-routes**.

3.3.1 Label operations

If an LSR is the ingress for a specific IP prefix, LDP programs push operation for the prefix in the forwarding engine. This creates an LSP ID to the Next Hop Label Forwarding Entry (NHLFE) (LTN) mapping and an LDP tunnel entry in the forwarding plane. LDP also informs the Tunnel Table Manager (TTM) of this tunnel. Both the LTN entry and the tunnel entry have a NHLFE for the label mapping that the LSR received from each of its next-hop peers.

If the LSR is to behave as a transit for a specific IP prefix, LDP programs a swap operation for the prefix in the forwarding engine. This involves creating an Incoming Label Map (ILM) entry in the forwarding plane. The ILM entry has to map an incoming label to possibly multiple NHLFEs. If an LSR is an egress for a specific IP prefix, LDP programs a POP entry in the forwarding engine. This too results in an ILM entry being created in the forwarding plane but with no NHLFEs.

When unlabeled packets arrive at the ingress LER, the forwarding plane consults the LTN entry and uses a hashing algorithm to map the packet to one of the NHLFEs (push label) and forward the packet to the corresponding next-hop peer. For labeled packets arriving at a transit or egress LSR, the forwarding plane consults the ILM entry and either use a hashing algorithm to map it to one of the NHLFEs if they exist (swap label) or simply route the packet if there are no NHLFEs (pop label).

Static FEC swap is not activated unless there is a matching route in system route table that also matches the user configured static FEC next-hop.

3.3.2 Weighted ECMP support for LDP

The router supports weighted ECMP in cases where LDP resolves a FEC over an ECMP set of direct next hops corresponding to IP network interfaces, and where it resolves the FEC over an ECMP set of RSVP-TE tunnels. See Weighted load-balancing for LDP over RSVP and SR-TE for information about LDP over RSVP.

Weighted ECMP for direct IP network interfaces uses a **load-balancing-weight** configured under the **config**>**router**>**ldp**>**interface-parameters**>**interface** context. Similar to LDP over RSVP, Weighted ECMP for LDP is enabled using the **weighted-ecmp** command under the **config**>**router**>**ldp** context. If the interface becomes an ECMP next hop for an LDP FEC, and all the other ECMP next hops are interfaces with configured (non-zero) load-balancing weights, then the traffic distribution over the ECMP interfaces is proportional to the normalized weight. Then, LDP performs the normalization with a granularity of 64.

If one or more of the LDP interfaces in the ECMP set does not have a configured-load-balancing weight, then the system falls back to ECMP.

If both an IGP shortcut tunnel and a direct next hop exist to resolve a FEC, LDP prefers the tunneled resolution. Therefore, if an ECMP set consists of both IGP shortcuts and direct next hops, LDP only load balances across the IGP shortcuts.

Note:

- LDP only uses configured LDP interface load balancing weights with non-LDP over RSVP resolutions.
- Weights are normalized across all possible next-hops for a FEC. If the number of ECMP routes configured with the **configure**>**router**>**ldp**>**max-ecmp-routes** is less than the actual number of next-hops, traffic is load-balanced using the normalized weights from the first **max-ecmp-routes** next-hop. This can cause load distribution within the LDP **max-ecmp-routes** that is not representative of the distribution that would occur across all ECMP next-hops.

3.4 Unnumbered interface support in LDP

This feature allows LDP to establish Hello adjacency and to resolve unicast and multicast FECs over unnumbered LDP interfaces.

This feature also extends the support of **lsp-ping**, **p2mp-lsp-ping**, and **ldp-treetrace** to test an LDP unicast or multicast FEC which is resolved over an unnumbered LDP interface.

3.4.1 Feature configuration

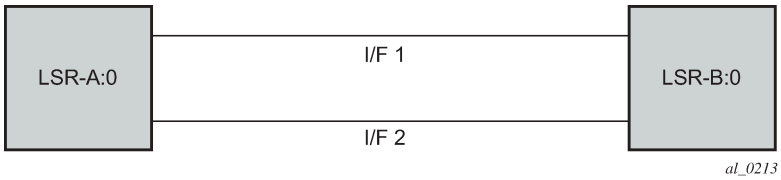
This feature does not introduce a new CLI command for adding an unnumbered interface into LDP. Rather, the **fec-originate** command is extended to specify the interface name because an unnumbered interface does not have an IP address of its own. The user can, however, specify the interface name for numbered interfaces.

See the CLI section for the changes to the **fec-originate** command.

3.4.2 Operation of LDP over an unnumbered IP interface

Consider the setup shown in Figure 41: LDP adjacency and session over unnumbered interface.

Figure 41: LDP adjacency and session over unnumbered interface



LSR A and LSR B have the following LDP identifiers respectively:

<LSR Id=A> : <label space id=0>

<LSR Id=B> : <label space id=0>

There are two P2P unnumbered interfaces between LSR A and LSR B. These interfaces are identified on each system with their unique local link identifier. In other words, the combination of {Router-ID, Local Link Identifier} uniquely identifies the interface in OSPF or IS-IS throughout the network.

A borrowed IP address is also assigned to the interface to be used as the source address of IP packets which need to be originated from the interface. The borrowed IP address defaults to the system loopback interface address, A and B respectively in this setup. The user can change the borrowed IP interface to any configured IP interface, loopback or not, by applying the following command:

config>router>if>unnumbered [<ip-int-name | ip-address>]

When the unnumbered interface is added into LDP, it has the following behavior.

3.4.2.1 Link LDP

When the IPv6 context of interfaces I/F1 and I/F2 are brought up, the following procedures are performed.

1. LSR A (LSR B) sends a IPv6 Hello message with source IP address set to the link-local unicast address of the specified local LSR ID interface, for example, fe80::a1 (fe80::a2), and a destination IP address set to the link-local multicast address ff02:0:0:0:0:0:0:2.
2. LSR A (LSR B) sets the LSR-ID in LDP identifier field of the common LDP PDU header to the 32-bit IPv4 address of the specified local LSR-ID interface LoA1 (LoB1), for example, A1/32 (B1/32).

   If the specified local LSR-ID interface is unnumbered or does not have an IPv4 address configured, the adjacency does not come up and an error is returned (lsrInterfaceNoValidIp [17]) in the output of the following command.

   ```
   show router ldp interface detail
   ```

3. LSR A (LSR B) sets the transport address TLV in the Hello message to the IPv6 address of the specified local LSR-ID interface LoA1 (LoB1), for example, A2/128 (B2/128).

   If the specified local LSR-ID interface is unnumbered or does not have an IPv6 address configured, the adjacency does not come up and an error is returned (interfaceNoValidIp [16]) in the output of the following command.

   ```
   show router ldp interface detail
   ```

4. LSR A (LSR B) includes in each IPv6 Hello message the dual-stack TLV with the transport connection preference set to IPv6 family.

- If the peer is a third-party LDP IPv6 implementation and does not include the dual-stack TLV, then LSR A (LSR B) resolves IPv6 FECs only because IPv6 addresses are not advertised in Address messages as per RFC 7552 [ldp-ipv6-rfc].
- If the peer is a third-party LDP IPv6 implementation and includes the dual-stack TLV with transport connection preference set to IPv4, LSR A (LSR B) does not bring up the Hello adjacency and discards the Hello message. If the LDP session was already established, then LSRA(B) sends a fatal Notification message with status code of 'Transport Connection Mismatch' (0x00000032)' and restart the LDP session [ldp-ipv6-rfc]. In both cases, a new counter for the transport connection mismatches is incremented in the output of the following command.

```
show router ldp statistics
```

5. The LSR with highest transport address takes on the active role and initiates the TCP connection for the LDP IPv6 session using the corresponding source and destination IPv6 transport addresses.

3.4.2.2 Targeted LDP

Source and destination addresses of targeted Hello packet are the LDP LSR-IDs of systems A and B. The user can configure the **local-lsr-id** option on the targeted session and change the value of the LSR-ID to either the local interface or to some other interface name, loopback or not, numbered or not. If the local interface is selected or the provided interface name corresponds to an unnumbered IP interface, the unnumbered interface borrowed IP address is used as the LSR-ID. In all cases, the transport address for the LDP session and the source IP address of targeted Hello message is updated to the new LSR-ID value.

The LSR with the highest transport address, that is, LSR-ID in this case, bootstraps the TCP connection and LDP session. Source and destination IP addresses of LDP messages are the transport addresses, that is, LDP LSR-IDs of systems A and B in this case.

3.4.2.3 FEC resolution

LDP advertises/withdraws unnumbered interfaces using the Address/Address-Withdraw message. The borrowed IP address of the interface is used.

A FEC can be resolved to an unnumbered interface in the same way as it is resolved to a numbered interface. The outgoing interface and next-hop are looked up in RTM cache. The next-hop consists of the router-id and link identifier of the interface at the peer LSR.

LDP FEC ECMP next-hops over a mix of unnumbered and numbered interfaces is supported.

All LDP FEC types are supported.

The **fec-originate** command is supported when the next-hop is over an unnumbered interface.

All LDP features are supported except for the following:

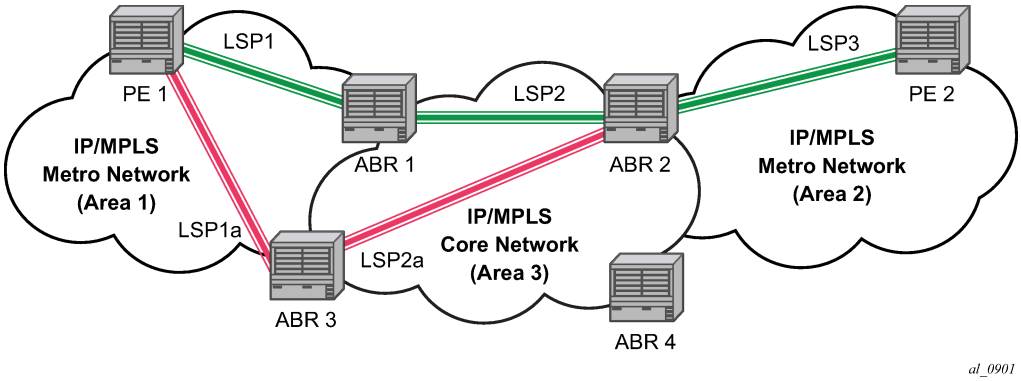
- BFD cannot be enabled on an unnumbered LDP interface. This is a consequence of the fact that BFD is not supported on unnumbered IP interface on the system.
- As a consequence of (1), LDP FRR procedures are not triggered via a BFD session timeout but only by physical failures and local interface down events.
- Unnumbered IP interfaces cannot be added into LDP global and peer prefix policies.

3.5 LDP over RSVP tunnels

LDP over RSVP-TE provides end-to-end tunnels that have two important properties, fast reroute and traffic engineering which are not available in LDP. LDP over RSVP-TE is focused at large networks (over 100 nodes in the network). Simply using end-to-end RSVP-TE tunnels do not scale. While an LER may not have that many tunnels, any transit node potentially has thousands of LSPs, and if each transit node also has to deal with detours or bypass tunnels, this number can make the LSR overly burdened.

LDP over RSVP-TE allows tunneling of user packets using an LDP LSP inside an RSVP LSP. The main application of this feature is for deployment of MPLS based services, for example, VPRN, VLL, and VPLS services, in large scale networks across multiple IGP areas without requiring full mesh of RSVP LSPs between PE routers.

Figure 42: LDP over RSVP application



The network displayed in Figure 42: LDP over RSVP application consists of two metro areas, Area 1 and 2 respectively, and a core area, Area 3. Each area makes use of TE LSPs to provide connectivity between the edge routers. To enable services between PE1 and PE2 across the three areas, LSP1, LSP2, and LSP3 are set up using RSVP-TE. There are in fact 6 LSPs required for bidirectional operation but we refer to each bidirectional LSP with a single name, for example, LSP1. A targeted LDP (T-LDP) session is associated with each of these bidirectional LSP tunnels. That is, a T-LDP adjacency is created between PE1 and ABR1 and is associated with LSP1 at each end. The same is done for the LSP tunnel between ABR1 and ABR2, and finally between ABR2 and PE2. The loopback address of each of these routers is advertised using T-LDP. Similarly, backup bidirectional LDP over RSVP tunnels, LSP1a and LSP2a, are configured by way of ABR3.

This setup effectively creates an end-to-end LDP connectivity which can be used by all PEs to provision services. The RSVP LSPs are used as a transport vehicle to carry the LDP packets from one area to another. Only the user packets are tunneled over the RSVP LSPs. The T-LDP control messages are still sent unlabeled using the IGP shortest path.

In this application, the bidirectional RSVP LSP tunnels are not treated as IP interfaces and are not advertised back into the IGP. A PE must always rely on the IGP to look up the next hop for a service packet. LDP-over-RSVP introduces a new tunnel type, tunnel-in-tunnel, in addition to the existing LDP tunnel and RSVP tunnel types. If multiple tunnels types match the destination PE FEC lookup, LDP prefers an LDP tunnel over an LDP-over-RSVP tunnel by default.

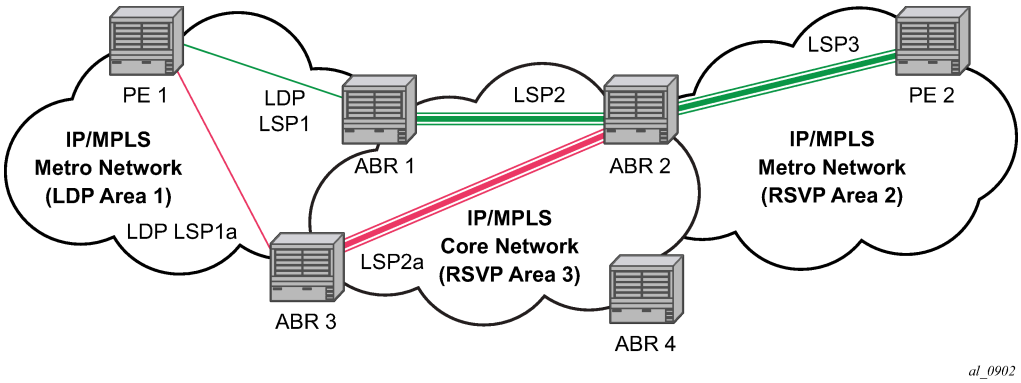
The design in Figure 42: LDP over RSVP application allows a service provider to build and expand each area independently without requiring a full mesh of RSVP LSPs between PEs across the three areas.

To participate in a VPRN service, the PE1 and PE2 perform the autobind to LDP. The LDP label which represents the target PE loopback address is used below the RSVP LSP label. Therefore a 3 label stack is required.

To provide a VLL service, PE1 and PE2 are still required to set up a targeted LDP session directly between them. Again a 3 label stack is required, the RSVP LSP label, followed by the LDP label for the loopback address of the destination PE, and finally the pseudowire label (VC label).

This implementation supports a variation of the application in Figure 42: LDP over RSVP application, in which area 1 is an LDP area. In that case, PE1 pushes a two label stack while ABR1 swaps the LDP label and push the RSVP label as illustrated in Figure 43: LDP over RSVP application variant. LDP-over-RSVP tunnels can also be used as IGP shortcuts.

Figure 43: LDP over RSVP application variant



3.5.1 Signaling and operation

3.5.1.1 LDP label distribution and FEC resolution

The user creates a targeted LDP (T-LDP) session to an ABR or the destination PE. This results in LDP hellos being sent between the two routers. These messages are sent unlabeled over the IGP path. Next, the user enables LDP tunneling on this T-LDP session and optionally specifies a list of LSP names to associate with this T-LDP session. By default, all RSVP LSPs which terminate on the T-LDP peer are candidates for LDP-over-RSVP tunnels. At this point in time, the LDP FECs resolving to RSVP LSPs are added into the Tunnel Table Manager as tunnel-in-tunnel type.

If LDP is running on regular interfaces also, the prefixes LDP learns are going to be distributed over both the T-LDP session as well as regular IGP interfaces. LDP FEC prefixes with a subnet mask lower or equal than 32 are resolved over RSVP LSPs. The policy controls which prefixes go over the T-LDP session, for example, only /32 prefixes, or a particular prefix range.

LDP-over-RSVP works with both OSPF and ISIS. These protocols include the advertising router when adding an entry to the RTM. LDP-over-RSVP tunnels can be used as shortcuts for BGP next-hop resolution.

3.5.1.2 Default FEC resolution procedure

When LDP tries to resolve a prefix received over a T-LDP session, it performs a lookup in the Routing Table Manager (RTM). This lookup returns the next hop to the destination PE and the advertising router (ABR or destination PE itself). If the next-hop router advertised the same FEC over link-level LDP, LDP prefers the LDP tunnel by default unless the user explicitly changed the default preference using the system wide prefer-tunnel-in-tunnel command. If the LDP tunnel becomes unavailable, LDP selects an LDP-over-RSVP tunnel if available.

When searching for an LDP-over-RSVP tunnel, LDP selects the advertising routers with best route. If the advertising router matches the T-LDP peer, LDP then performs a second lookup for the advertising router in the Tunnel Table Manager (TTM) which returns the user configured RSVP LSP with the best metric. If there are more than one configured LSP with the best metric, LDP selects the first available LSP.

If all user configured RSVP LSPs are down, no more action is taken. If the user did not configure any LSPs under the T-LDP session, the lookup in TTM returns the first available RSVP LSP which terminates on the advertising router with the lowest metric.

3.5.1.3 FEC resolution procedure When prefer-tunnel-in-tunnel is enabled

When LDP tries to resolve a prefix received over a T-LDP session, it performs a lookup in the Routing Table Manager (RTM). This lookup returns the next hop to the destination PE and the advertising router (ABR or destination PE itself).

When searching for an LDP-over-RSVP tunnel, LDP selects the advertising routers with best route. If the advertising router matches the targeted LDP peer, LDP then performs a second lookup for the advertising router in the Tunnel Table Manager (TTM) which returns the user configured RSVP LSP with the best metric. If there are more than one configured LSP with the best metric, LDP selects the first available LSP.

If all user configured RSVP LSPs are down, then an LDP tunnel is selected if available.

If the user did not configure any LSPs under the T-LDP session, a lookup in TTM returns the first available RSVP LSP which terminates on the advertising router. If none are available, then an LDP tunnel is selected if available.

3.5.2 Rerouting around failures

Every failure in the network can be protected against, except for the ingress and egress PEs. All other constructs have protection available. These constructs are LDP-over-RSVP tunnel and ABR.

3.5.2.1 LDP-over-RSVP tunnel protection

An RSVP LSP can deal with a failure in two ways:

- If the LSP is a loosely routed LSP, then RSVP finds a new IGP path around the failure, and traffic follows this new path. This may involve some churn in the network if the LSP comes down and then gets re-routed. The tunnel damping feature was implemented on the LSP so that all the dependent protocols and applications do not flap unnecessarily.
- If the LSP is a CSPF-computed LSP with the fast reroute option enabled, then RSVP switches to the detour path very quickly. From that point, a new LSP is attempted from the head-end (global revertive). When the new LSP is in place, the traffic switches over to the new LSP with make-before-break.

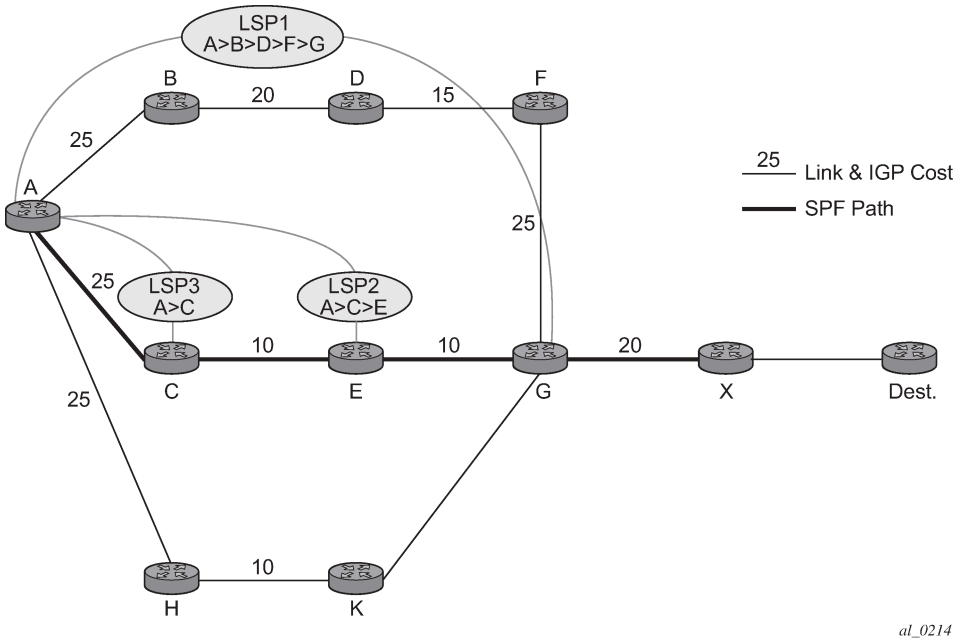
3.5.2.2 ABR protection

If an ABR fails, then routing around the ABR requires that a new next-hop LDP-over-RSVP tunnel be found to a backup ABR. If an ABR fails, then the T-LDP adjacency fails. Eventually, the backup ABR becomes the new next hop (after SPF converges), and LDP learns of the new next-hop and can reprogram the new path.

3.6 LDP over RSVP without area boundary

The LDP over RSVP capability set includes the ability to stitch LDP-over-RSVP tunnels at internal (non-ABR) OSPF and IS-IS routers.

Figure 44: LDP over RSVP without ABR stitching point



In Figure 44: LDP over RSVP without ABR stitching point, assume that the user wants to use LDP over RSVP between router A and destination "Dest". The first thing that happens is that either OSPF or IS-IS performs an SPF calculation resulting in an SPF tree. This tree specifies the lowest possible cost to the destination. In the example shown, the destination "Dest" is reachable at the lowest cost through router X. The SPF tree has the following path: A>C>E>G>X.

Using this SPF tree, router A searches for the endpoint that is closest (farthest/highest cost from the origin) to "Dest" that is eligible. Assuming that all LSPs in the above diagram are eligible, LSP endpoint G is selected as it terminates on router G while other LSPs only reach routers C and E, respectively.

IGP and LSP metrics associated with the various LSP are ignores; only tunnel endpoint matters to IGP. The endpoint that terminates closest to "Dest" (highest IGP path cost) is selected for further selection of the LDP over RSVP tunnels to that endpoint. The explicit path the tunnel takes may not match the IGP path that the SPF computes.

If router A and G have an additional LSP terminating on router G, there would now be two tunnels both terminating on the same router closest to the final destination. For IGP, it does not make any difference on the numbers of LDPs to G, only that there is at least one LSP to G. In this case, the LSP metric is considered by LDP when deciding which LSP to stitch for the LDP over RSVP connection.

The IGP only passes endpoint information to LDP. LDP looks up the tunnel table for all tunnels to that endpoint and picks up the one with the least tunnel metric. There may be many tunnels with the same least cost. LDP FEC prefixes with a subnet mask lower or equal than 32 is resolved over RSVP LSPs within an area.

3.6.1 LDP over RSVP and ECMP

ECMP for LDP over RSVP is supported (also see ECMP support for LDP). If ECMP applies, all LSP endpoints found over the ECMP IGP path is installed in the routing table by the IGP for consideration by LDP. IGP costs to each endpoint may differ because IGP selects the farthest endpoint per ECMP path.

LDP chooses the endpoint that is highest cost in the route entry and does further tunnel selection over those endpoints. If there are multiple endpoints with equal highest cost, then LDP considers all of them.

3.7 Weighted load-balancing for LDP over RSVP and SR-TE

Weighted load-balancing (Weighted ECMP) is supported for LDP over RSVP (LoR):

- when the LDP next hop resolves to an IGP shortcut tunnel over RSVP
- when the LDP resolves to a static route with next hops which in turn uses RSVP tunnels
- where the **tunneling** command is configured for the LDP peer (classic LDP over RSVP)

It is also supported when the LDP next hop resolves to an IGP shortcut tunnel over SR-TE. Weighted load-balancing is supported for both push and swap NHLFEs.

At a high level, weighted load-balancing operates as follows:

1. All the RSVP or SR-TE LSPs in the ECMP set must have a **load-balancing-weight** configured; otherwise, non-weighted ECMP behavior is used.
2. The normalized weight of each RSVP or SR-TE LSP is calculated based on its configured load-balancing weight. LDP performs the calculation to a resolution of 64, meaning if there are values between 1 and 200, the system buckets these into 64 values. These LSP next-hops are then populated in TTM.
3. RTM entries are updated accordingly for LDP shortcuts.
4. When weighted ECMP is configured for LDP, the normalized weight is downloaded to the IOM when the LDP route is resolved. This occurs for both push and swap NHLFEs.
5. LDP labeled packets are then sprayed in proportion to the normalized weight of the RSVP or SR-TE LSPs that they are forwarded over.
6. No per-service differentiation exists between packets. LDP-labeled packets from all services are sprayed in proportion to the normalized weight.
7. Tunnel-in-tunnel takes precedence over the existence of a static route with a tunneled next hop. If tunneling is configured, then LDP uses these LSPs instead of those used by the static route. This means that LDP may use different tunnels to those pointed to by static routes.

Weighted ECMP for LDP over RSVP, when using IGP shortcuts or static routes, or LDP over SR-TE, when using IGP shortcuts, is enabled as follows:

- **Classic CLI commands**

```
configure
   router
      weighted-ecmp [strict]
      no weighted-ecmp

configure
   router
      ldp
         [no] weighted-ecmp
```

- **MD-CLI commands**

```
configure
   router
      weighted-ecmp {false|true|strict}

configure
   router
      ldp
         weighted-ecmp {true|false}
```

However, in the case of classic LoR, the operator only needs to configure weighted ECMP needs under LDP. The maximum number of ECMP tunnels is taken from the lower of the **config**>**router**>**ecmp** and **config**>**router**>**ldp**>**max-ecmp-routes** commands.

The following configuration illustrates the case of LDP resolving to a static route with one or more indirect next hops and a set of RSVP tunnels specified in the resolution filter:

- **Classic CLI**

```
config>router
   static-route-entry 192.0.2.102/32
      indirect 192.0.2.2
        tunnel-next-hop
           resolution-filter
              rsvp-te
                 lsp "LSP-ABR-1-1"
                 lsp "LSP-ABR-1-2"
                 lsp "LSP-ABR-1-3"
                 exit
           exit
      indirect 192.0.2.3
        tunnel-next-hop
           resolution-filter
              rsvp-te
                 lsp "LSP-ABR-2-1"
                 lsp "LSP-ABR-2-2"
                 lsp "LSP-ABR-2-3"
                 exit
            exit
            no shutdown
       exit
```

- **MD-CLI**

```
!*[gl:/configure router "Base"]
```

```
    static-routes route 192.0.2.102/32 route-type unicast
      indirect 192.0.2.2
        tunnel-next-hop
          resolution-filter
            rsvp-te
              lsp "LSP-ABR-1-1"
              lsp "LSP-ABR-1-2"
              lsp "LSP-ABR-1-3"
              exit
        exit
      indirect 192.0.2.3
        tunnel-next-hop
           resolution-filter
              rsvp-te
                 lsp "LSP-ABR-2-1"
                 lsp "LSP-ABR-2-2"
                 lsp "LSP-ABR-2-3"
                 exit
           exit
        exit
```

If both **config>router>weighted-ecmp** and **config>router>ldp>weighted-ecmp** are configured, then the weights of all of the RSVP tunnels for the static route are normalized to 64 and these are used to spray LDP labeled packets across the set of LSPs. This applies across all shortcuts (static and IGP) to which a route is resolved to the far-end prefix.

3.7.1 Interaction with Class-Based Forwarding

Class Based Forwarding (CBF) is not supported together with Weighted ECMP in LoR.

If both weighted ECMP and class-forwarding are configured under LDP, then LDP uses weighted ECMP only if all LSP next hops have non-default-weighted values configured. If any of the ECMP set LSP next hops do not have the weight configured, then LDP uses CBF. Otherwise, LDP uses CBF if possible. If weighted ECMP is configured for both LDP and the IGP shortcut for the RSVP tunnel, (**config**>**router**>**weighted-ecmp**), then weighted ECMP is used.

LDP resolves and programs FECs according to the weighted ECMP information if the following conditions are met:

- LDP has both CBF and weighted ECMP fully configured.
- All LSPs in ECMP set have both a load-balancing weight and CBF information configured.
- **weighted-ecmp** is enabled under **config**>**router**.

Subsequently, deleting the CBF configuration has no effect; however, deleting the weighted ECMP configuration causes LDP to resolve according to CBF, if complete, consistent CBF information is available. Otherwise LDP sprays over all the LSPs equally, using non-weighted ECMP behavior.

If the IGP shortcut tunnel using the RSVP LSP does not have complete weighted ECMP information (for example, **config**>**router**>**weighted-ecmp** is not configured or one or more of the RSVP tunnels has **no load-balancing-weight**) then LDP attempts CBF resolution. If the CBF resolution is complete and consistent, then LDP programs that resolution. If a complete, consistent CBF resolution is not received, then LDP sprays over all the LSPs equally, using regular ECMP behavior.

Where entropy labels are supported on LoR, the entropy label (both insertion and extraction at LER for the LDP label and hashing at LSR for the LDP label) is supported when weighted ECMP is in use.

3.8 Class-Based Forwarding of LDP prefix packets over IGP shortcuts

Within large ISP networks, services are typically required from any PE to any PE and can traverse multiple domains. Also, within a service, different traffic classes can coexist, each with specific requirements on latency and jitter.

SR OS provides a comprehensive set of Class Based Forwarding capabilities. Specifically the following can be performed:

- class-based forwarding, in conjunction with ECMP, for incoming unlabeled traffic resolving to an LDP FEC, over IGP IPv4 shortcuts (LER role)
- class-based forwarding, in conjunction with ECMP, for incoming labeled LDP traffic, over IGP IPv4 shortcuts (LSR role)
- class-based forwarding, in conjunction with ECMP, of GRT IPv4/IPv6 prefixes over IGP IPv4 shortcuts

  See chapter IP Router Configuration, Section 2.3 in *7450 ESS, 7750 SR, 7950 XRS, and VSR Router Configuration Guide*, for a description of this case.
- class-based forwarding, in conjunction with ECMP, of VPN-v4/-v6 prefixes over RSVP-TE or SR-TE

  See chapter Virtual Private Routed Network Service, Section 3.2.27 in *7450 ESS, 7750 SR, 7950 XRS, and VSR Layer 3 Services Guide: IES and VPRN*, for a description of this case.

IGP IPv4 shortcuts, in all four cases, see MPLS RSVP-TE or SR-TE LSPs.

3.8.1 Configuration and operation

The class-based forwarding feature enables service providers to control which LSPs, of a set of ECMP tunnel next hops that resolve an LDP FEC prefix, to forward packets that were classified to specific forwarding classes, as opposed to normal ECMP spraying where packets are sprayed over the whole set of LSPs.

To activate CBF, the user should enable the following:

- IGP shortcuts or forwarding adjacencies in the routing instance
- ECMP
- advertisement of unicast prefix FECs on the Targeted LDP session to the peer
- class-based forwarding in the LDP context (LSR role, LER role or both)

The **FC-to-Set based configuration** mode is controlled by the following commands:

config>router>mpls>class-forwarding-policy *policy-name*

config>router>mpls>class-forwarding-policy>fc> {**be** | **l2** | **af** | **l1** | **h2** | **ef** | **h1** | **nc**} **forwarding-set** *value*

config>router>mpls>class-forwarding-policy>default-set *value*

config>router>mpls>lsp>class-forwarding>forwarding-set policy *policy-name* **set** *set-id*

The last command applies to the **lsp-template** context. So, LSPs that are created from that template, acquire the assigned CBF configurations.

Multiple FCs can be assigned to a specific set. Also, multiple LSPs can map to the same (policy, set) pair. However, an LSP cannot map to more than one (policy, set) pair.

Both configuration modes are mutually exclusive on a per LSP basis.

The CBF behavior depends on the configuration used, and on whether CBF was enabled for the LER or LSR roles, or both. The table below illustrates the different modes of operation of Class Based Forwarding depending on the node functionality where enabled, and on the type of configuration present in the ECMP set.

These modes of operation are described in following sections.

3.8.1.1 LSR and LER roles with FC-to-Set configuration

Both LSR and LER roles behave in the same way with this type of configuration. Before installing CBF information in the forwarding path, the system performs a consistency check on the CBF information of the ECMP set of tunnel next hops that resolve an LDP prefix FEC.

If no LSP, in the full ECMP set, has been assigned with a class forwarding policy configuration, the set is considered as inconsistent from a CBF perspective. The system, then, programs in the forwarding path, the whole ECMP set without any CBF information, and regular ECMP spraying occurs over the full set.

If the ECMP set is assigned to more than one class forwarding policy, the set is inconsistent from a CBF perspective. Then, the system programs, in the forwarding path, the whole ECMP set without any CBF information, and regular ECMP spraying occurs over the full set.

A full ECMP set is consistent from a CBF perspective when the ECMP:

- is assigned to a single class forwarding policy
- contains either an LSP assigned to the default set (implicit or explicit)
- contains an LSP assigned to a non-default set that has explicit FC mappings

If there is no default set in a consistent ECMP set, the system automatically selects one set as the default one. The selected set is one set with the lowest ID among those referenced by the LSPs of the ECMP set.

If the ECMP set is consistent from a CBF perspective, the system programs in the forwarding path all the LSPs which have CBF configuration, and packets classified to a specific FC are forwarded by using the LSPs of the corresponding forwarding set.

If there are more than one LSPs in a forwarding set, the system performs a modulo operation on these LSPs only to select one. As a result, ECMP spraying occurs for multiple packets of this forwarding class. Also, the system programs, in the forwarding path, the remaining LSPs of the ECMP set, without any CBF information. These LSPs are not used for class-based forwarding.

If there is no operational LSP in a specific forwarding set, the system forwards packets which have been classified to the corresponding forwarding class onto the default set. Additionally, if there is no operational LSP in the default set, the system reverts to regular ECMP spraying over the full ECMP set.

If the user changes (by adding, modifying or deleting) the CBF configuration associated with an LSP that was previously selected as part of an ECMP set, then the FEC resolution is automatically updated, and a CBF consistency check is performed. Moreover, the user changes can update the forwarding configuration.

The LSR role applies to incoming labeled LDP traffic whose FEC is resolved to IGP IPv4 shortcuts.

The LER role applies to the following:

- IPv4 and IPv6 prefixes in GRT (with an IPv4 BGP NH)
- VPN-v4 and VPN-v6 routes

However, LER does not apply to any service which uses either explicit binding to an SDP (static or T-LDP signaled services), or auto-binding to SDP (BGP-AD VPLS, BGP-VPLS, BGP-VPWS, Dynamic MS-PW).

For BGP-LU, ECMP+CBF is supported only in the absence of the VPRN label. Therefore, ECMP+CBF is not supported when a VPRN label runs on top of BGP-LU (itself running over LDPoRSVP).

The CBF capability is available with any system profile. The number of sets is limited to four with system profile None or A, and to six with system profile B. This capability does not apply to CPM generated packets, including OAM packets, which are looked-up in RTM, and which are forwarded over tunnel next hops. These packets are forwarded by using either regular ECMP, or by selecting one nexthop from the set.

3.9 LDP ECMP uniform failover

LDP ECMP uniform failover allows the fast re-distribution by the ingress datapath of packets forwarded over an LDP FEC next-hop to other next-hops of the same FEC when the currently used next-hop fails. The switchover is performed within a bounded time, which does not depend on the number of impacted LDP ILMs (LSR role) or service records (ingress LER role). The uniform failover time is only supported for a single LDP interface or LDP next-hop failure event.

This feature complements the coverage provided by the LDP Fast-ReRoute (FRR) feature, which provides a Loop-Free Alternate (LFA) backup next-hop with uniform failover time. Prefixes that have one or more ECMP next-hop protection are not programmed with a LFA back-up next-hop, and the other way around.

The LDP ECMP uniform failover feature builds on the concept of Protect Group ID (PG-ID) introduced in LDP FRR. LDP assigns a unique PG-ID to all FECs that have their primary Next-Hop Label Forwarding Entry (NHLFE) resolved to the same outgoing interface and next-hop.

When an ILM record (LSR role) or LSPid-to-NHLFE (LTN) record (LER role) is created on the IOM, it has the PG-ID of each ECMP NHLFE the FEC is using.

When a packet is received on this ILM/LTN, the hash routine selects one of the up to 64, or the ECMP value configured on the system, whichever is less, ECMP NHLFEs for the FEC based on a hash of the packet's header. If the selected NHLFE has its PG-ID in DOWN state, the hash routine re-computes the hash to select a backup NHLFE among the first 16, or the ECMP value configured on the system, whichever is less, NHLFEs of the FEC, excluding the one that is in DOWN state. Packets of the subset of flows that resolved to the failed NHLFE are therefore sprayed among a maximum of 16 NHLFEs.

LDP then re-computes the new ECMP set to exclude the failed path and downloads it into the IOM. At that point, the hash routine updates the computation and begin spraying over the updated set of NHLFEs.

LDP sends the DOWN state update of the PG-ID to the IOM when the outgoing interface or a specific LDP next-hop goes down. This can be the result of any of the following events:

- interface failure detected directly
- failure of the LDP session detected via T-LDP BFD or LDP keepalive
- failure of LDP Hello adjacency detected via link LDP BFD or LDP Hello

In addition, PIP sends an interface down event to the IOM if the interface failure is detected by other means than the LDP control plane or BFD. In that case, all PG-IDs associated with this interface have their state updated by the IOM.

When tunneling LDP packets over an RSVP LSP, it is the detection of the T-LDP session going down, via BFD or keepalive, which triggers the LDP ECMP uniform failover procedures. If the RSVP LSP alone fails and the latter is not protected by RSVP FRR, the failure event triggers the re-resolution of the impacted FECs in the slow path.

When a multicast LDP (mLDP) FEC is resolved over ECMP links to the same downstream LDP LSR, the PG-ID DOWN state causes packets of the FEC resolved to the failed link to be switched to another link using the linear FRR switchover procedures.

The LDP ECMP uniform failover is not supported in the following forwarding contexts:

- VPLS BUM packets
- packets forwarded to an IES/VPRN spoke-interface
- packets forwarded toward VPLS spoke in routed VPLS

Finally, the LDP ECMP uniform failover is only supported for a single LDP interface, LDP next-hop, or peer failure event.

3.10 LDP Fast-Reroute for IS-IS and OSPF prefixes

LDP Fast Re-Route (FRR) is a feature which allows the user to provide local protection for an LDP FEC by pre-computing and downloading to the IOM or XCM both a primary and a backup NHLFE for this FEC.

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 RTM. The backup NHLFE corresponds to the label received for the same FEC from a Loop-Free Alternate (LFA) next-hop.

The LFA next-hop pre-computation by IGP is described in RFC 5286 – *Basic Specification for IP Fast Reroute: Loop-Free Alternates*. LDP FRR relies on using the label-FEC binding received from the LFA next-hop to forward traffic for a prefix as soon as the primary next-hop is not available. This means that a node resumes forwarding LDP packets to a destination prefix without waiting for the routing convergence. The label-FEC binding is received from the loop-free alternate next-hop ahead of time and is stored in the Label Information Base because LDP on the router operates in the liberal retention mode.

This feature requires that IGP performs the Shortest Path First (SPF) computation of an LFA next-hop, in addition to the primary next-hop, for all prefixes used by LDP to resolve FECs. IGP also populates both routes in the Routing Table Manager (RTM).

3.10.1 LDP FRR configuration

Use the follow commands to enable Loop-Free Alternate (LFA) computation by SPF under the IS-IS or OSPF routing protocol level:

- **MD-CLI**

```
configure router isis loopfree-alternate
configure router ospf loopfree-alternate
```

- **classic CLI**

```
configure router isis loopfree-alternates
configure router ospf loopfree-alternates
```

The preceding commands instruct the IGP SPF to attempt to pre-compute both a primary next hop and an LFA next hop for every learned prefix. When found, the LFA next hop is populated into the RTM along with the primary next hop for the prefix.

Next the user enables the use by LDP of the LFA next hop by configuring the following command.

```
configure router ldp fast-reroute
```

When this command is enabled, LDP uses both the primary next hop and LFA next hop, when available, for resolving the next hop of an LDP FEC against the corresponding prefix in the RTM. This results in LDP programming a primary NHLFE and a backup NHLFE into the IOM or XCM for each next hop of a FEC prefix for the purpose of forwarding packets over the LDP FEC.

Because LDP can detect the loss of a neighbor/next hop independently, it is possible that it switches to the LFA next hop while IGP is still using the primary next hop. To avoid this situation, Nokia recommends the user enable IGP-LDP synchronization on the LDP interface with the following command.

```
configure router interface ldp-sync-timer
```

3.10.2 LDP FRR procedures

The LDP FEC resolution when LDP FRR is not enabled operates as follows. When LDP receives a *FEC, label* binding for a prefix, it resolves it by checking if the exact prefix, or a longest match prefix when the following command is enabled in LDP, exists in the routing table, and is resolved against a next hop which is an address belonging to the LDP peer which advertised the binding, as identified by its LSR-id.

```
configure router ldp aggregate-prefix-match
```

When the next hop is no longer available, LDP deactivates the FEC and deprograms the NHLFE in the datapath. LDP also immediately withdraws the labels it advertised for this FEC and deletes the ILM in the datapath unless the user configured the following command to delay this operation.

```
configure router ldp label-withdrawal-delay
```

Traffic that is received while the ILM is still in the datapath is dropped. When routing computes and populates the routing table with a new next hop for the prefix, LDP resolves again the FEC and programs the datapath accordingly.

When LDP FRR is enabled and an LFA backup next hop exists for the FEC prefix in RTM, or for the longest prefix the FEC prefix matches to when the **aggregate-prefix-match** command is enabled in LDP, LDP resolves the FEC as above but programs the datapath with both a primary NHLFE and a backup NHLFE for each next hop of the FEC.

In order perform a switchover to the backup NHLFE in the fast path, LDP follows the uniform FRR failover procedures which are also supported with RSVP FRR.

When any of the following events occurs, LDP instructs in the fast path the IOM on the line cards to enable the backup NHLFE for each FEC next hop impacted by this event. The IOM line cards do that by simply flipping a single state bit associated with the failed interface or neighbor/next hop:

- An LDP interface goes operationally down, or is admin shutdown. In this case, LDP sends a neighbor/next hop down message to the IOM line cards for each LDP peer it has adjacency with over this interface.
- An LDP session to a peer went down as the result of the Hello or keepalive timer expiring over a specific interface. In this case, LDP sends a neighbor/next-hop down message to the IOM line cards for this LDP peer only.

- The TCP connection used by a link LDP session to a peer went down, due say to next-hop tracking of the LDP transport address in RTM, which brings down the LDP session. In this case, LDP sends a neighbor/next-hop down message to the IOM line cards for this LDP peer only.
- A BFD session, enabled on a T-LDP session to a peer, times-out and as a result the link LDP session to the same peer and which uses the same TCP connection as the T-LDP session goes also down. In this case, LDP sends a neighbor/next-hop down message to the IOM line cards for this LDP peer only.
- A BFD session enabled on the LDP interface to a directly connected peer, times-out and brings down the link LDP session to this peer. In this case, LDP sends a neighbor/next-hop down message to the IOM line cards for this LDP peer only. BFD support on LDP interfaces is a new feature introduced for faster tracking of link LDP peers.

The following commands, when enabled, do not cause the corresponding timer to be activated for a FEC as long as a backup NHLFE is still available.

```
configure router ldp tunnel-down-damp-time
configure router ldp label-withdrawal-delay
```

3.10.2.1 ECMP considerations

Whenever the SPF computation determined that there is more than one primary next hop for a prefix, it does not program any LFA next hop in RTM. In this case, the LDP FEC resolves to the multiple primary next hops, which provides the required protection.

Also, when the system ECMP value is configured as **configure router ecmp 1** which is the default value, SPF can use the overflow ECMP links as LFA next hops in these two cases.

3.10.2.2 LDP FRR and LDP shortcut

When LDP FRR is enabled in LDP and the ldp-shortcut option is enabled in the router level, in transit IPv4 packets and specific CPM generated IPv4 control plane packets with a prefix resolving to the LDP shortcut are protected by the backup LDP NHLFE.

3.10.2.3 LDP FRR and LDP-over-RSVP

When LDP-over-RSVP is enabled, the RSVP LSP is modeled as an endpoint, that is, the destination node of the LSP, and not as a link in the IGP SPF. Thus, it is not possible for IGP to compute a primary or alternate next hop for a prefix which FEC path is tunneled over the RSVP LSP. Only LDP is aware of the FEC tunneling but it cannot determine on its own a loop-free backup path when it resolves the FEC to an RSVP LSP.

As a result, LDP does not activate the LFA next hop it learned from RTM for a FEC prefix when the FEC is resolved to an RSVP LSP. LDP activates the LFA next hop as soon as the FEC is resolved to direct primary next hop.

LDP FEC tunneled over an RSVP LSP because of enabling the LDP-over-RSVP feature therefore does not support the LDP FRR procedures and follows the slow path procedure of prior implementation.

When the user enables the following command option for an RSVP LSP, as described in "Loop-Free Alternate calculation in the presence of IGP shortcuts" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide*, the LSP is not used by LDP to tunnel an LDP FEC even when IGP shortcut is disabled but LDP-over-RSVP is enabled in IGP.

- **MD-CLI**

```
configure router mpls lsp igp-shortcut lfa-type lfa-only
```

- **classic CLI**

```
configure router mpls lsp igp-shortcut lfa-only
```

3.10.2.4 LDP FRR and RSVP shortcut (IGP shortcut)

When an RSVP LSP is used as a shortcut by IGP, it is included by SPF as a P2P link and can also be optionally advertised into the rest of the network by IGP. Thus the SPF is able of using a tunneled next hop as the primary next hop for a specific prefix. LDP is also able of resolving a FEC to a tunneled next hop when the IGP shortcut feature is enabled.

When both IGP shortcut and LFA are enabled in IS-IS or OSPF, and LDP FRR is also enabled, then the following additional LDP FRR capabilities are supported:

- A FEC which is resolved to a direct primary next hop can be backed up by a LFA tunneled next hop.
- A FEC which is resolved to a tunneled primary next hop does not have an LFA next hop. It relies on RSVP FRR for protection.

The LFA SPF is extended to use IGP shortcuts as LFA next hops as described in "Loop-Free Alternate calculation in the presence of IGP shortcuts" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide*.

3.10.3 IS-IS and OSPF support for Loop-Free Alternate calculation

See "OSPF and IS-IS support for LFA calculation" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide*.

3.10.3.1 Loop-Free Alternate calculation in the presence of IGP shortcuts

See "Loop-Free Alternate calculation in the presence of IGP shortcuts" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide*.

3.10.3.2 Loop-Free Alternate calculation for inter-area/inter-level prefixes

See "LFA calculation for inter-area and inter-level prefixes" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide*.

3.10.3.3 LFA SPF Policies

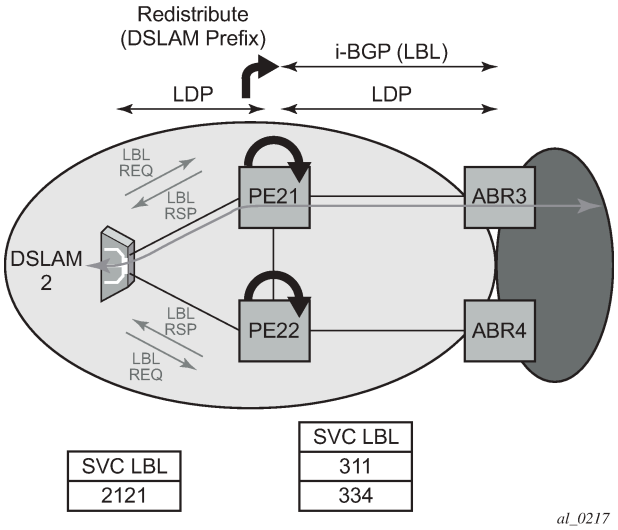
A Loop-Free Alternate Shortest Path First (LFA SPF) policy allows the user to apply specific criteria, such as admin group and SRLG constraints, to the selection of a LFA backup next hop for a subset of prefixes that resolve to a specific primary next hop. For more information, see "Loop-Free Alternate Shortest Path First (LFA SPF) Policies" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide*.

3.11 LDP FEC to BGP labeled route stitching

The stitching of an LDP FEC to a BGP labeled route allows the LDP capable PE devices to offer services to PE routers in other areas or domains without the need to support BGP labeled routes.

This feature is used in a large network to provide services across multiple areas or autonomous systems. Figure 45: Application of LDP to BGP FEC stitching shows a network with a core area and regional areas.

Figure 45: Application of LDP to BGP FEC stitching



Specific /32 routes in a regional area are not redistributed into the core area. Therefore, only nodes within a regional area and the ABR nodes in the same area exchange LDP FECs. A PE router, for example, PE21, in a regional area learns the reachability of PE routers in other regional areas by way of RFC 8277 BGP labeled routes redistributed by the remote ABR nodes by way of the core area. The remote ABR then sets the next-hop self on the labeled routes before re-distributing them into the core area. The local ABR for PE2, for example, ABR3 may or may not set next-hop self when it re-distributes these labeled BGP routes from the core area to the local regional area.

When forwarding a service packet to the remote PE, PE21 inserts a VC label, the BGP route label to reach the remote PE, and an LDP label to reach either ABR3, if ABR3 sets next-hop self, or ABR1.

In the same network, an MPLS capable DSLAM also acts as PE router for VLL services and needs to establish a PW to a PE in a different regional area by way of router PE21, acting now as an LSR. To achieve that, PE21 is required to perform the following operations:

- Translate the LDP FEC it learned from the DSLAM into a BGP labeled route and re-distribute it by way of Interior Border Gateway Protocol (IBGP) within its area. This is in addition to redistributing the FEC to its LDP neighbors in the same area.
- Translate the BGP labeled routes it learns through IBGP into an LDP FEC and re-distribute it to its LDP neighbors in the same area. In the application in Figure 45: Application of LDP to BGP FEC stitching, the DSLAM requests the LDP FEC of the remote PE router using LDP Downstream on Demand (DoD).
- When a packet is received from the DSLAM, PE21 swaps the LDP label into a BGP label and pushes the LDP label to reach ABR3 or ABR1. When a packet is received from ABR3, the top label is removed and the BGP label is swapped for the LDP label corresponding to the DSLAM FEC.

3.11.1 Configuration

Note: The **no local-lsr-id** or **local-lsr-id system** commands are synonymous and mean that there is no local LSR ID for a session. These commands apply to classic CLI only.

A community is assigned to an LDP session by configuring a community string in the corresponding session parameters for the peer or the targeted session peer template. A community only applies to a local LSR ID for a session for the following commands.

```
configure router ldp interface-parameters interface ipv4 local-lsr-id
configure router ldp interface-parameters interface ipv6 local-lsr-id
configure router ldp targeted-session peer local-lsr-id
configure router ldp targeted-session peer-template local-lsr-id
```

It is never applied to a system FEC or local static FEC. A system FEC or static FEC cannot have a community associated with it and is therefore not advertised over an LDP session with a configured community. Only a single community string can be configured for a session toward a specified peer or within a specified targeted peer template. The FEC advertised by the following commands is automatically put in the community configured on the session.

```
configure router ldp session-parameters peer adv-local-lsr-id
configure router ldp targeted-session peer-template adv-local-lsr-id
```

The specified community is only associated with IPv4 and IPv6 address FECs incoming or outgoing on the relevant session, and not to IPv4/IPv6 P2MP FECs, or service FECs incoming/outgoing on the session.

Static FECs are treated as having no community associated with them, even if they are also received over another session with an assigned community. A mismatch is declared if this situation arises.

3.11.2 Detailed LDP FEC resolution

When an LSR receives a FEC-label binding from an LDP neighbor for a specific FEC1 element, the following procedures are performed:

1. LDP installs the FEC if:
   - It was able to perform a successful exact match or a longest match, if the following command is enabled in LDP, of the FEC /32 prefix with a prefix entry in the routing table.

     ```
     configure router ldp aggregate-prefix-match
     ```

   - The advertising LDP neighbor is the next hop to reach the FEC prefix.
2. When such a FEC-label binding has been installed in the LDP FIB, LDP performs the following:
   a. Program a push and a swap NHLFE entries in the egress datapath to forward packets to FEC1.
   b. Program the CPM tunnel table with a tunnel entry for the NHLFE.
   c. Advertise a new FEC-label binding for FEC1 to all its LDP neighbors according to the global and per-peer LDP prefix export policies.
   d. Install the ILM entry pointing to the swap NHLFE.
3. When BGP learns the LDP FEC by way of the CPM tunnel table and the FEC prefix exists in the BGP route export policy, it performs the following:

a. Originate a labeled BGP route for the same prefix with this node as the next hop and advertise it by way of IBGP to its BGP neighbors. For example, the local ABR/ASBR nodes, which have the following command enabled:

- **MD-CLI**

```
configure router bgp neighbor advertise-ldp-prefix
```

- **classic CLI**

```
configure router bgp group neighbor advertise-ldp-prefix
```

b. Install the ILM entry pointing to the swap NHLFE programmed by LDP.

3.11.3 Detailed BGP labeled route resolution

When an LSR receives a BGP labeled route by way of IBGP for a specific /32 prefix, the following procedures are performed:

1. BGP resolves and installs the route in BGP if an LDP LSP to the BGP neighbor exists, for example, the ABR or ASBR, which advertised it and which is the next hop of the BGP labeled route.
2. When the BGP route is installed, BGP does the following:
   a. pushes NHLFE in the egress datapath to forward packets to this BGP labeled route
   b. programs the CPM tunnel table with a tunnel entry for the NHLFE
3. When LDP learns the BGP labeled route from the CPM tunnel table and the prefix exists in the new LDP tunnel table route export policy, it does the following:
   a. Advertise a new LDP FEC-label binding for the same prefix to its LDP neighbors according the global and per-peer LDP export prefix policies. If LDP already advertised a FEC for the same /32 prefix after receiving it from an LDP neighbor then no action is required. For LDP neighbors that negotiated LDP Downstream on Demand (DoD), the FEC is advertised only when this node receives a Label Request message for this FEC from its neighbor.
   b. Install the ILM entry pointing to the BGP NHLFE if a new LDP FEC-label binding is advertised. If an ILM entry exists and points to an LDP NHLFE for the same prefix then no update to the ILM entry is performed. The LDP route is always preferred over the BGP labeled route.

The following command (in the LDP context) has no effect on LDP-to-BGP stitching except for one specific case as described below.

```
configure router ldp prefer-protocol-stitching
```

Typically BGP does not add a TTM entry if the BGP-LU route is not the most preferred route in RTM. Because a BGP-LU route cannot be used for LDP FEC resolution, there are no two TTM entries to choose from, so the command has no effect. However, it is possible to program BGP-LU tunnels for prefixes available in the IGP by blocking those prefixes from the label IPv4 RIB using the following command.

```
configure router bgp rib-management label-ipv4 route-table-import
```

In this case, the **prefer-protocol-stitching** command impacts the stitching and prefers stitching to BGP instead of LDP.

Note: The following BGP command, if set to a lower value than the IGP preference in the route table, overrides the IGP preference.

```
configure router bgp label-preference
```

When resolving a FEC, LDP prefers the RTM over the TTM when both resolutions are possible. That is, swapping the LDP ILM to an LDP NHLFE is preferred over stitching the LDP ILM to an SR NHLFE. This behavior can be overridden by enabling the **prefer-protocol-stitching** command in the LDP context, in which case LDP prefers stitching to the SR tunnel, even if an LDP tunnel exists. This capability interacts with SR-to-LDP stitching. When SR stitches to LDP, no SR tunnel entry is added to the TTM and the command has no effect.

3.11.4 Data plane forwarding

When a packet is received from an LDP neighbor, the LSR swaps the LDP label into a BGP label and pushes the LDP label to reach the BGP neighbor, for example, ABR/ASBR, which advertised the BGP labeled route with itself as the next hop.

When a packet is received from a BGP neighbor such as an ABR/ASBR, the top label is removed and the BGP label is swapped for the LDP label to reach the next hop for the prefix.

3.12 LDP-SR stitching for IPv4 prefixes

This feature enables stitching between an LDP FEC and SR node-SID route for the same IPv4 /32prefix.

3.12.1 LDP-SR stitching configuration

The user enables the stitching between an LDP FEC and SR node-SID route for the same prefix by configuring the export of SR (LDP) tunnels from the CPM Tunnel Table Manager (TTM) into LDP (IGP).

In the LDP-to-SR datapath direction, the existing tunnel table route export policy in LDP, which was introduced for LDP-BGP stitching, is enhanced to support the export of SR tunnels from the TTM to LDP. The user adds the following IS-IS or OSPF configuration information:

- **IS-IS (MD-CLI)**

```
configure policy-options policy-statement entry from protocol name isis
configure policy-options policy-statement entry from protocol instance
```

- **IS-IS (classic CLI)**

```
configure router policy-options policy-statement entry from protocol isis instance
```

- **OSPF (MD-CLI)**

```
configure policy-options policy-statement entry from protocol name ospf
configure policy-options policy-statement entry from protocol instance
```

- **OSPF (classic CLI)**

```
configure router policy-options policy-statement entry from protocol ospf instance
```

The preceding configuration information is added to the LDP tunnel table export policy using the following command.

```
configure router ldp export-tunnel-table
```

The user can restrict the export to LDP of SR tunnels from a specific prefix list. The user can also restrict the export to a specific IGP instance by optionally specifying the instance ID in the "from" statement.

The "from protocol" statement has an effect only when the protocol value is IS-IS, OSPF, or BGP. Policy entries configured with any other value are ignored when the policy is applied. If the user configures multiple "from" statements in the same policy or does not include the "from" statement but adds a default accept action using the following command:

- **MD-CLI**

```
configure policy-options policy-statement default-action action-type accept
```

- **classic CLI**

```
configure router policy-options policy-statement default-action accept
```

When the accept action is enabled, the LDP follows the TTM selection rules as described in the "Segment Routing Tunnel Management" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide* to select a tunnel to which it stitches the LDP ILM to:

1. LDP selects the tunnel from the lowest TTM preference protocol.
2. If IS-IS and BGP protocols have the same preference, then LDP uses the default TTM protocol preference to select the protocol.
3. Within the same IGP protocol, LDP selects the lowest instance ID.

When this policy is enabled in LDP, LDP listens to SR tunnel entries in the TTM. If an LDP FEC primary next hop cannot be resolved using an RTM route and a SR tunnel of type SR IS-IS or SR OSPF to the same destination exists in TTM, LDP programs an LDP ILM and stitches it to the SR node-SID tunnel endpoint. LDP also originates an FEC for the prefix and re-distributes it to its LDP and T-LDP peers. The latter allows an LDP FEC that is tunneled over a RSVP-TE LSP to have its ILM stitched to an SR tunnel endpoint. When a LDP FEC is stitched to a SR tunnel, forwarded packets benefit from the protection provided by the LFA/remote LFA backup next hop of the SR tunnel.

When resolving a FEC, LDP prefers the RTM over the TTM when both resolutions are possible. That is, swapping the LDP ILM to an LDP NHLFE is preferred over stitching the LDP ILM to an SR NHLFE. This behavior can be overridden by enabling the **prefer-protocol-stitching** command (in the LDP context), in which case LDP prefers stitching to the SR tunnel, even if an LDP tunnel exists. This capability interacts with SR-to-LDP stitching; when SR stitches to LDP no SR tunnel entry is added to the TTM and the command has no effect.

Note: Forcing the stitching to SR affects forwarding at the LER and LSR roles. Typically, a specific prefix has a "push" and a "swap" binding for the LER and LSR roles, respectively. When **prefer-protocol-stitching** is enabled, the "swap" binding points to an SR tunnel and the "push" binding is removed. Services using the LDP tunnel should use the SR tunnel instead.

In the SR-to-LDP datapath direction, the SR mapping server provides a global policy for prefixes corresponding to the LDP FECs the SR needs to stitch to. For more information, see "Segment Routing Mapping Server" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide*. As a result, a tunnel table export policy is not required. Instead, you can export to an IGP instance the LDP tunnels for FEC prefixes advertised by the mapping server using the following commands:

```
configure router isis segment-routing export-tunnel-table ldp
configure router ospf segment-routing export-tunnel-table ldp
```

When this command is enabled in the segment-routing context of an IGP instance, IGP listens to LDP tunnel entries in the TTM. When a /32 LDP tunnel destination matches a prefix for which IGP has received a prefix-SID sub-TLV from a mapping server, IGP instructs the SR module to program the SR ILM and stitch it to the LDP tunnel endpoint. The SR ILM can stitch to an LDP FEC resolved over either link LDP or T-LDP. In the latter case, the stitching is performed to an LDP-over-RSVP tunnel. When an SR tunnel is stitched to an LDP FEC, packets forwarded benefit from the FRR protection of the LFA backup next hop of the LDP FEC.

When resolving a node SID, IGP prefers a prefix SID received in an IP Reach TLV over a prefix SID received via the mapping server. That is, swapping the SR ILM to a SR NHLFE is preferred over stitching it to a LDP tunnel endpoint. For more information about prefix SID resolution, see "Segment Routing Mapping Server Prefix SID Resolution" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide*.

Nokia recommends enabling the BFD option on the interfaces in both LDP and IGP instance contexts to speed up the failure detection and the activation of the LFA/remote-LFA backup next hop in either direction. This is particularly true if the injected failure is a remote failure.

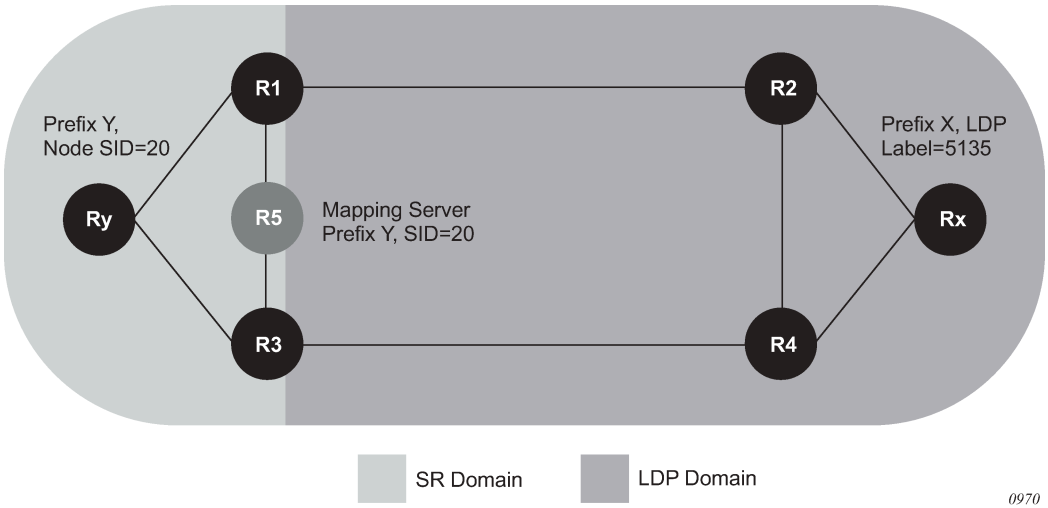
This feature is limited to IPv4 /32 prefixes in both LDP and SR.

3.12.2 Stitching in the LDP-to-SR direction

Prerequisites

Stitching in dataplane from the LDP-to-SR direction is based on the LDP module monitoring the TTM for a SR tunnel of a prefix matching an entry in the LDP TTM export policy.

Figure 46: Stitching in the LDP-to-SR direction



In Figure 46: Stitching in the LDP-to-SR direction, the boundary router R1 performs the following procedure to effect stitching:

Procedure

Step 1. Router R1 is at the boundary between an SR domain and LDP domain and is configured to stitch between SR and LDP.

Step 2. Link R1-R2 is LDP-enabled, but router R2 does not support SR (or SR is disabled).

Step 3. Router R1 receives a prefix-SID sub-TLV in an IS-IS IP reachability TLV originated by router Ry for prefix Y.

Step 4. R1 resolves the prefix-SID and programs an NHLFE on the link toward the next hop in the SR domain. R1 programs an SR ILM and points it to this NHLFE.

Step 5. Because R1 is programmed to stitch LDP to SR, the LDP in R1 discovers in TTM the SR tunnel to Y. LDP programs an LDP ILM and points it to the SR tunnel. As a result, both the SR ILM and LDP ILM now point to the SR tunnel, one via the SR NHLFE and the other via the SR tunnel endpoint.

Step 6. R1 advertises the LDP FEC for the prefix Y to all its LDP peers. R2 is now able to install a LDP tunnel toward Ry.

Step 7. If R1 finds multiple SR tunnels to destination prefix Y, it uses the following steps of the TTM tunnel selection rules to select the SR tunnel.

a. R1 selects the tunnel from the lowest preference IGP protocol.

b. Select the protocol using the default TTM protocol preference.

c. Within the same IGP protocol, R1 uses the lowest instance ID to select the tunnel.

Step 8. If the user concurrently configured BGP, IS-IS, and OSPF from protocol statements (as follows) in the same LDP tunnel table export policy, or did not include the from statement but added a default action of accept, R1 selects the tunnel to destination prefix Y to stitch the LDP ILM to using the TTM tunnel selection rules.

- **MD-CLI**

```
configure policy-options policy-statement entry from protocol name {bgp | isis |
 ospf}
```

- **classic CLI**

```
configure router policy-options policy-statement entry from protocol {bgp | isis |
 ospf}
```

The TTM tunnel selection rules are:

a. R1 selects the tunnel from the lowest preference protocol.

b. If any two or all of IS-IS, OSPF, and BGP protocols have the same preference, then R1 selects the protocol using the default TTM protocol preference.

c. Within the same IGP protocol, R1 uses the lowest instance ID to select the tunnel.

Note: If R1 has already resolved a LDP FEC for prefix Y, it has an ILM for it, but this ILM is not updated to point toward the SR tunnel. This is because LDP resolves in RTM first before going to TTM and, therefore, prefers the LDP tunnel over the SR tunnel. Similarly, if an LDP FEC is received after the stitching is programmed, the LDP ILM is updated to point to the LDP NHLFE because LDP can resolve the LDP FEC in RTM.

Step 9. The user enables SR in R2. R2 resolves the prefix SID for Y and installs the SR ILM and the SR NHLFE. R2 is now able of forwarding packets over the SR tunnel to router Ry. No processing occurs in R1 because the SR ILM is already programmed.

Step 10. The user disables LDP on the interface R1-R2 (both directions) and the LDP FEC ILM and NHLFE are removed in R1. The same occurs in R2 which can then only forward using the SR tunnel toward Ry.

3.12.3 Stitching in the SR-to-LDP direction

Prerequisites

The stitching in data plane from the SR-to-LDP direction is based on the IGP monitoring the TTM for a LDP tunnel of a prefix matching an entry in the SR TTM export policy.

In Figure 46: Stitching in the LDP-to-SR direction, the boundary router R1 performs the following procedure to effect stitching:

Procedure

Step 1. Router R1 is at the boundary between a SR domain and a LDP domain and is configured to stitch between SR and LDP.

Link R1-R2 is LDP enabled but router R2 does not support SR (or SR is disabled).

Step 2. R1 receives an LDP FEC for prefix X owned by router Rx further down in the LDP domain.

RTM in R1 shows that the interface to R2 is the next hop for prefix X.

Step 3. LDP in R1 resolves this FEC in RTM and creates an LDP ILM for it with, for example, ingress label L1, and points it to an LDP NHLFE toward R2 with egress label L2.

Step 4. Later on, R1 receives a prefix-SID sub-TLV from the mapping server R5 for prefix X.

Step 5. IGP in R1 is resolving in its routing table the next hop of prefix X to the interface to R2. R1 knows that R2 did not advertise support of Segment Routing and, therefore, SID resolution for prefix X in routing table fails.

Step 6. IGP in R1 attempts to resolve prefix SID of X in TTM because it is configured to stitch SR-to-LDP. R1 finds a LDP tunnel to X in TTM, instructs the SR module to program a SR ILM with ingress label L3, and points it to the LDP tunnel endpoint, consequently stitching ingress L3 label to egress L2 label.

Note:

- Here, two ILMs, the LDP and SR, are pointing to the same LDP tunnel one via NHLFE and one via tunnel endpoint.
- No SR tunnel to destination X should be programmed in TTM following this resolution step.
- A trap is generated for prefix SID resolution failure only after IGP fails to complete step 5 and step 6. The existing trap for prefix SID resolution failure is enhanced to state whether the prefix SID which failed resolution was part of mapping server TLV or a prefix TLV.

Step 7. The user enables segment routing on R2.

Step 8. IGP in R1 discovers that R2 supports SR via the SR capability.

Because R1 still has a prefix-SID for X from the mapping server R5, it maintains the stitching of the SR ILM for X to the LDP FEC unchanged.

Step 9. The operator disables the LDP interface between R1 and R2 (both directions) and the LDP FEC ILM and NHLFE for prefix X are removed in R1.

Step 10. This triggers the re-evaluation of the SIDs. R1 first attempts the resolution in routing table and because the next hop for X now supports SR, IGP instructs the SR module to program a NHLFE for prefix-SID of X with egress label L4 and outgoing interface to R2. R1 installs a SR tunnel in TTM for destination X. R1 also changes the SR ILM with ingress label L3 to point to the SR NHLFE with egress label L4.

Router R2 now becomes the SR-LDP stitching router.

Step 11. Later, router Rx, which owns prefix X, is upgraded to support SR. R1 now receives a prefix-SID sub-TLV in a ISIS or OSPF prefix TLV originated by Rx for prefix X. The SID information may or may not be the same as the one received from the mapping server R5. In this case, IGP in R1 prefers the prefix-SID originated by Rx and update the SR ILM and NHLFE with appropriate labels.

Step 12. Finally, the operator cleans up the mapping server and removes the mapping entry for prefix X, which then gets withdrawn by IS-IS.

3.13 LDP FRR LFA backup using SR tunnel for IPv4 prefixes

The user enables the use of an SR tunnel as a remote LFA or as a TI-LFA backup tunnel next hop by an LDP FEC via the following command.

```
configure router ldp fast-reroute backup-sr-tunnel
```

As a prerequisite, the user must enable the stitching of LDP and SR in the LDP-to-SR direction as described in LDP-SR stitching configuration. That is because the LSR must perform the stitching of the LDP ILM to SR tunnel when the primary LDP next hop of the FEC fails. Thus, LDP must listen to SR tunnels programmed by the IGP in TTM, but the mapping server feature is not required.

Assume the **backup-sr-tunnel** command option is enabled in LDP and **remote-lfa** or **ti-lfa**, or both are enabled by the IGP instance:

- **MD-CLI**

```
configure router isis loopfree-alternate remote-lfa
configure router ospf loopfree-alternate remote-lfa
configure router isis loopfree-alternate ti-lfa
configure router ospf loopfree-alternate ti-lfa
```

- **classic CLI**

```
configure router isis loopfree-alternates remote-lfa
configure router ospf loopfree-alternates remote-lfa
configure router isis loopfree-alternates ti-lfa
configure router ospf loopfree-alternates ti-lfa
```

and that LDP was able to resolve the primary next hop of the LDP FEC in RTM. IGP SPF runs both the base LFA and the TI-LFA algorithms and if it does not find a backup next hop for a prefix of an LDP FEC, it also runs the remote LFA algorithm. If IGP finds a TI-LFA or a remote LFA tunnel next hop, LDP programs the primary next hop of the FEC using an LDP NHLFE and programs the LFA backup next hop using an LDP NHLFE pointing to the SR tunnel endpoint.

Note: The LDP packet is not "tunneled" over the SR tunnel. The LDP label is actually stitched to the segment routing label stack. LDP points both the LDP ILM and the LTN to the backup LDP NHLFE which itself uses the SR tunnel endpoint.

The behavior of the feature is similar to the LDP-to-SR stitching feature described in the LDP-SR stitching for IPv4 prefixes section, except the behavior is augmented to allow the stitching of an LDP ILM/LTN to an SR tunnel for the LDP FEC backup NHLFE when the primary LDP NHLFE fails.

The following is the behavior of this feature:

- When LDP resolves a primary next hop in RTM and a TI-LFA or a remote LFA backup next hop using SR tunnel in TTM, LDP programs a primary LDP NHLFE as usual and a backup LDP NHLFE pointing to the SR tunnel, which has the TI-LFA or remote LFA backup for the same prefix.
- If the LDP FEC primary next hop failed and LDP has pre-programmed a TI-LFA or a remote LFA next hop with an LDP backup NHLFE pointing to the SR tunnel, the LDP ILM/LTN switches to it.

  Note: If, for some reason, the failure impacted only the LDP tunnel primary next hop but not the SR tunnel primary next hop, the LDP backup NHLFE effectively points to the primary next hop of the SR tunnel and traffic of the LDP ILM/LTN follows this path instead of the TI-LFA or remote LFA next hop of the SR tunnel until the latter is activated.

- If the LDP FEC primary next hop becomes unresolved in RTM, LDP switches the resolution to a SR tunnel in TTM, if one exists, as per the LDP-to-SR stitching procedures described in Stitching in the LDP-to-SR direction.
- If both the LDP primary next hop and a regular LFA next hop become resolved in RTM, the LDP FEC programs the primary and backup NHLFEs as usual.

- It is recommended to enable the **bfd-enable** command option on the interfaces in both LDP and IGP instance contexts to speed up the failure detection and the activation of the LFA/TI-LFA/remote-LFA backup next hop in either direction.

3.14 LDP Remote LFA

LDP Remote LFA (rLFA) builds on the pre-existing capability to compute repair paths to a remote LFA node (or PQ node), which puts the packets onto the shortest path without looping them back to the node that forwarded them over the repair tunnel. See "Remote LFA with Segment Routing" in the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide* for more information about rLFA computation. In SR OS, a repair tunnel can also be an SR tunnel, however this section describes an LDP-in-LDP tunnel.

As a prerequisite for LDP rLFA configuration, enable Remote LFA computation using the following commands:

- **MD-CLI**

```
configure router isis loopfree-alternate remote-lfa
configure router ospf loopfree-alternate remote-lfa
```

- **classic CLI**

```
configure router isis loopfree-alternates remote-lfa
configure router ospf loopfree-alternates remote-lfa
```

Enable attaching rLFA information to RTM entries using the following commands:

- **MD-CLI**

```
configure router isis loopfree-alternate augment-route-table
configure router ospf loopfree-alternate augment-route-table
```

- **classic CLI**

```
configure router isis loopfree-alternates augment-route-table
configure router ospf loopfree-alternates augment-route-table
```

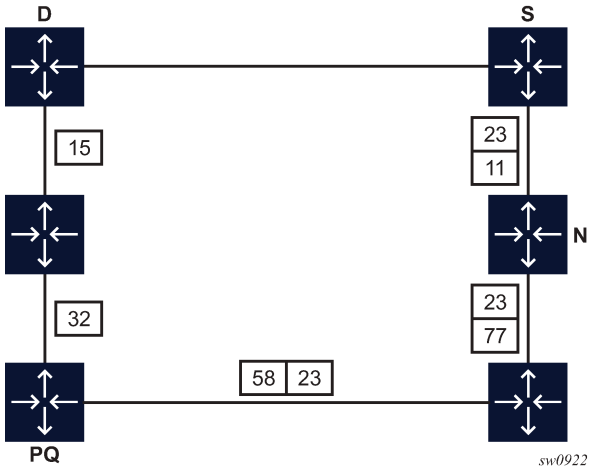
These commands attach rLFA-specific information to route entries that are necessary for LDP to program repair tunnels toward the PQ node using a specific neighbor.

Finally, enable tunneling on both the PQ node and the source node using the following command.

```
configure router ldp targeted-session peer tunneling
```

The following figure shows the general principles of LDP rLFA operation.

Figure 47: General principles of LDP rLFA operation



In the preceding figure, S is the source node and D is the destination node. The primary path is the direct link between S and D. The rLFA algorithm has determined the PQ node. In the event of a failure between S and D, for traffic not to loopback to S, the traffic must be sent directly to the PQ node. An LDP targeted session is required between PQ and S. Over that T-LDP session, the PQ node advertises label 23 for FEC D. All other labels are link LDP bindings, which allow traffic to reach the PQ node. On S, LDP creates an NHLFE that has two labels, where label 23 is the inner label. Label 23 is tunneled up to the PQ node, which then forwards traffic on the shortest path to D.

Note: LDP rLFA applies to IPv4 FECs only. LDP rLFA requires the targeted sessions (between Source node and PQ node) to be manually configured beforehand (the system does not automatically set-up T-LDP sessions toward the PQ nodes that the rLFA algorithm has identified). These targeted sessions must be set up with router IDs that match the ones the rLFA algorithm uses. LDP rLFA is designed to be operated in LDP-only environments; therefore, LDP does not establish rLFA backups when in the presence of LDP over RSVP-TE or LDP over SR-TE tunnels. The following OAM command is not supported over the repair tunnels.

```
oam lsp-trace
```

3.15 Automatic LDP rLFA

The manual LDP rLFA configuration method requires the user to specify beforehand, on each node, the list of peers with which a targeted session is established. See LDP Remote LFA for information about the rLFA LDP tunneling technology, and how to configure LDP to establish targeted sessions.

This section describes the automatic LDP rLFA mechanisms used to automatically establish targeted LDP sessions without the need to specify, on each node, the list of peers with which the targeted sessions must be established. The automatic LDP rLFA method considerably minimizes overall configuration, and increases dynamic flexibility.

The basic principles of operation for the automatic LDP rLFA capability are described in LDP Remote LFA. In the example shown in Figure 47: General principles of LDP rLFA operation, considering a failure on the shortest path between S and D nodes, S needs a targeted LDP session toward the PQ node to learn the

label-binding information configured on PQ node for FEC D. As a prerequisite, the LFA algorithm has run successfully and the PQ node information is attached to the route entries used by LDP.

Enable remote LFA computation using the following command:

- **MD-CLI**

```
configure router isis loopfree-alternate remote-lfa
```

- **classic CLI**

```
configure router isis loopfree-alternates remote-lfa
```

Enable attaching rLFA information to RTM entries using the following command:

- **MD-CLI**

```
configure router isis loopfree-alternate augment-route-table
```

- **classic CLI**

```
configure router isis loopfree-alternates augment-route-table
```

In the Figure 47: General principles of LDP rLFA operation scenarios, because the S node requires the T-LDP session, it should initiate the T-LDP session request. The PQ node receives the request for this session. Therefore, S node configuration is as follows.

Example: MD-CLI

```
[ex:/configure router "Base" ldp targeted-session auto-tx ipv4]
A:admin@node-2# info
    admin-state enable
    tunneling false
```

Example: classic CLI

```
A:node-2>config>router>ldp>targ-session>auto-tx>ipv4# info
----------------------------------------------
                        no shutdown
----------------------------------------------
```

And PQ node configuration is as follows:

Example: MD-CLI

```
[ex:/configure router "Base" ldp targeted-session auto-tx ipv4]
A:admin@node-2# info
    admin-state enable
    tunneling true
```

Example: classic CLI

```
A:node-2>config>router>ldp>targ-session>auto-tx>ipv4# info
----------------------------------------------
                        tunneling
                        no shutdown
----------------------------------------------
```

Based on the preceding configurations, the S node, using the PQ node information attached to the route entries, automatically starts sending LDP targeted Hello messages to the PQ node. The PQ node accepts them and the T-LDP session is established. For the same reason, as in case of manual LDP rLFA, enabling tunneling at the PQ node is required to enable PQ to send to S the label that it is bound to FEC D. In such a simple configuration, if there is a change in both the network topology and the PQ node of S for FEC D, S automatically kills the session to the previous PQ node and establish a new one (toward the new PQ node).

Note: It is not possible to configure command options specifically for automatic T-LDP sessions. The system inherits command options, either those defined for the IPv4 family (under targeted-session) or the default command options of the system. This applies to the following configurations.

```
configure router ldp targeted-session ipv4 hello
configure router ldp targeted-session ipv4 hello-reduction
configure router ldp targeted-session ipv4 keepalive
```

Also, the automatic T-LDP session can use parameters defined for the following configuration if the specified address is the router ID of the peer.

```
configure router ldp tcp-session-parameters peer-transport
```

In typical network deployments, each node is potentially the source node as well as the PQ node of a source node for a specific destination FEC. Therefore, all nodes may have both **auto-tx** and **auto-rx** configured and enabled as follows:

```
configure router ldp targeted-session auto-tx
configure router ldp targeted-session auto-rx
```

Nodes may also have other configurations defined (for example, peer, peer-template, and so on).

There are several implications (explicit or implicit) of having multiple configurations on a peer (either explicit or implicit).

One implication is that LDP operates using precedence levels. When a targeted session is established with a peer, LDP uses the session parameters with the highest precedence. The order of precedence is as follows (highest to lowest):

- peer
- template
- auto-tx
- auto-rx
- sdp

Allow us to consider the case where a T-LDP session is needed between nodes A (source) and B (PQ node). If A has **auto-tx** enabled and a per-peer configuration for B also exists, A establishes the session using the parameters defined in the per-peer configuration for B, instead of using those defined under **auto-tx**. The same applies on B. However, if B uses per-peer configuration for A and the chosen configuration does not enable tunneling, LDP rLFA does not work because the PQ node does not tunnel the FEC/label bindings. This mechanism also applies to **auto-tx** and **auto-rx**.

In a typical scenario in which the **auto-tx** and **auto-rx** modes are both enabled on a node that acts as the PQ node, and the node chooses the **auto-tx** configuration for the T-LDP session (because it has the higher

precedence than **auto-rx**), LDP rLFA only works if tunneling is enabled under **auto-tx**. The configuration from which the session command options are taken is indicated in the following command ("creator" label).

```
show router ldp targ-peer detail
```

Another implication is that redundant T-LDP sessions may remain up after a topology change when they are no longer required. The following **clear** command enables the user to delete these redundant T-LDP sessions.

```
clear router ldp targeted-auto-rx hold-time
```

The operator must run the command during a specific time window on all nodes on which **auto-rx** is configured. The **hold-time** value should be greater than the hello-timer value plus the time required to run the **clear** command on all applicable nodes. A system check verifies that a non-zero value is configured; no other checks are enforced. It is the responsibility of the operator to ensure that the configured non-zero value is long enough to meet the preceding criterion.

While the hold timer for the **clear** command is in progress, the remaining timeout value can be displayed using the following command.

```
tools dump router ldp timers
```

The **clear** command is not synchronized to the standby CPM. If a user does a clear with a large hold-time value and the CPM does a switchover during this time, the operator needs to restart the clear on the newly active CPM.

Note: The following considerations apply when configuring automatic LDP rLFA:

- works with IS-IS only
- only supports IPv4 FECs
- **local-lsr-id** configuration and templates are not supported
- **lsp-trace** on backup path is not supported

3.16 Automatic creation of a targeted Hello adjacency and LDP session

This feature enables the automatic creation of a targeted Hello adjacency and LDP session to a discovered peer.

3.16.1 Feature configuration

The user first creates a targeted LDP session peer parameter template by using the following command.

```
configure router ldp targeted-session peer-template
```

Inside the template the user configures the common T-LDP session command options shared by all peers using this template with the following commands:

- **MD-CLI**

```
configure router ldp targeted-session peer-template bfd-liveness
```

```
configure router ldp targeted-session peer-template hello
configure router ldp targeted-session peer-template hello-reduction
configure router ldp targeted-session peer-template keepalive
configure router ldp targeted-session peer-template local-lsr-id
configure router ldp targeted-session peer-template tunneling
```

- **classic CLI**

```
configure router ldp targeted-session peer-template bfd-enable
configure router ldp targeted-session peer-template hello
configure router ldp targeted-session peer-template hello-reduction
configure router ldp targeted-session peer-template keepalive
configure router ldp targeted-session peer-template local-lsr-id
configure router ldp targeted-session peer-template tunneling
```

The tunneling option does not support adding explicit RSVP LSP names. LDP selects RSVP LSP for an endpoint in LDP-over-RSVP directly from the Tunnel Table Manager (TTM).

Then the user references the peer prefix list which is defined inside a policy statement defined in the global policy manager using the following command:

- **MD-CLI**

```
configure router ldp targeted-session peer-template-map template-map-name
configure router ldp targeted-session peer-template-map policy-map
```

- **classic CLI**

```
configure router ldp targeted-session peer-template-map peer-template policy
```

Each application of a targeted session template to a specific prefix in the prefix list results in the establishment of a targeted Hello adjacency to an LDP peer using the template parameters as long as the prefix corresponds to a router-id for a node in the TE database. The targeted Hello adjacency either triggers a new LDP session or is associated with an existing LDP session to that peer.

Up to five (5) peer prefix policies can be associated with a single peer template at all times. Also, the user can associate multiple templates with the same or different peer prefix policies. Thus multiple templates can match with a specific peer prefix. In all cases, the targeted session parameters applied to a specific peer prefix are taken from the first created template by the user. This provides a more deterministic behavior regardless of the order in which the templates are associated with the prefix policies.

Each time the user executes the above command, with the same or different prefix policy associations, or the user changes a prefix policy associated with a targeted peer template, the system re-evaluates the prefix policy. The outcome of the re-evaluation tells LDP if an existing targeted Hello adjacency needs to be torn down or if an existing targeted Hello adjacency needs to have its parameters updated on the fly.

If a /32 prefix is added to (removed from) or if a prefix range is expanded (shrunk) in a prefix list associated with a targeted peer template, the same prefix policy re-evaluation described above is performed.

The template comes up in the enabled state and therefore it takes effect immediately. After a template is in use, the user can change any of the parameters on the fly without shutting down the template. In this case, all targeted Hello adjacencies are updated.

3.16.2 Feature behavior

Whether the prefix list contains one or more specific /32 addresses or a range of addresses, an external trigger is required to indicate to LDP to instantiate a targeted Hello adjacency to a node which address

matches an entry in the prefix list. The objective of the feature is to provide an automatic creation of a T-LDP session to the same destination as an auto-created RSVP LSP to achieve automatic tunneling of LDP-over-RSVP. The external trigger is when the router with the matching address appears in the Traffic Engineering database. In the latter case, an external module monitoring the TE database for the peer prefixes provides the trigger to LDP. As a result of this, the user must enable the following command option in IS-IS or OSPF.

```
configure router isis traffic-engineering
configure router ospf traffic-engineering
```

Each mapping of a targeted session peer parameter template to a policy prefix which exists in the TE database results in LDP establishing a targeted Hello adjacency to this peer address using the targeted session parameters configured in the template. This Hello adjacency then either gets associated with an LDP session to the peer if one exists or it triggers the establishment of a new targeted LDP session to the peer.

The SR OS supports multiple ways of establishing a targeted Hello adjacency to a peer LSR:

- User configuration of the peer with the targeted session command options inherited from the following top level context.

  ```
  configure router ldp targeted-session ipv4
  ```

  User configuration of the peer with the targeted session command options explicitly configured for this peer in the following context and which overrides the top level command options shared by all targeted peers.

  ```
  configure router ldp targeted-session peer
  ```

  This allows us to refer to the top level configuration context as the global context. Some command options only exist in the global context; their value is always inherited by all targeted peers regardless of which event triggered it.
- User configuration of an SDP of any type to a peer with the following command enabled (default configuration). In this case the targeted session command option values are taken from the global context.

  ```
  configure service sdp signaling tldp
  ```
- User configuration of a (FEC 129) PW template binding in a BGP-VPLS service. In this case the targeted session parameter values are taken from the global context.
- User configuration of a (FEC 129 type II) PW template binding in a VLL service (dynamic multisegment PW). In this case the target session parameter values are taken from the global context.
- User configuration of a mapping of a targeted session peer parameter template to a prefix policy when the peer address exists in the TE database. In this case, the targeted session command option values are taken from the template.
- Features using an LDP LSP, which itself is tunneled over an RSVP LSP (LDP-over-RSVP), as a shortcut do not trigger automatically the creation of the targeted Hello adjacency and LDP session to the destination of the RSVP LSP. The user must configure manually the peer command options or configure a mapping of a targeted session peer parameter template to a prefix policy. These features are the following:

– BGP shortcut

```
configure router bgp next-hop-resolution shortcut-tunnel
```

– IGP shortcut

```
configure router isis igp-shortcut
configure router ospf igp-shortcut
configure router ospf3 igp-shortcut
```

– LDP shortcut for IGP routes

- **MD-CLI**

```
configure router ldp ldp-shortcut
```

- **classic CLI**

```
configure router ldp-shortcut
```

– static route LDP shortcut (**ldp** option in a static route)

- **MD-CLI**

```
configure router static-routes route indirect tunnel-next-hop resolution-filter ldp
```

- **classic CLI**

```
configure router static-route-entry indirect tunnel-next-hop resolution-filter ldp
```

– VPRN service

```
configure service vprn bgp-ipvpn mpls auto-bind-tunnel resolution-filter ldp
configure service vprn bgp-evpn mpls auto-bind-tunnel resolution-filter ldp
```

Because the above triggering events can occur simultaneously or in any arbitrary order, the LDP code implements a priority handling mechanism to decide which event overrides the active targeted session parameters. The overriding trigger becomes the owner of the targeted adjacency to a specific peer and is displayed using the following command.

```
show router ldp targ-peer
```

Table 17: Targeted LDP adjacency triggering events and priority summarizes the triggering events and the associated priority.

Table 17: Targeted LDP adjacency triggering events and priority

Triggering event	Automatic creation of targeted Hello adjacency	Active targeted adjacency parameter override priority
Manual configuration of peer parameters (creator=manual)	Yes	1
Mapping of targeted session template to prefix policy (creator=template)	Yes	2

Triggering event	Automatic creation of targeted Hello adjacency	Active targeted adjacency parameter override priority
Manual configuration of SDP with **signaling tldp** option enabled (creator=service manager)	Yes	3
PW template binding in BGP-AD VPLS (creator=service manager)	Yes	3
PW template binding in FEC 129 VLL (creator=service manager)	Yes	3
LDP-over-RSVP as a BGP/IGP/LDP/Static shortcut	No	—
LDP-over-RSVP in VPRN auto-bind	No	—
LDP-over-RSVP in BGP Labeled Route resolution	No	—

Any parameter value change to an active targeted Hello adjacency caused by any of the above triggering events is performed by having LDP immediately send a Hello message with the new parameters to the peer without waiting for the next scheduled time for the Hello message. This allows the peer to adjust its local state machine immediately and maintains both the Hello adjacency and the LDP session in UP state. The only exceptions are the following:

- The triggering event caused a change to the **local-lsr-id** value. In this case, the Hello adjacency is brought down which also causes the LDP session to be brought down if this is the last Hello adjacency associated with the session. A new Hello adjacency and LDP session then get established to the peer using the new value of the local LSR ID.
- The triggering event caused the targeted peer to become disabled. In this case, the Hello adjacency is brought down which also causes the LDP session to be brought down if this is the last Hello adjacency associated with the session.

Finally, the value of any LDP parameter which is specific to the LDP/TCP session to a peer is inherited from the following context.

```
configure router ldp session-parameters peer
```

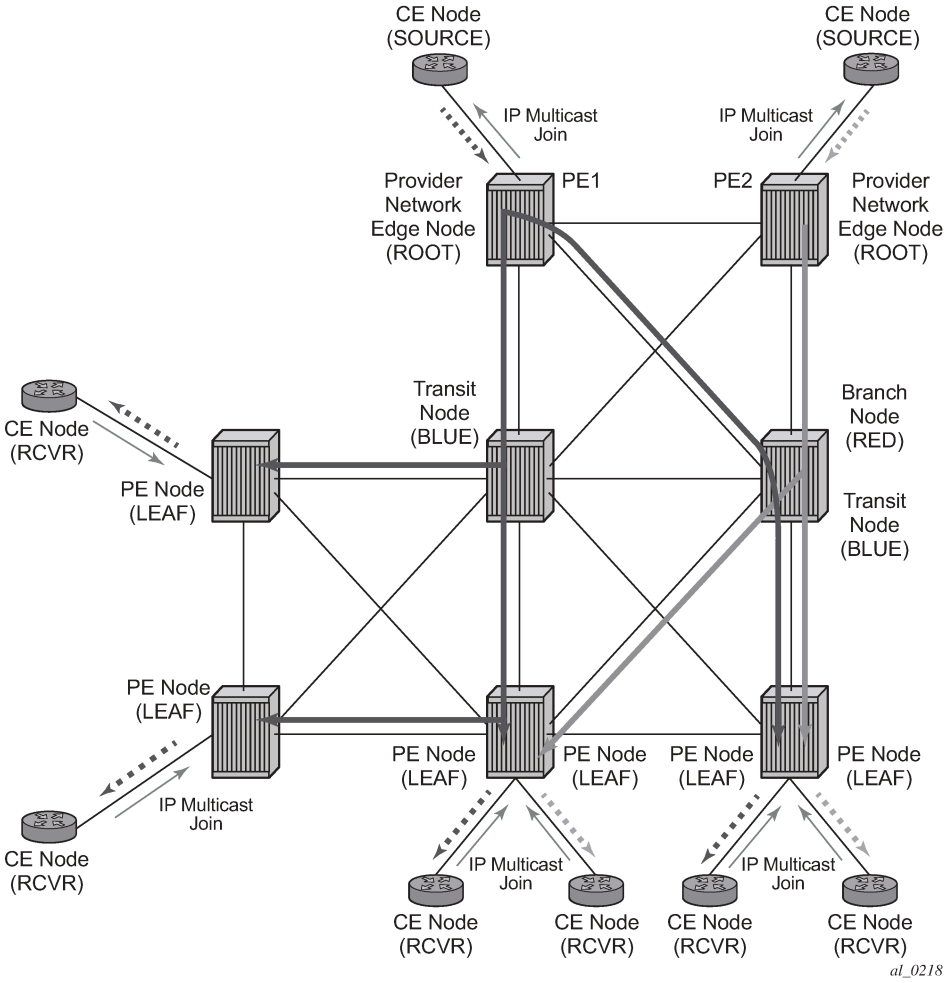
This includes MD5 authentication, LDP prefix per-peer policies, label distribution mode (DU or DOD), and so on.

3.17 Multicast P2MP LDP for GRT

The P2MP LDP LSP setup is initiated by each leaf node of multicast tree. A leaf PE node learns to initiate a multicast tree setup from client application and sends a label map upstream toward the root node of the multicast tree. On propagation of label map, intermediate nodes that are common on path for multiple leaf nodes become branch nodes of the tree.

Figure 48: Video distribution using P2MP LDP illustrates wholesale video distribution over P2MP LDP LSP. Static IGMP entries on edge are bound to P2MP LDP LSP tunnel-interface for multicast video traffic distribution.

Figure 48: Video distribution using P2MP LDP



3.18 LDP P2MP support

3.18.1 LDP P2MP configuration

A node running LDP also supports P2MP LSP setup using LDP. By default, it would advertise the capability to a peer node using P2MP capability TLV in LDP initialization message.

This configuration option per interface is provided to restrict/allow the use of interface in LDP multicast traffic forwarding toward a downstream node. Interface configuration option does not restrict/allow exchange of P2MP FEC by way of established session to the peer on an interface, but it would only restrict/allow use of next-hops over the interface.

3.18.2 LDP P2MP protocol

Only a single generic identifier range is defined for signaling multipoint tree for all client applications. Implementation on the 7750 SR or 7950 XRS reserves the range (1..8292) of generic LSP P2MP-ID on root node for static P2MP LSP.

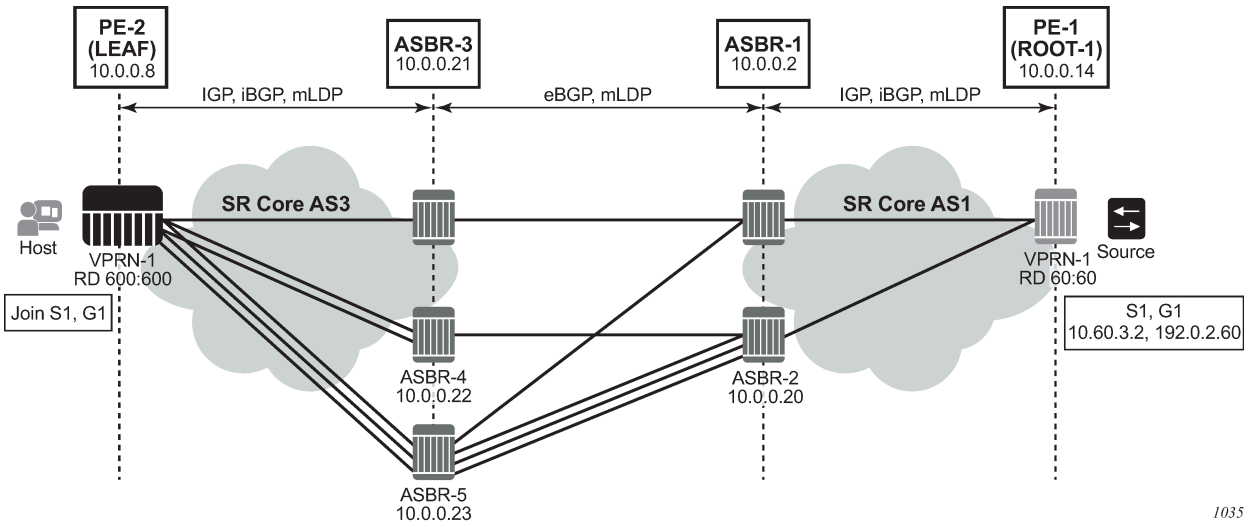
3.18.3 MBB

When a transit or leaf node detects that the upstream node toward the root node of multicast tree has changed, it follows graceful procedure that allows make-before-break transition to the new upstream node. Make-before-break support is optional. If the new upstream node does not support MBB procedures then the downstream node waits for the configured timer before switching over to the new upstream node.

3.18.4 ECMP support

In Figure 49: ECMP support, the leaf discovers the ROOT-1 from all three ASBRs (ASBR-3, ASBR-4 and ASBR-5).

Figure 49: ECMP support



The leaf chooses uses the following process to choose the ASBR used for the multicast stream:

1. The leaf determines the number of ASBRs that should be part of the hash calculation.

   The number of ASBRs that are part of the hash calculation comes from the configured ECMP (**configure router ecmp**). For example, if the ECMP value is set to 2, only two of the ASBRs are part of the hash algorithm selection.

2. After deciding the upstream ASBR, the leaf determines whether there are multiple equal cost paths between it and the chosen ASBR.

   - If there are multiple ECMP paths between the leaf and the ASBR, the leaf performs another ECMP selection based on the configured value in **configure router ecmp**. This is a recursive ECMP lookup.

- The first lookup chooses the ASBR and the second lookup chooses the path to that ASBR.

  For example, if the ASBR 5 was chosen in Figure 49: ECMP support, there are three paths between the leaf and ASBR-5. As such, a second ECMP decision is made to choose the path.

3. At ASBR-5, the process is repeated. For example, in Figure 49: ECMP support, ASBR-5 goes through steps 1 and 2 to choose between ASBR-1 and ASBR-2, and a second recursive ECMP lookup to choose the path to that ASBR.

When there are several candidate upstream LSRs, the LSR must select one upstream LSR. The algorithm used for the LSR selection is a local matter. If the LSR selection is done over a LAN interface and the Section 6 procedures are applied, the procedure described in ECMP hash algorithm is applied to ensure that the same upstream LSR is elected among a set of candidate receivers on that LAN.

The ECMP hash algorithm ensures that there is a single forwarder over the LAN for a specific LSP.

3.18.5 Inter-AS non-segmented mLDP

This feature allows multicast services to use segmented protocols and span them over multiple autonomous systems (ASs), like in unicast services. As IP VPN or GRT services span multiple IGP areas or multiple ASs, either because of a network designed to deal with scale or as result of commercial acquisitions, operators may require inter-AS VPN (unicast) connectivity. For example, an inter-AS VPN can break the IGP, MPLS, and BGP protocols into access segments and core segments, allowing higher scaling of protocols by segmenting them into their own islands. SR OS allows for similar provision of multicast services and for spanning these services over multiple IGP areas or multiple ASs.

mLDP supports non-segmented mLDP trees for inter-AS solutions, applicable for multicast services in the GRT (Global Routing Table) where they need to traverse mLDP point-to-multipoint tunnels as well as NG-MVPN services.

3.18.5.1 In-band signaling with non-segmented mLDP trees in GRT

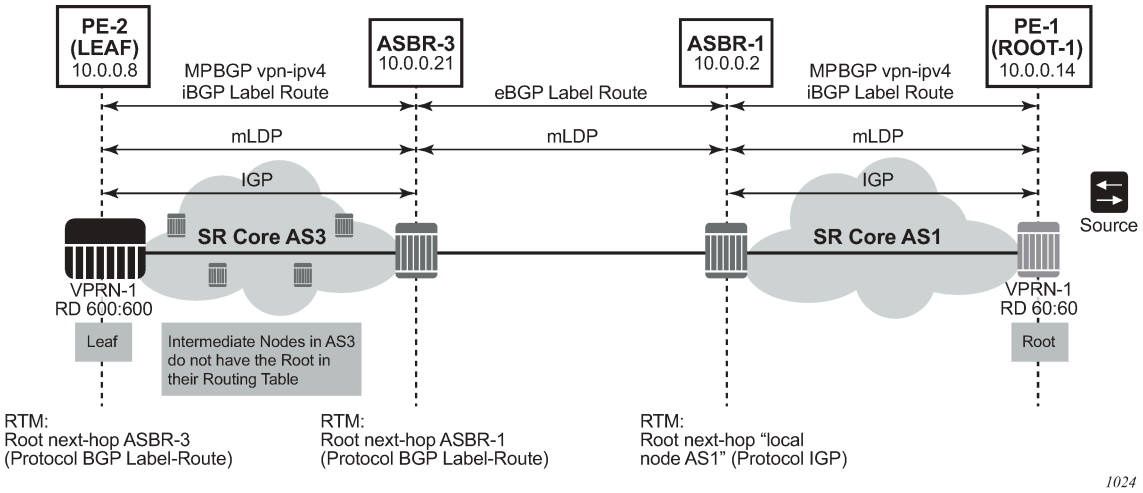
mLDP can be used to transport multicast in GRT. For mLDP LSPs to be generated, a multicast request from the leaf node is required to force mLDP to generate a downstream unsolicited (DU) FEC toward the root to build the P2MP LSPs.

For inter-AS solutions, the root may not be in the RTM of the leaf node or, if it is present, it is installed using BGP with ASBRs acting as the local AS root of the leaf. Therefore, the local AS intermediate routers on the leaf may not know the path to the root.

Control protocols used for constructing P2MP LSPs contain a field that identifies the address of a root node. Intermediate nodes are expected to be able to look up that address in their routing tables; however, this is not possible if the route to the root node is a BGP route and the intermediate nodes are part of a BGP-free core (for example, if they use IGP).

To enable an mLDP LSP to be constructed through a BGP-free segment, the root node address is temporarily replaced by an address that is known to the intermediate nodes and is on the path to the true root node. For example, Figure 50: Inter-AS Option C shows the procedure when the PE-2 (leaf) receives the route for root through ASBR3. This route resembles the root next-hop ASBR-3. The leaf, in this case, generates an LDP FEC which has an opaque value, and has the root address set as ASBR-3. This opaque value has more information needed to reach the root from ASBR-3. As a result, the SR core AS3 only needs to be able to resolve the local AS ASBR-3 for the LDP FEC. The ASBR-3 uses the LDP FEC opaque value to find the path to the root.

Figure 50: Inter-AS Option C



Because non-segmented d-mLDP requires end-to-end mLDP signaling, the ASBRs support both mLDP and BGP signaling between them.

3.18.5.2 LDP recursive FEC process

For inter-AS networks where the leaf node does not have the root in the RTM or where the leaf node has the root in the RTM using BGP, and the leaf’s local AS intermediate nodes do not have the root in their RTM because they are not BGP-enabled, RFC 6512 defines a recursive opaque value and procedure for LDP to build an LSP through multiple ASs.

For mLDP to be able to signal through a multiple-AS network where the intermediate nodes do not have a routing path to the root, a recursive opaque value is needed. The LDP FEC root resolves the local ASBR, and the recursive opaque value contains the P2MP FEC element, encoded as specified in RFC 6513, with a type field, a length field, and a value field of its own.

RFC 6826 section 3 defines the Transit IPv4 opaque for P2MP LDP FEC, where the leaf in the local AS wants to establish an LSP to the root for P2MP LSP. Figure 51: mLDP FEC for single AS with transit IPv4 opaque shows this FEC representation.

Figure 51: mLDP FEC for single AS with transit IPv4 opaque

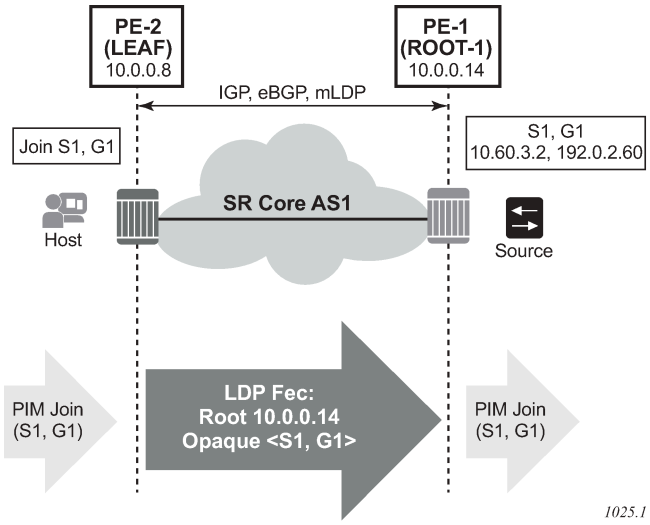
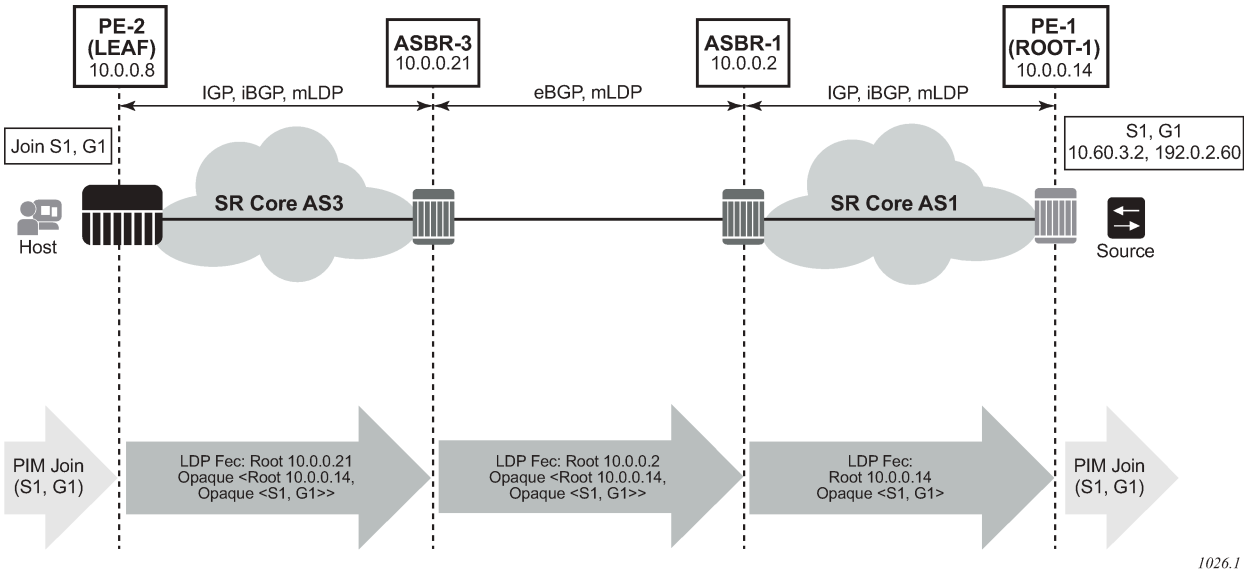


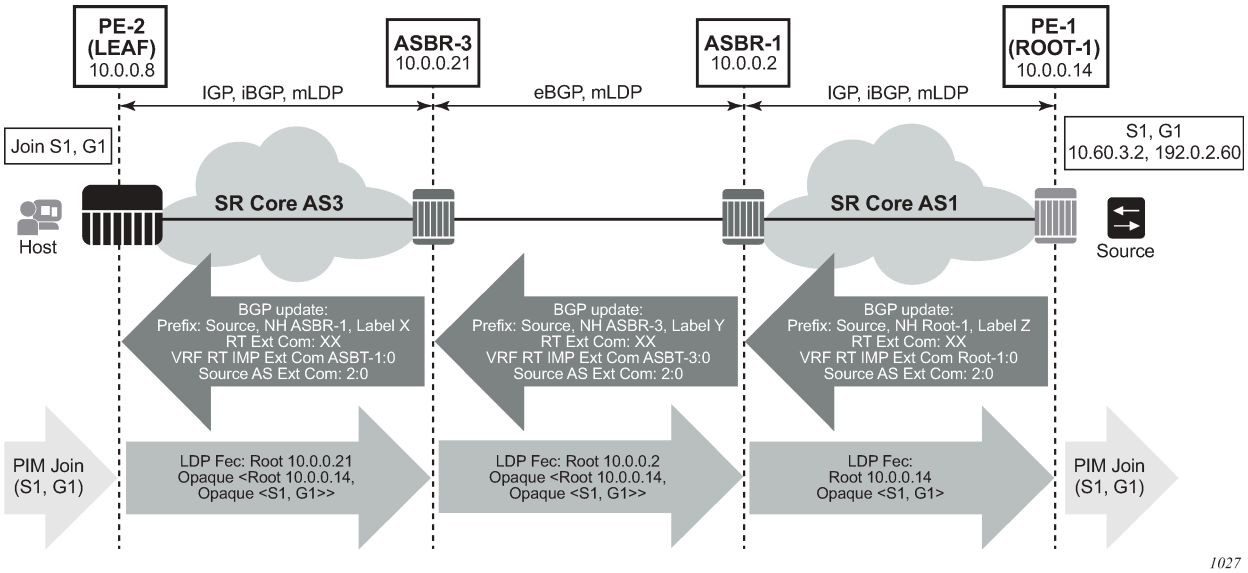
Figure 52: mLDP FEC for inter-AS with recursive opaque value shows an inter-AS FEC with recursive opaque based on RFC 6512.

Figure 52: mLDP FEC for inter-AS with recursive opaque value



As shown in the preceding figure, the root "10.0.0.21" is an ASBR and the opaque value contains the original mLDP FEC. As such, in the AS of the leaf where the actual root "10.0.0.14" is not known, the LDP FEC can be routed using the local root of ASBR. When the FEC arrives at an ASBR that co-locates in the same AS as the actual root, an LDP FEC with transit IPv4 opaque is generated. The end-to-end picture for inter-AS mLDP for non-VPN multicast is shown in Figure 53: Non-VPN mLDP with recursive opaque for inter-AS.

Figure 53: Non-VPN mLDP with recursive opaque for inter-AS



As shown in the preceding figure, the leaf is in AS3s where the AS3 intermediate nodes do not have the ROOT-1 in their RTM. The leaf has the S1 installed in the RTM via BGP. All ASBRs are acting as next-hop-self in the BGP domain. The leaf resolving the S1 via BGP generates an mLDP FEC with recursive opaque, represented as:

Leaf FEC: <Root=ASBR-3, opaque-value=<Root=Root-1, <opaque-value = S1,G1>>>

This FEC is routed through the AS3 Core to ASBR-3.

Note: AS3 intermediate nodes do not have ROOT-1 in their RTM; that is, are not BGP-capable.

At ASBR-3 the FEC is changed to:

ASBR-3 FEC: <Root=ASBR-1, opaque-value=<Root=Root-1, <opaque-value = S1,G1>>>

This FEC is routed from ASBR-3 to ASBR-1. ASBR-1 is colocated in the same AS as ROOT-1. Therefore, the ASBR-1 does not need a FEC with a recursive opaque value.

ASBR-1 FEC: <Root=Root-1, <opaque-value =S1,G1>>

This process allows all multicast services to work over inter-AS networks. All d-mLDP opaque types can be used in a FEC with a recursive opaque value.

3.18.5.3 Supported recursive opaque values

A recursive FEC is built using the Recursive Opaque Value and VPN-Recursive Opaque Value types (opaque values 7 and 8 respectively). All SR non-recursive opaque values can be recursively embedded into a recursive opaque.

The following table lists all supported opaque values in SR OS.

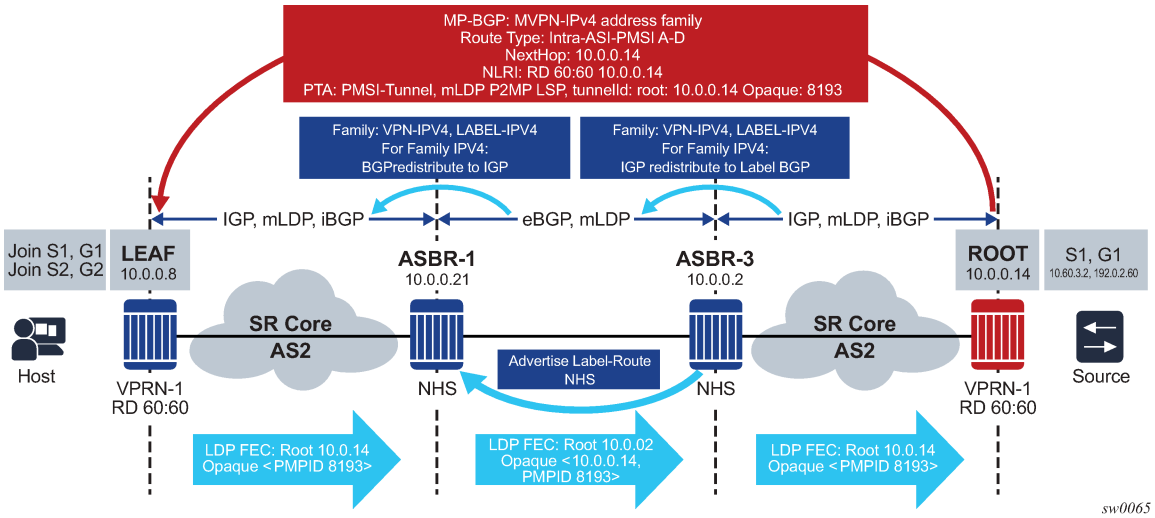
Table 18: Opaque types supported by SR OS

Opaque type	Opaque name	RFC	SR OS use	FEC representation
1	Generic LSP Identifier	RFC 6388	VPRN Local AS	<Root, Opaque<P2MPID>>
3	Transit IPv4 Source TLV Type	RFC 6826	IPv4 multicast over mLDP in GRT	<Root, Opaque<SourceIPv4, GroupIPv4>>
4	Transit IPv6 Source TLV Type	RFC 6826	IPv6 multicast over mLDP in GRT	<Root, Opaque<SourceIPv6, GroupIPv6>>
7	Recursive Opaque Value	RFC 6512	Inter-AS IPv4 multicast over mLDP in GRT	<ASBR, Opaque<Root, Opaque<SourceIPv4, GroupIPv4>>>
			Inter-AS IPv6 multicast over mLDP in GRT	<ASBR, Opaque<Root, Opaque<SourceIPv6, GroupIPv6>>>
			Inter-AS Option C MVPN over mLDP	<ASBR, Opaque<Root, Opaque<P2MPID>>>
8	VPN-Recursive Opaque Value	RFC 6512	Inter-AS Option B MVPN over mLDP	<ASBR, Opaque <RD, Root, P2MPID>>
250	Transit VPNv4 Source TLV Type	RFC 7246	In-band signaling for VPRN	<Root, Opaque<SourceIPv4 or RPA, GroupIPv4, RD>>
251	Transit VPNv6 Source TLV Type	RFC 7246	In-band signaling for VPRN	<Root, Opaque<SourceIPv6 or RPA, GroupIPv6, RD>>

3.18.5.4 Optimized Option C and basic FEC generation for inter-AS

Not all leaf nodes can support labeled route or recursive opaque, so recursive opaque functionality can be transferred from the leaf to the ASBR, as shown in Figure 54: Optimized Option C — leaf router not responsible for recursive FEC.

Figure 54: Optimized Option C — leaf router not responsible for recursive FEC



In Figure 54: Optimized Option C — leaf router not responsible for recursive FEC, the root advertises its unicast routes to ASBR-3 using IGP, and the ASBR-3 advertises these routes to ASBR-1 using label-BGP. ASBR-1 can redistribute these routes to IGP with next-hop ASBR-1. The leaf resolves the actual root 10.0.0.14 using IGP and creates a type 1 opaque value <Root 10.0.0.14, Opaque <8193>> to ASBR-1. In addition, all P routers in AS 2 know how to resolve the actual root because of BGP-to-IGP redistribution within AS 2.

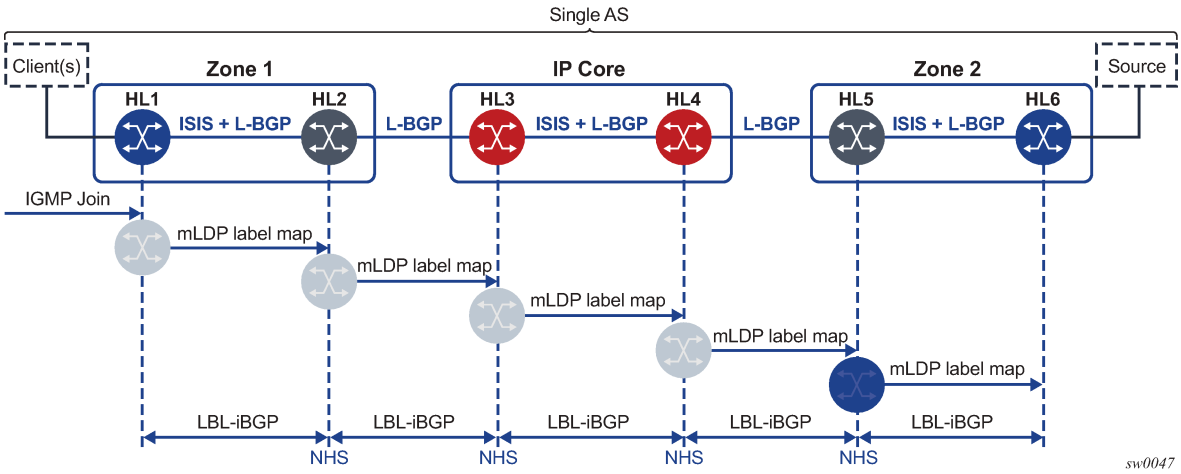
ASBR-1 attempts to resolve the 10.0.0.14 actual route via BGP, and creates a recursive type 7 opaque value <Root 10.0.0.2, Opaque <10.0.0.14, 8193>>.

3.18.5.5 Basic opaque generation when root PE is resolved using BGP

For inter-AS or intra-AS MVPN, the root PE (the PE on which the source resides) loopback IP address is usually not advertised into each AS or area. As such, the P routers in the ASs or areas that the root PE is not part of are not able to resolve the root PE loopback IP address. To resolve this issue, the leaf PE, which has visibility of the root PE loopback IP address using BGP, creates a recursive opaque with an outer root address of the local ASBR or ABR and an inner recursive opaque of the actual root PE.

Some non-Nokia routers do not support recursive opaque FEC when the root node loopback IP address is resolved using IBGP or EBGP. These routers accept and generate a basic opaque type. In such cases, there should not be any P routers between a leaf PE and ASBR or ABR, or any P routers between ASBR or ABR and the upstream ASBR or ABR. Figure 55: Example AS shows an example of this situation.

Figure 55: Example AS



In Figure 55: Example AS, the leaf HL1 is directly attached to ABR HL2, and ABR HL2 is directly attached to ABR HL3. In this case, it is possible to generate a non-recursive opaque simply because there is no P router that cannot resolve the root PE loopback IP address in between any of the elements. All elements are BGP-speaking and have received the root PE loopback IP address via IBGP or EBGP.

In addition, SR OS does not generate a recursive FEC. The following global command disables recursive opaque FEC generation when the provider needs basic opaque FEC generation on the node.

```
configure router ldp generate-basic-fec-only
```

In Figure 55: Example AS, the basic non-recursive FEC is generated even if the root node HL6 is resolved via BGP (IBGP or EBGP).

Currently, when the root node HL6 systemIP is resolved via BGP, a recursive FEC is generated by the leaf node HL1:

HL1 FEC = <HL2, <HL6, OPAQUE>>

When the **generate-basic-fec-only** command is enabled on the leaf node or any ABR, they generate a basic non-recursive FEC:

HL1 FEC = <HL6, OPAQUE>

When this FEC arrives at HL2, if the **generate-basic-fec-only** command is enabled then HL2 generates the following FEC:

HL2 FEC = <HL6, OPAQUE>

If there are any P routers between the leaf node and an ASBR or ABR, or any P routers between ASBRs or ABRs that do not have the root node (HL6) in their RTM, then this type 1 opaque FEC is not resolved and forwarded upstream, and the solution fails.

3.18.5.5.1 Leaf and ABR behavior

When the following command is enabled on a leaf node, LDP generates a basic opaque type 1 FEC.

```
configure router ldp generate-basic-fec-only
```

When **generate-basic-fec-only** is enabled on the ABR, LDP accepts a lower FEC of basic opaque type 1 and generate a basic opaque type 1 upper FEC. LDP then stitches the lower and upper FECs together to create a cross connect.

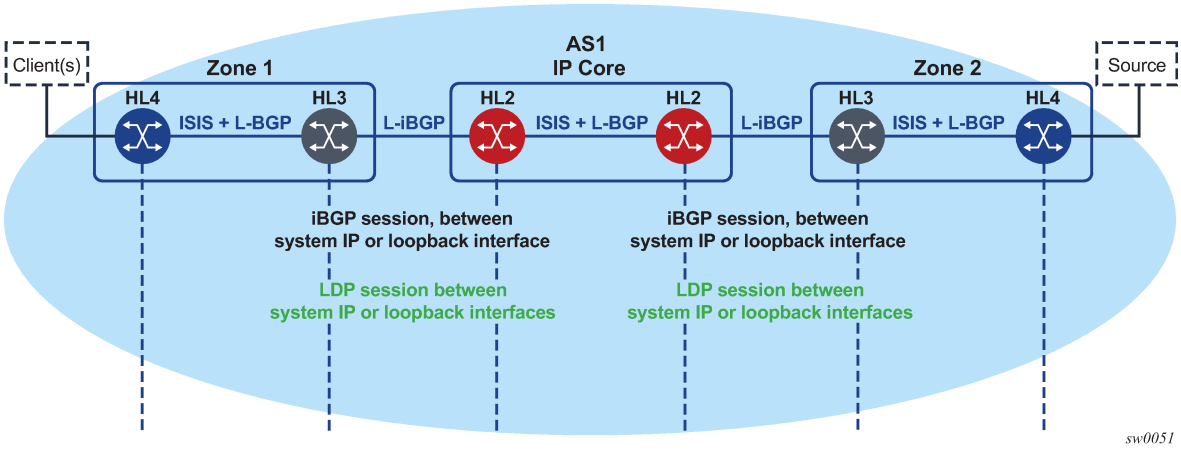
When **generate-basic-fec-only** is enabled and the ABR receives a lower FEC of:

1. For recursive FEC with type 7 opaque, the ABR stitches the lower FEC to an upper FEC with basic opaque type 1.
2. For any FEC type other than a recursive FEC with type 7 opaque or a non-recursive FEC with type 1 basic opaque, ABR processes the packet in the same manner as when **generate-basic-fec-only** is disabled.

3.18.5.5.2 Intra-AS support

ABR uses IBGP and peers between the system IP or loopback IP addresses, as shown in Figure 56: ABR and IBGP.

Figure 56: ABR and IBGP



The **generate-basic-fec-only** command is supported on leaf PE and ABR nodes. The **generate-basic-fec-only** command only interoperates with intra-AS as option C, or opaque type 7 with inner opaque type 1. No other opaque type is supported.

3.18.5.5.3 Opaque type behavior with basic FEC generation

Table 19: Opaque type behavior with basic FEC generation describes the behavior of different opaque types when the **generate-basic-fec-only** command is enabled or disabled.

Table 19: Opaque type behavior with basic FEC generation

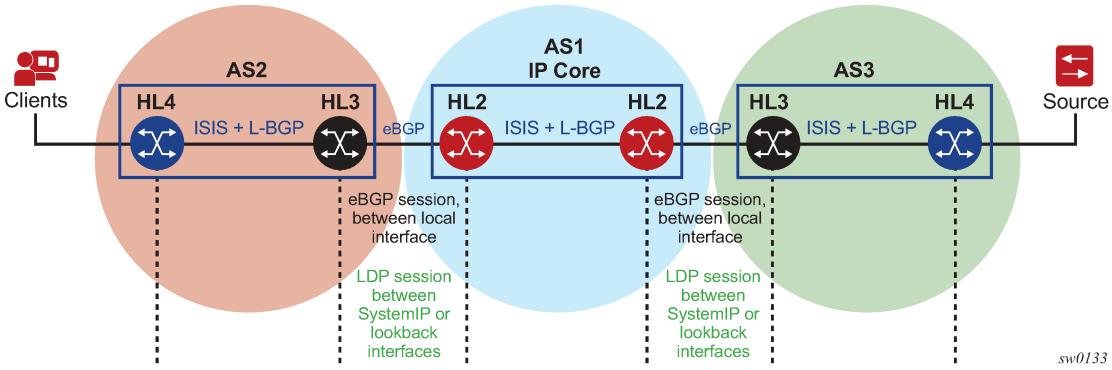
FEC opaque type	generate-basic-fec-only enabled
1	Generate type 1 basic opaque when FEC is resolved using BGP route
3	Same behavior as when **generate-basic-fec-only** is disabled
4	Same behavior as when **generate-basic-fec-only** is disabled
7 with inner type 1	Generate type 1 basic opaque
7 with inner type 3 or 4	Same behavior as when **generate-basic-fec-only** is disabled
8 with inner type 1	Same behavior as when **generate-basic-fec-only** is disabled

3.18.5.5.4 Inter-AS support

In the inter-AS case, the ASBRs use EBGP as shown in Figure 57: ASBR and EBGP.

The two ASBRs become peers via local interface. The **generate-basic-fec-only** command can be used on the LEAF or the ASBR to force SR OS to generate a basic opaque FEC when the actual ROOT is resolved via BGP. The opaque type behavior is on par with the intra-AS scenario as shown in Figure 56: ABR and IBGP.

Figure 57: ASBR and EBGP

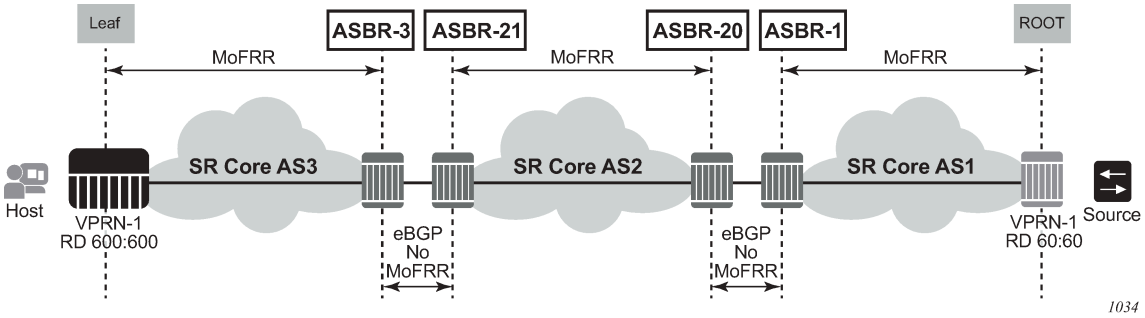


The **generate-basic-fec-only** command is supported on LEAF PE and ASBR nodes in case of inter-AS. The **generate-basic-fec-only** command only interoperates with inter-AS as option C and opaque type 7 with inner opaque type 1.

3.18.5.6 Redundancy and resiliency

For mLDP, MoFRR is supported with the IGP domain; for example, ASBRs that are not directly connected. MoFRR is not supported between directly connected ASBRs, such as ASBRs that use EBGP without IGP.

Figure 58: ASBRs using EBGP without IGP



3.18.5.7 ASBR physical connection

Non-segmented mLDP functions with ASBRs directly connected or connected via an IGP domain, as shown in the preceding figure.

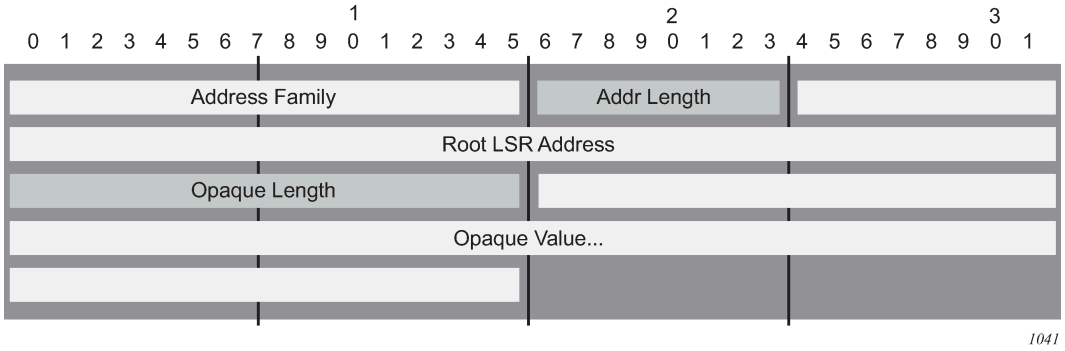
3.18.5.8 OAM

Note: The **oam p2mp-lsp-ping** command only applies to the classic CLI.

LSPs are unidirectional tunnels. When an LSP ping is sent, the echo request is transmitted via the tunnel and the echo response is transmitted via the vanilla IP to the source. Similarly, for the **oam p2mp-lsp-ping** command, on the root, the echo request is transmitted via the mLDP P2MP tunnel to all leafs and the leafs use vanilla IP to respond to the root.

The echo request for mLDP is generated carrying a root Target FEC Stack TLV, which is used to identify the multicast LDP LSP under test at the leaf. The Target FEC Stack TLV must carry an mLDP P2MP FEC Stack Sub-TLV from RFC 6388 or RFC 6512. See Figure 59: ECHO request target FEC Stack TLV.

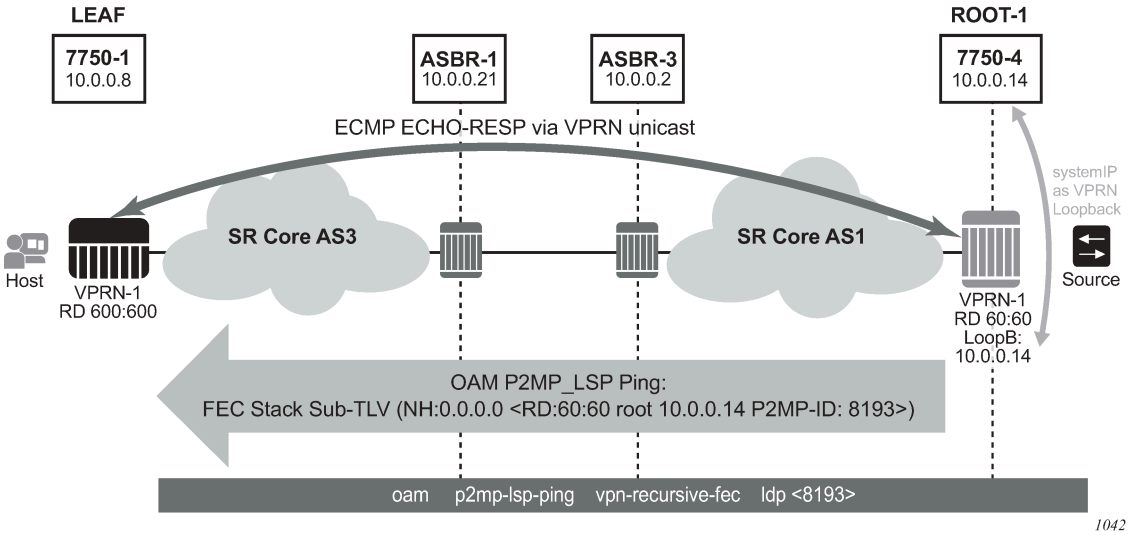
Figure 59: ECHO request target FEC Stack TLV



The same concept applies to inter-AS and non-segmented mLDP. The leafs in the remote AS should be able to resolve the root via GRT routing. This is possible for inter-AS Option C where the root is usually in the leaf RTM, which is a next-hop ASBR.

For inter-AS Option B where the root is not present in the leaf RTM, the echo reply cannot be forwarded via the GRT to the root. To solve this problem, for inter-AS Option B, the SR OS uses VPRN unicast routing to transmit the echo reply from the leaf to the root via VPRN.

Figure 60: MVPN inter-AS Option B OAM



Note: The **vpn-recursive-fec** command option only applies to the classic CLI.

As shown in the preceding figure, the echo request for VPN recursive FEC is generated from the root node by executing the **oam p2mp-lsp-ping** with the **vpn-recursive-fec** command option. When the echo request reaches the leaf, the leaf uses the sub-TLV within the echo request to identify the corresponding VPN via the FEC which includes the RD, the root, and the P2MP-ID.

After identifying the VPRN, the echo response is sent back via the VPRN and unicast routes. A unicast route (for example, root 10.0.0.14, as shown in Figure 60: MVPN inter-AS Option B OAM) must be present in the leaf VPRN to allow the unicast routing of the echo reply back to the root via VPRN. To distribute this root from the root VPRN to all VPRN leafs, a loopback interface should be configured in the root VPRN and distributed to all leafs via MP-BGP unicast routes.

The OAM functionality for Options B and C is summarized in Table 20: OAM functionality for Options B and C.

Notes:

Note: The **vpn-recursive-fec** command option only applies to the classic CLI.

- For SR OS in the classic CLI, all P2MP mLDP FEC types respond to the **vpn-recursive-fec** echo request. Leafs in the local-AS and inter-AS Option C respond to the recursive-FEC TLV echo request in addition to the leafs in the inter-AS Option B.

For non inter-AS Option B where the root system IP is visible through the GRT, the echo reply is sent via the GRT, that is, not via the VPRN.

- In the classic CLI, this **vpn-recursive-fec** is a Nokia proprietary implementation, and therefore third-party routers do not recognize the recursive FEC and do not generate an echo respond.

  In the classic CLI, the user can generate the **p2mp-lsp-ping** without the **vpn-recursive-fec** to discover non-Nokia routers in the local-AS and inter-AS Option C, but not the inter-AS Option B leafs.

Note: The information in the following table only applies to the classic CLI.

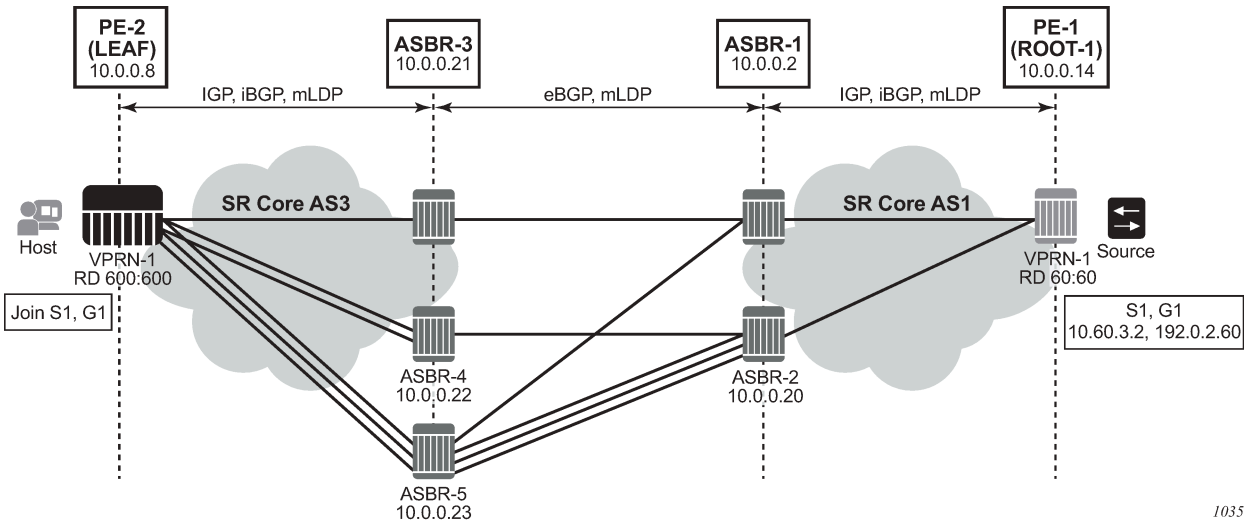
Table 20: OAM functionality for Options B and C

OAM command (for mLDP)	Leaf and root in same AS	Leaf and root in different AS (Option B)	Leaf and root in different AS (Option C)
p2mp-lsp-ping ldp	✓		✓
p2mp-lsp-ping ldp-ssm	✓		✓
p2mp-lsp-ping ldp vpn-recursive-fec	✓	✓	✓
p2mp-lsp-trace			

3.18.5.9 ECMP support

In Figure 61: ECMP support, the leaf discovers the ROOT-1 from all three ASBRs (ASBR-3, ASBR-4 and ASBR-5).

Figure 61: ECMP support



The leaf chooses uses the following process to choose the ASBR used for the multicast stream:

1. The leaf determines the number of ASBRs that should be part of the hash calculation.

   The number of ASBRs that are part of the hash calculation comes from the configured ECMP (**configure router ecmp**). For example, if the ECMP value is set to 2, only two of the ASBRs are part of the hash algorithm selection.
2. After deciding the upstream ASBR, the leaf determines whether there are multiple equal cost paths between it and the chosen ASBR.
   - If there are multiple ECMP paths between the leaf and the ASBR, the leaf performs another ECMP selection based on the configured value in **configure router ecmp**. This is a recursive ECMP lookup.
   - The first lookup chooses the ASBR and the second lookup chooses the path to that ASBR.

     For example, if the ASBR 5 was chosen in Figure 61: ECMP support, there are three paths between the leaf and ASBR-5. As such, a second ECMP decision is made to choose the path.
3. At ASBR-5, the process is repeated. For example, in Figure 61: ECMP support, ASBR-5 goes through steps 1 and 2 to choose between ASBR-1 and ASBR-2, and a second recursive ECMP lookup to choose the path to that ASBR.

When there are several candidate upstream LSRs, the LSR must select one upstream LSR. The algorithm used for the LSR selection is a local matter. If the LSR selection is done over a LAN interface and the Section 6 procedures are applied, the procedure described in ECMP hash algorithm is applied to ensure that the same upstream LSR is elected among a set of candidate receivers on that LAN.

The ECMP hash algorithm ensures that there is a single forwarder over the LAN for a specific LSP.

3.18.5.9.1 ECMP hash algorithm

The ECMP hash algorithm requires the opaque value of the FEC (see ECMP hash algorithm) and is based on RFC 6388 section 2.4.1.1.

- The candidate upstream LSRs are numbered from lower to higher IP addresses.
- The following hash is performed: H = (CRC32 (Opaque Value)) modulo N, where *N* is the number of upstream LSRs and "Opaque Value" is the field identified in the FEC element after "Opaque Length". The "Opaque Length" indicates the size of the opaque value used in this calculation.
- The selected upstream LSR U is the LSR that has the number *H* above.

3.18.5.10 Dynamic mLDP and static mLDP coexisting on the same node

When creating a static mLDP tunnel, use the commands in the following context to configure the P2MP tunnel ID.

```
configure router tunnel-interface
```

This P2MP ID can coincide with a dynamic mLDP P2MP ID. The dynamic mLDP is created by the PIM automatically without manual configuration. If the node has a static and dynamic mLDP with same label and P2MP ID, there are collisions and OAM errors.

Do not use a static and dynamic mLDP on the same node. If it is necessary to do so, ensure that the P2MP ID is not the same between the two tunnel types.

Static mLDP FECs originate at the leaf node. If the FEC is resolved using BGP, it is not forwarded downstream. A static mLDP FEC is only created and forwarded if it is resolved using IGP. For optimized Option C, the static mLDP can originate at the leaf node because the root is exported from BGP to IGP at the ASBR; therefore the leaf node resolves the root using IGP.

In the optimized Option C scenario, it is possible to have a static mLDP FEC originate from a leaf node as follows:

static-mLDP <Root: ROOT-1, Opaque: <p2mp-id-1>>

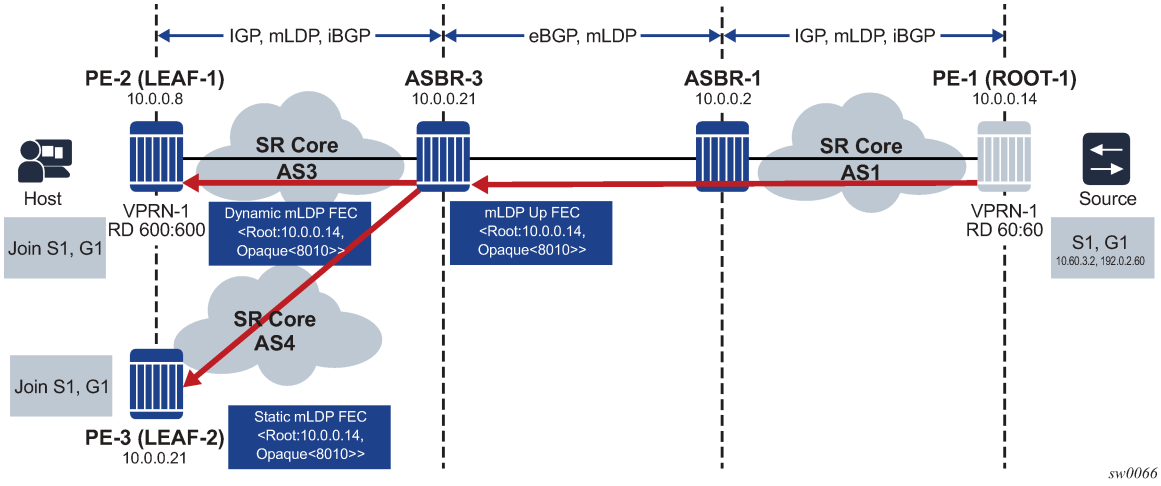
A dynamic mLDP FEC can also originate from a separate leaf node with the same FEC:

dynamic-mLDP <Root: ROOT-1, Opaque: <p2mp-id-1>>

In this case, the tree and the up-FEC merge the static mLDP and dynamic mLDP traffic at the ASBR. The user must ensure that the static mLDP P2MP ID is not used by any dynamic mLDP LSPs on the path to the root.

Figure 62: Static and dynamic mLDP interaction illustrates the scenario where one leaf (LEAF-1) is using dynamic mLDP for NG-MVPN and a separate leaf (LEAF-2) is using static mLDP for a tunnel interface.

Figure 62: Static and dynamic mLDP interaction

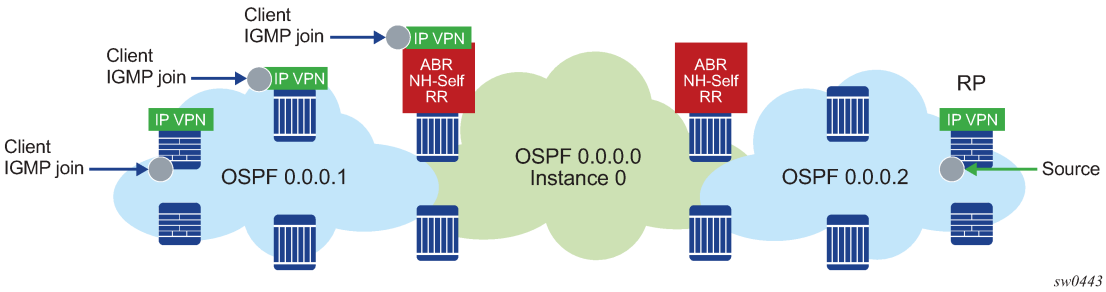


In the preceding figure, both FECs generated by LEAF-1 and LEAF-2 are identical, and the ASBR-3 merges the FECs into a single upper FEC. Any traffic arriving from ROOT-1 to ASBR-3 over VPRN-1 is forked to LEAF-1 and LEAF-2, even if the tunnels were signaled for different services.

3.18.6 Intra-AS non-segmented mLDP

Non-segmented mLDP intra-AS (inter-area) is supported on option B and C only. Figure 63: Intra-AS non-segmented topology shows a typical intra-AS topology. With a backbone IGP area 0 and access non-backbone IGP areas 1 and 2. In these topologies, the ABRs usually does next-hop-self for BGP labeled routes, which requires recursive FEC.

Figure 63: Intra-AS non-segmented topology



For option B, the ABR routers change the next hop of the MVPN AD routes to the ABR system IP or Loopback IP. The following commands for BGP do not change the next hop of the MVPN AD routes.

```
configure router bgp group next-hop-self
configure router bgp group neighbor next-hop-self
configure service vprn bgp group next-hop-self
configure service vprn bgp group neighbor next-hop-self
```

Instead, a BGP policy can be used to change the MVPN AD routes next hop at the ABR.

In the meantime a BGP policy can be used to change the MVPN AD routes next hop at the ABR.

3.18.6.1 ABR MoFRR for intra-AS

With ABR MoFRR in the intra-AS environment, the leaf chooses a local primary ABR and a backup ABR, with separate mLDP signaling toward these two ABRs. In addition, each path from a leaf to the primary ABR and from a leaf to the backup ABR supports IGP MoFRR. This behavior is similar to ASBR MoFRR in the inter-AS environment; for more details, see ASBR MoFRR. MoFRR is only supported for intra-AS option C, with or without RR.

3.18.6.2 Interaction with an inter-AS non-segmented mLDP solution

Intra-AS option C is supported in conjunction to inter-AS option B or C. Intra-AS option C with inter-AS option B is not supported.

3.18.6.3 Intra-AS/inter-AS Option B

For intra/inter-AS option B the root is not visible on the leaf. LDP is responsible for building the recursive FEC and signaling the FEC to ABR/ASBR on the leaf. The ABR/ASBR needs to have the PMSI AD router to re-build the FEC (recursive or basic) depending on if they are connected to another ABR/ASBR or to a root node. LDP must import the MVPN PMSI AD routes. To reduce resource usage, importing of the MVPN PMSI AD routes is done manually using the following command.

```
configure router ldp import-pmsi-routes mvpn
```

When enabled, LDP requests BGP to provide the LDP task with all of the MVPN PMSI AD routes and LDP caches these routes internally. If **import-pmsi-routes mvpn** is disabled, MVPN discards the cached routes to save resources.

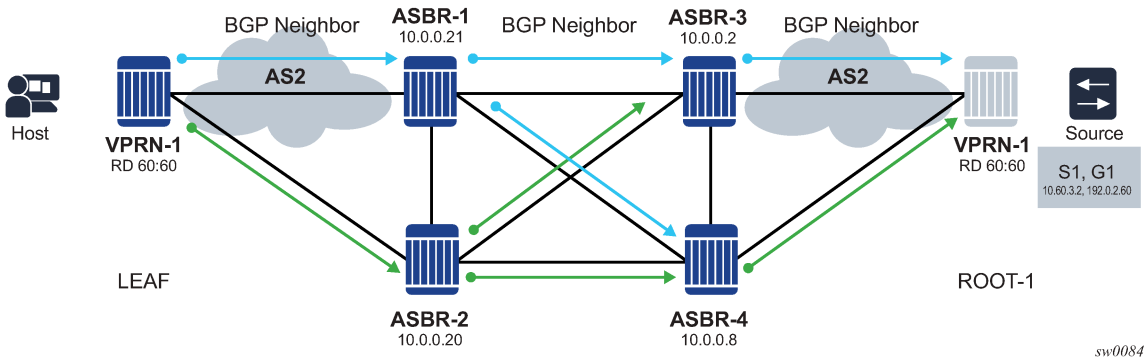
The **import-pmsi-routes mvpn** command is enabled if there is an upgrade from a software version that does not support this inter-AS case. Otherwise, by default **import-pmsi-routes mvpn** is disabled for MVPN inter-AS, MVPN intra-AS, and EVPN, so LDP does not cache any MVPN PMSI AD routes.

3.18.7 ASBR MoFRR

ASBR MoFRR in the inter-AS environment allows the leaf PE to signal a primary path to the remote root through the first ASBR and a backup path through the second ASBR, so that there is an active LSP signaled from the leaf node to the first local root (ASBR-1 in Figure 64: BGP neighboring for MoFRR) and a backup LSP signaled from the leaf node to the second local root (ASBR-2 in Figure 64: BGP neighboring for MoFRR) through the best IGP path in the AS.

Using Figure 64: BGP neighboring for MoFRR as an example, ASBR-1 and ASBR-2 are local roots for the leaf node, and ASBR-3 and ASBR-4 are local roots for ASBR-1 or ASBR-2. The actual root node (ROOT-1) is also a local root for ASBR-3 and ASBR-4.

Figure 64: BGP neighboring for MoFRR

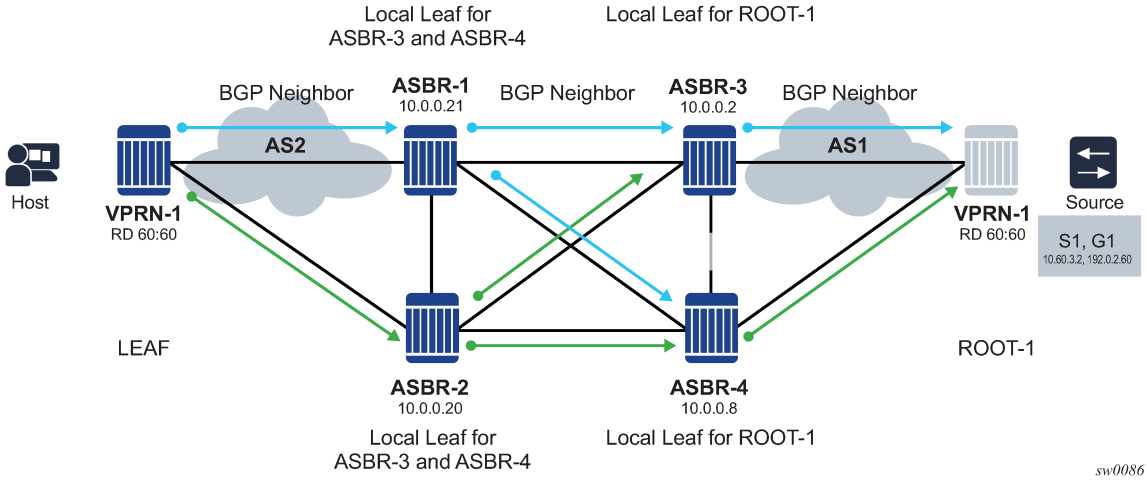


In Figure 64: BGP neighboring for MoFRR, ASBR-2 is a disjointed ASBR; with the AS spanning from the leaf to the local root, which is the ASBR selected in the AS, the traditional IGP MoFRR is used. ASBR MoFRR is used from the leaf node to the local root, and IGP MoFRR is used for any P router that connects the leaf node to the local root.

3.18.7.1 IGP MoFRR versus BGP (ASBR) MoFRR

The local leaf can be the actual leaf node that is connected to the host, or an ASBR node that acts as the local leaf for the LSP in that AS, as illustrated in Figure 65: ASBR node acting as local leaf.

Figure 65: ASBR node acting as local leaf



Two types of MoFRR can exist in a unique AS:

- **IGP MoFRR**

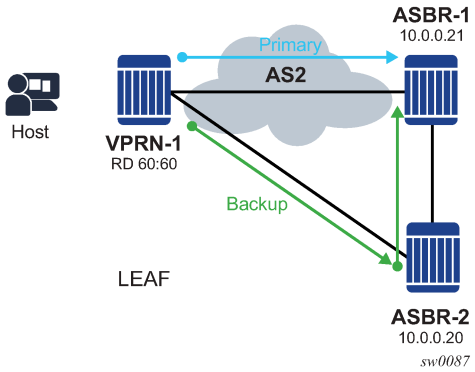
  When the following command is enabled for LDP, the local leaf selects a single local root, either ASBR or actual, and creates a FEC toward two different upstream LSRs using LFA/ECMP for the ASBR route.

  ```
  configure router ldp mcast-upstream-frr
  ```

  If there are multiple ASBRs directed toward the actual root, the local leaf only selects a single ASBR; for example, ASBR-1 in Figure 66: IGP MoFRR. In this example, LSPs are not set up for ASBR-2. The local root ASBR-1 is selected by the local leaf and the primary path is set up to ASBR-1, while the backup path is set up through ASBR-2.

  For more information, see Multicast LDP fast upstream switchover.

  Figure 66: IGP MoFRR

- **ASBR MoFRR**

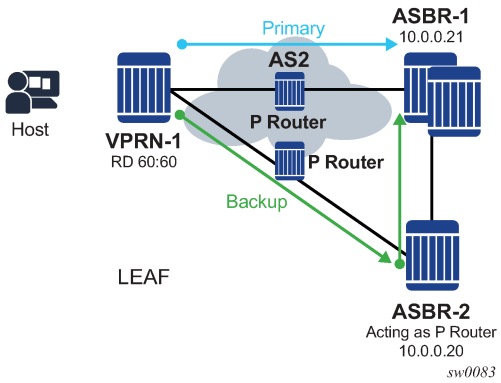
When the following command is enabled for LDP, and the **mcast-upstream-frr** command is not enabled, the local leaf selects a single ASBR as the primary ASBR and another ASBR as the backup ASBR.

```
configure router ldp mcast-upstream-asbr-frr
```

The primary and backup LSPs are set to these two ASBRs, as shown in Figure 67: ASBR MoFRR. Because the **mcast-upstream-frr** command is not configured, IGP MoFRR is not enabled in the AS2, and therefore none of the P routers perform local IGP MoFRR.

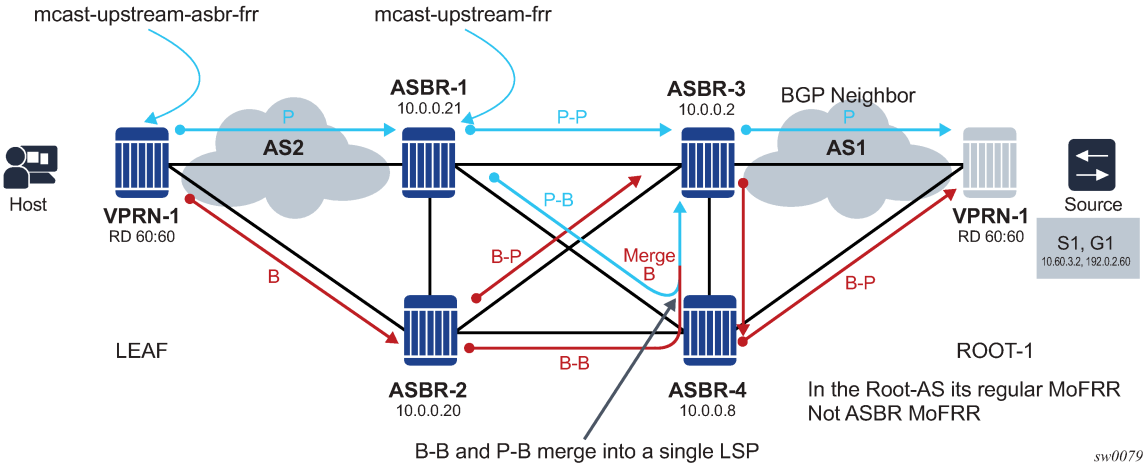
BGP neighboring and sessions can be used to detect BGP peer failure from the local leaf to the ASBR, and can cause a MoFRR switch from the primary LSP to the backup LSP. Multihop BFD can be used between BGP neighbors to detect failure more quickly and remove the primary BGP peer (ASBR-1 in Figure 67: ASBR MoFRR) and its routes from the routing table so that the leaf can switch to the backup LSP and backup ASBR.

Figure 67: ASBR MoFRR



The **mcast-upstream-frr** and **mcast-upstream-asbr-frr** commands can be configured together on the local leaf of each AS to create a high-resilience MoFRR solution. When both commands are enabled, the local leaf sets up ASBR MoFRR first and sets up a primary LSP to one ASBR (ASBR-1 in Figure 68: ASBR MoFRR and IGP MoFRR) and a backup LSP to another ASBR (ASBR-2 in Figure 68: ASBR MoFRR and IGP MoFRR). In addition, the local leaf protects each LSP using IGP MoFRR through the P routers in that AS.

Figure 68: ASBR MoFRR and IGP MoFRR



Note: Enabling both the **mcast-upstream-frr** and **mcast-upstream-asbr-frr** commands can cause extra multicast traffic to be created. Ensure that the network is designed and the appropriate commands are enabled to meet network resiliency needs.

At each AS, either command can be configured; for example, in Figure 68: ASBR MoFRR and IGP MoFRR, the leaf is configured with **mcast-upstream-asbr-frr** enabled and sets up a primary LSP to ASBR-1 and a backup LSP to ASBR-2. ASBR-1 and ASBR-2 are configured with **mcast-upstream-frr** enabled, and both perform IGP MoFRR to ASBR-3 only. ASBR-2 can select ASBR-3 or ASBR-4 as its local root for IGP MoFRR; in this example, ASBR-2 has selected ASBR-3 as its local root.

There are no ASBRs in the root AS (AS-1), so IGP MoFRR is performed if **mcast-upstream-frr** is enabled on ASBR-3.

The **mcast-upstream-frr** and **mcast-upstream-asbr-frr** commands work separately depending on the needed behavior. If there is more than one local root, then **mcast-upstream-asbr-frr** can provide extra resiliency between the local ASBRs, and **mcast-upstream-frr** can provide extra redundancy between the local leaf and the local root by creating a disjointed LSP for each ASBR.

If the **mcast-upstream-asbr-frr** command is disabled and **mcast-upstream-frr** is enabled, and there is more than one local root, only a single local root is selected and IGP MoFRR can provide local AS resiliency.

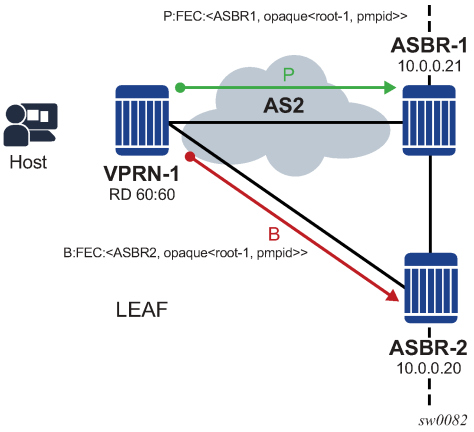
In the actual root AS, only the **mcast-upstream-frr** command needs to be configured.

3.18.7.2 ASBR MoFRR leaf behavior

With inter-AS MoFRR at the leaf, the leaf selects a primary ASBR and a backup ASBR. These ASBRs are disjointed ASBRs.

The primary and backup LSPs is set up using the primary and backup ASBRs, as illustrated in Figure 69: ASBR MoFRR leaf behavior.

Figure 69: ASBR MoFRR leaf behavior



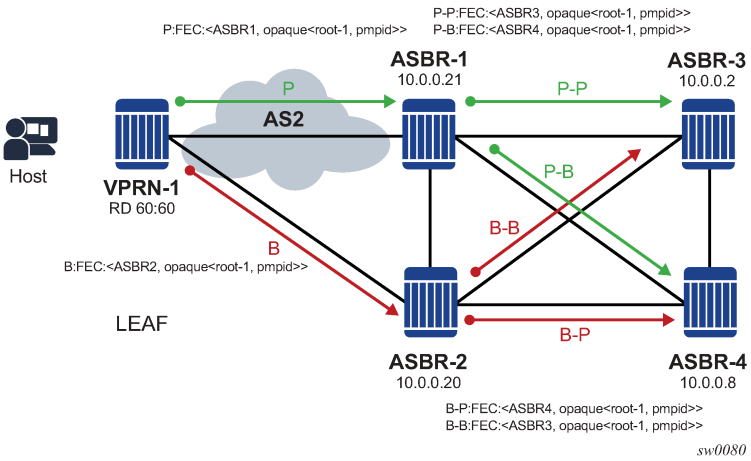
Note: Using Figure 69: ASBR MoFRR leaf behavior as a reference, ensure that the paths to ASBR-1 and ASBR-2 are disjointed from the leaf. MLDP does not support TE and cannot create two disjointed LSPs from the leaf to ASBR-1 and ASBR-2. The operator and IGP architect must define the disjointed paths.

3.18.7.3 ASBR MoFRR ASBR behavior

Each LSP at the ASBR creates its own primary and backup LSPs.

As shown in Figure 70: ASBR MoFRR ASBR behavior, the primary LSP from the leaf to ASBR-1 generates a primary LSP to ASBR-3 (P-P) and a backup LSP to ASBR-4 (P-B). The backup LSP from the leaf also generates a backup primary to ASBR-4 (B-P) and a backup backup to ASBR-3 (B-B). When two similar FECs of an LSP intersect, the LSPs merge.

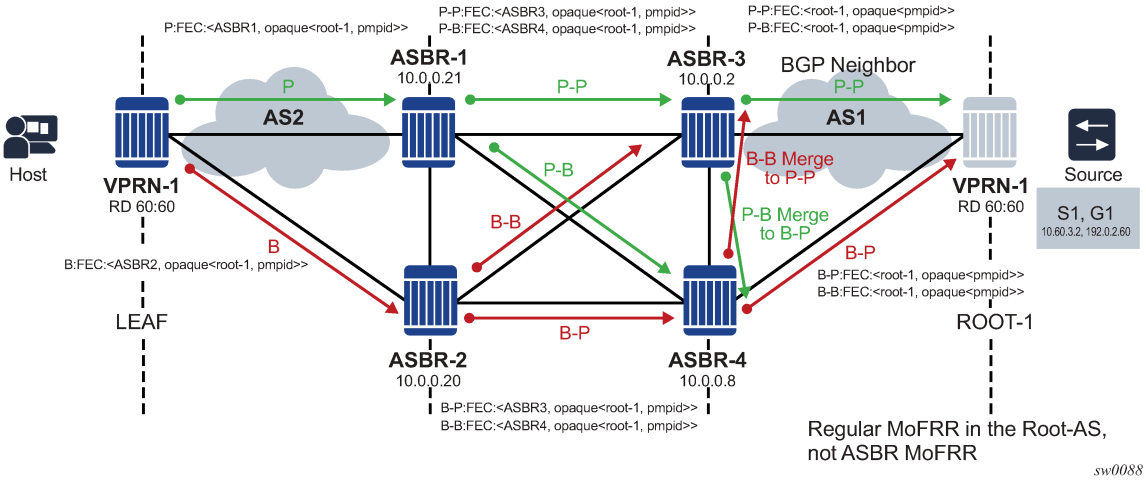
Figure 70: ASBR MoFRR ASBR behavior



3.18.7.4 MoFRR root AS behavior

In the root AS, MoFRR is based on regular IGP MoFRR. At the root, there are primary and backup LSPs for each of the primary and backup LSPs that arrive from the neighboring AS, as shown in Figure 71: MoFRR root AS behavior.

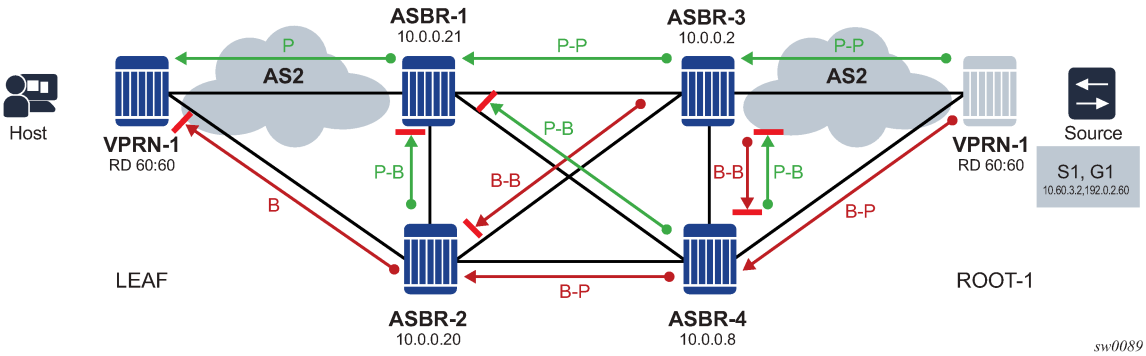
Figure 71: MoFRR root AS behavior



3.18.7.5 Traffic flow

Figure 72: Traffic flow illustrates traffic flow based on the LSP setup. The backup LSPs of the primary and backup LSPs (B-B, P-B) are blocked in the non-leaf AS.

Figure 72: Traffic flow



3.18.7.6 Failure detection and handling

Failure detection can be achieved by using either of the following:

- **IGP failure detection**
  - Enabling BFD is recommended for IGP protocols or static route (if static route is used for IGP forwarding). This enables faster IGP failure detection.

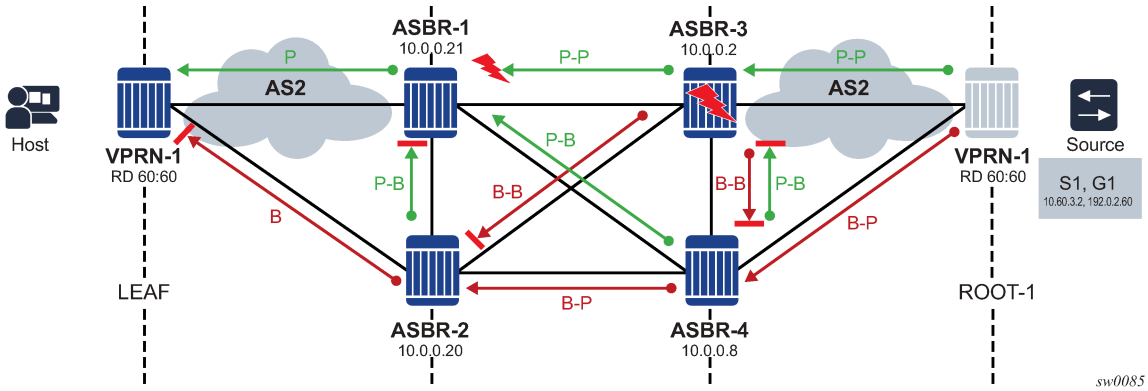
- IGP can detect P router failures for IGP MoFRR (single AS).
- If the ASBR fails, IGP can detect the failure and converge the route table to the local leaf. The local leaf in an AS can be either the ASBR or the actual leaf.
- IGP routes to the ASBR address must be deleted for IGP failure to be handled.

- **BGP failure detection**
  - BGP neighboring must be established between the local leaf and each ASBR. Using multihop BFD for ASBR failure is recommended.
  - Each local leaf attempts to calculate a primary ASBR or backup ASBR. The local leaf sets up a primary LSP to the primary ASBR and a backup LSP to the backup ASBR. If the primary ASBR has failed, the local leaf removes the primary ASBR from the next-hop list and allows traffic to be processed from the backup LSP and the backup ASBR.
  - BGP MoFRR can offer faster ASBR failure detection than IGP MoFRR.
  - BGP MoFRR can also be activated via IGP changes, such as if the node detects a direct link failure, or if IGP removes the BGP neighbor system IP address from the routing table. These events can cause a switch from the primary ASBR to a backup ASBR. It is recommended to deploy IGP and BFD in tandem for fast failure detection.

3.18.7.7 Failure scenario

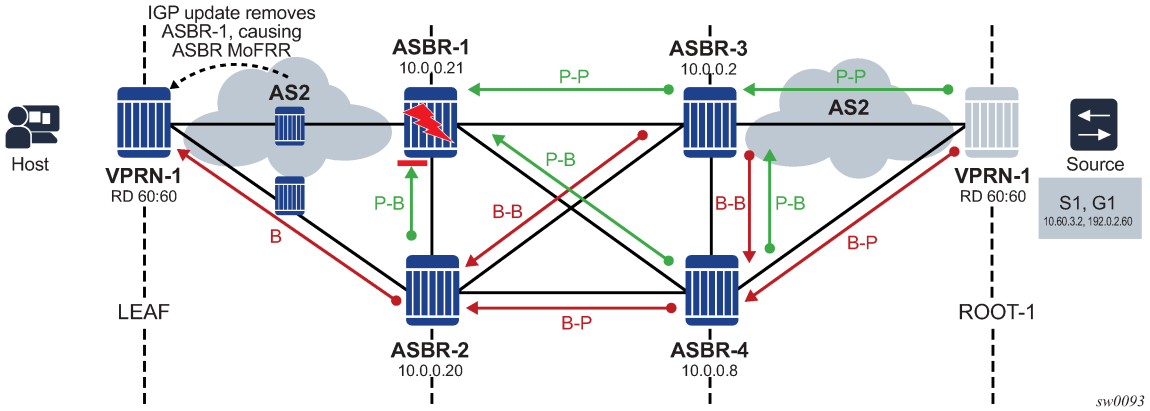
As shown in Figure 73: Failure scenario 1, when ASBR-3 fails, ASBR-1 detects the failure using ASBR MoFRR and enables the primary backup path (P-B). This is the case for every LSP that has been set up for ASBR MoFRR in any AS.

Figure 73: Failure scenario 1



In another example, as shown in Figure 74: Failure scenario 2, failure on ASBR-1 causes the attached P router to generate a route update to the leaf, removing the ASBR-1 from the routing table and causing an ASBR-MoFRR on the leaf node.

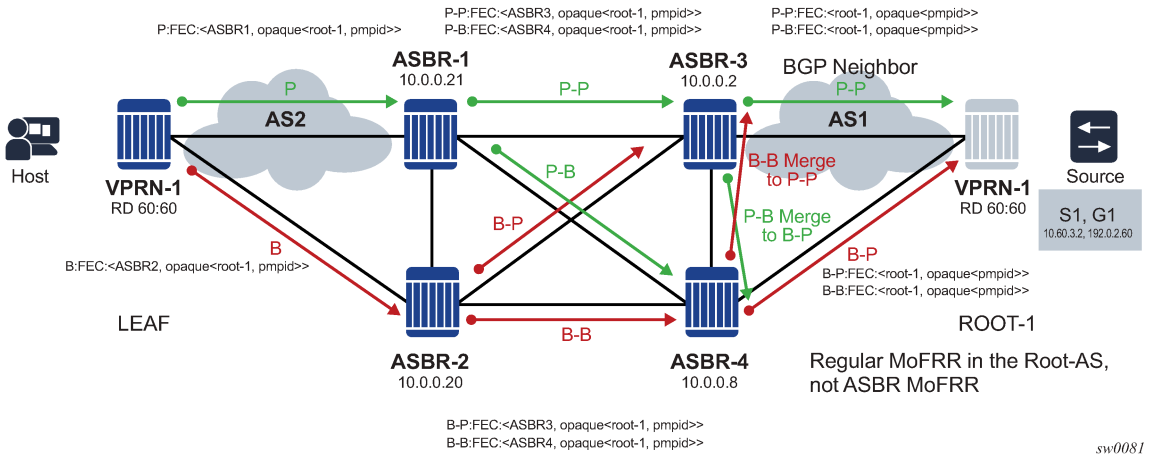
Figure 74: Failure scenario 2



3.18.7.8 ASBR MoFRR consideration

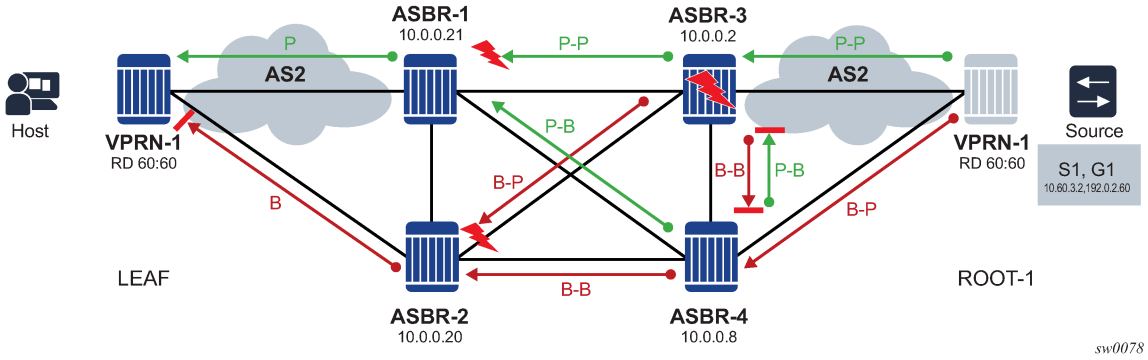
As illustrated in Figure 75: Resolution via ASBR-3, it is possible for the ASBR-1 primary-primary (P-P) LSP to be resolved using ASBR-3, and for the ASBR-2 backup-primary (B-P) LSP to be resolved using the same ASBR-3.

Figure 75: Resolution via ASBR-3



In this case, both the backup-primary LSP and primary-primary LSP are affected when a failure occurs on ASBR-3, as illustrated in Figure 76: ASBR-3 failure.

Figure 76: ASBR-3 failure



In Figure 76: ASBR-3 failure, the MoFRR can switch to the primary-backup LSP between ASBR-4 and ASBR-1 by detecting BGP MoFRR failure on ASBR-3.

It is strongly recommended that LDP signaling be enabled on all links between the local leaf and local roots, and that all P routers enable ASBR MoFRR and IGP MoFRR. If only LDP signaling is configured, the routing table may resolve a next-hop for LDP FEC when there is no LDP signaling and the primary or backup MoFRR LSPs may not be set up.

ASBR MoFRR guarantees that ASBRs are disjointed, but does not guarantee that the path from the local leaf to the local ASBR are disjointed. The primary and backup LSPs take the best paths as calculated by IGP, and if IGP selects the same path for the primary ASBR and the backup ASBR, then the two LSPs are not disjointed. Ensure that 2 disjointed paths are created to the primary and backup ASBRs.

3.18.7.9 ASBR MoFRR opaque support

Table 21: ASBR MoFRR opaque support lists the FEC opaque types that are supported by ASBR MoFRR.

Table 21: ASBR MoFRR opaque support

FEC opaque type	Supported for ASBR MoFRR
Type 1	✓
Type 3	
Type 4	
Type 7, inner type 1	✓
Type 7, inner type 3 or 4	
Type 8, inner type 1	✓
Type 250	
Type 251	

3.18.8 MBB for MoFRR

Any optimization of the MoFRR primary LSP should be performed by the Make Before Break (MBB) mechanism. For example, if the primary LSP fails, a switch to the backup LSP occurs and the primary LSP is signaled. After the primary LSP is successfully re-established, MoFRR switches from the backup LSP to the primary LSP.

MBB is performed from the leaf node to the root node, and therefore it is not performed per autonomous system (AS); the MBB signaling must be successful from the leaf PE to the root PE, including all ASBRs and P routers in between.

The conditions of MBB for mLDP LSPs are:

- re-calculation of the SFP
- failure of the primary ASBR

If the primary ASBR fails and a switch is made to the backup ASBR, and the backup ASBR is the only other ASBR available, the MBB mechanism does not signal any new LSP and uses this backup LSP as the primary.

3.18.9 Add-paths for route reflectors

If the ASBRs and the local leaf are connected by a route reflector, the following BGP **add-paths** command must be enabled on the route reflector.

```
configure router bgp add-paths
```

This allows for the configuration of the following commands.

```
configure router bgp add-paths mcast-vpn-ipv4
configure router bgp add-paths mcast-vpn-ipv6
configure router bgp add-paths label-ipv4 (if Option C is used)
```

The **add-paths** command forces the route reflector to advertise all ASBRs to the local leaf as the next hop for the actual root.

If the **add-paths** command is not enabled for the route reflector, only a single ASBR is advertised to the local root, and ASBR MoFRR is not available.

3.19 Multicast LDP fast upstream switchover

This feature allows a downstream LSR of a multicast LDP (mLDP) FEC to perform a fast switchover and source the traffic from another upstream LSR while IGP and LDP are converging because of a failure of the upstream LSR which is the primary next-hop of the root LSR for the P2MP FEC. In essence it provides an upstream Fast-Reroute (FRR) node-protection capability for the mLDP FEC packets. It does it at the expense of traffic duplication from two different upstream nodes into the node which performs the fast upstream switchover.

The detailed procedures for this feature are described in *draft-pdutta-mpls-mldp-up-redundancy*.

3.19.1 Feature configuration

The user enables the mLDP fast upstream switchover feature by configuring the following option in CLI.

```
configure router ldp mcast-upstream-frr
```

When this command is enabled and LDP is resolving a mLDP FEC received from a downstream LSR, it checks if an ECMP next hop or a LFA next hop exist to the root LSR node. If LDP finds one, it programs a primary ILM on the interface corresponding to the primary next hop and a backup ILM on the interface corresponding to the ECMP or LFA next hop. LDP then sends the corresponding labels to both upstream LSR nodes. In normal operation, the primary ILM accepts packets while the backup ILM drops them. If the interface or the upstream LSR of the primary ILM goes down causing the LDP session to go down, the backup ILM then starts accepting packets.

To make use of the ECMP next hop, the user must configure the following command value in the system to two or more.

```
configure router ecmp max-ecmp-routes
```

To make use of the LFA next hop, the user must enable LFA using the following commands:

- **MD-CLI**

```
configure router isis loopfree-alternate
configure router ospf loopfree-alternate
```

- **classic CLI**

```
configure router isis loopfree-alternates
configure router ospf loopfree-alternates
```

Enabling IP FRR or LDP FRR using the following commands is not strictly required because LDP only needs to know where the alternate next hop to the root LSR is to be able to send the Label Mapping message to program the backup ILM at the initial signaling of the tree. Thus enabling the LFA option is sufficient. If however, unicast IP and LDP prefixes need to be protected, these features and the mLDP fast upstream switchover can be enabled concurrently using the following commands:

- **MD-CLI**

```
configure routing-options ip-fast-reroute
configure router ldp fast-reroute
```

- **classic CLI**

```
configure router ip-fast-reroute
configure router ldp fast-reroute
```

Caution: The mLDP FRR fast switchover relies on the fast detection of loss of **LDP session** to the upstream peer to which the primary ILM label had been advertised. Nokia strongly recommends that you perform the following:

1. Enable BFD on all LDP interfaces to upstream LSR nodes. When BFD detects the loss of the last adjacency to the upstream LSR, it brings down immediately the LDP session which causes the IOM to activate the backup ILM.

2. If there is a concurrent TLDP adjacency to the same upstream LSR node, enable BFD on the T-LDP peer in addition to enabling it on the interface.
3. Enable the following command option on all interfaces to the upstream LSR nodes.

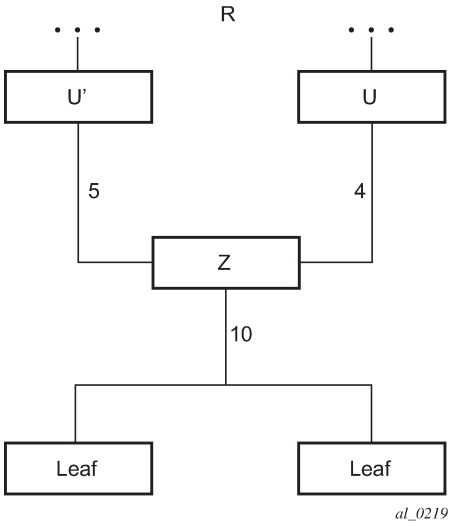
```
configure router interface ldp-sync-timer
```

If an LDP session to the upstream LSR to which the primary ILM is resolved goes down for any other reason than a failure of the interface or of the upstream LSR, routing and LDP goes out of sync. This means the backup ILM remains activated until the next time SPF is rerun by IGP. By enabling IGP-LDP synchronization feature, the advertised link metric is changed to max value as soon as the LDP session goes down. This in turn triggers an SPF and LDP likely downloads a new set of primary and backup ILMs.

3.19.2 Feature behavior

This feature allows a downstream LSR to send a label binding to a couple of upstream LSR nodes but only accept traffic from the ILM on the interface to the primary next hop of the root LSR for the P2MP FEC in normal operation, and accept traffic from the ILM on the interface to the backup next hop under failure. A candidate upstream LSR node must either be an ECMP next hop or a Loop-Free Alternate (LFA) next hop. This allows the downstream LSR to perform a fast switchover and source the traffic from another upstream LSR while IGP is converging because of a failure of the LDP session of the upstream peer which is the primary next hop of the root LSR for the P2MP FEC. In a sense it provides an upstream Fast-Reroute (FRR) node-protection capability for the mLDP FEC packets.

Figure 77: mLDP LSP with backup upstream LSR nodes



Upstream LSR U in Figure 77: mLDP LSP with backup upstream LSR nodes is the primary next hop for the root LSR *R* of the P2MP FEC. This is also referred to as primary upstream LSR. Upstream LSR *U'* is an ECMP or LFA backup next hop for the root LSR *R* of the same P2MP FEC. This is referred to as backup upstream LSR. Downstream LSR *Z* sends a label mapping message to both upstream LSR nodes and programs the primary ILM on the interface to LSR *U* and a backup ILM on the interface to LSR *U'*. The labels for the primary and backup ILMs must be different. LSR *Z* therefore attracts traffic from both of them.

However, LSR *Z* blocks the ILM on the interface to LSR *U*' and only accepts traffic from the ILM on the interface to LSR *U*.

In case of a failure of the link to LSR *U* or of the LSR *U* itself causing the LDP session to LSR *U* to go down, LSR *Z* detects it and reverses the ILM blocking state and immediately starts receiving traffic from LSR *U*' until IGP converges and provides a new primary next hop, and ECMP or LFA backup next hop, which may or may not be on the interface to LSR *U*'. At that point LSR *Z* updates the primary and backup ILMs in the datapath.

The LDP uses the interface of either an ECMP next hop or a LFA next hop to the root LSR prefix, whichever is available, to program the backup ILM. ECMP next hop and LFA ext hop are however mutually exclusive for a specified prefix. IGP installs the ECMP next hop in preference to an LFA next hop for a prefix in the Routing Table Manager (RTM).

If one or more ECMP next hops for the root LSR prefix exist, LDP picks the interface for the primary ILM based on the rules of mLDP FEC resolution specified in RFC 6388:

- The candidate upstream LSRs are numbered from lower to higher IP address.
- The following hash is performed: H = (CRC32(Opaque Value)) modulo N, where *N* is the number of upstream LSRs. The Opaque Value is the field identified in the P2MP FEC Element right after 'Opaque Length' field. The 'Opaque Length' indicates the size of the opaque value used in this calculation.
- The selected upstream LSR *U* is the LSR that has the number *H*.

LDP then picks the interface for the backup ILM using the following new rules:

if (H + 1 < NUM_ECMP) {

// If the hashed entry is not last in the next hops then pick up the next as backup.

backup = H + 1;

} else {

// Wrap around and pickup the first.

backup = 1;

}

In some topologies, it is possible that no ECMP or LFA next hop is found. In this case, LDP programs the primary ILM only.

3.19.3 Uniform failover from primary to backup ILM

When LDP programs the primary ILM record in the datapath, it provides the IOM with the Protect-Group Identifier (PG-ID) associated with this ILM and which identifies which upstream LSR is protected.

For the system to perform a fast switchover to the backup ILM in the fast path, LDP applies to the primary ILM uniform FRR failover procedures similar in concept to the ones applied to an NHLFE in the existing implementation of LDP FRR for unicast FECs. There are however important differences to note. LDP associates a unique Protect Group ID (PG–ID) to all mLDP FECs which have their primary ILM on any LDP interface pointing to the same upstream LSR. This PG-ID is assigned per upstream LSR regardless of the number of LDP interfaces configured to this LSR. Therefore, this PG-ID is different from the one associated with unicast FECs and which is assigned to each downstream LDP interface and next hop. However, if a failure caused an interface to go down and also caused the LDP session to upstream peer to go down, both PG-IDs have their state updated in the IOM and therefore the uniform FRR procedures are triggered for both the unicast LDP FECs forwarding packets toward the upstream LSR and the mLDP FECs receiving packets from the same upstream LSR.

When the mLDP FEC is programmed in the datapath, the primary and backup ILM records therefore contain the PG-ID the FEC is associated with. The IOM also maintains a list of PG-IDs and a state bit which indicates if it is UP or DOWN. When the PG-ID state is UP the primary ILM for each mLDP FEC is open and accepts mLDP packets while the backup ILM is blocked and drops mLDP packets. LDP sends a PG-ID DOWN notification to IOM when it detects that the LDP session to the peer is gone down. This notification causes the backup ILMs associated with this PG-ID to open and accept mLDP packets immediately. When IGP re-converges, an updated pair of primary and backup ILMs is downloaded for each mLDP FEC by LDP into the IOM with the corresponding PG-IDs.

If multiple LDP interfaces exist to the upstream LSR, a failure of one interface brings down the link Hello adjacency on that interface but not the LDP session which is still associated with the remaining link Hello adjacencies. In this case, the upstream LSR updates in IOM the NHLFE for the mLDP FEC to use one of the remaining links. The switchover time in this case is not managed by the uniform failover procedures.

3.20 Multi-area and multi-instance extensions to LDP

To extend LDP across multiple areas of an IGP instance or across multiple IGP instances, the current standard LDP implementation based on RFC 3036 requires that all /32 prefixes of PEs be leaked between the areas or instances. This is because an exact match of the prefix in the routing table is required to install the prefix binding in the LDP Forwarding Information Base (FIB). Although a router does this by default when configured as Area Border Router (ABR), this increases the convergence of IGP on routers when the number of PE nodes scales to thousands of nodes.

Multi-area and multi-instance extensions to LDP provide an optional behavior by which LDP installs a prefix binding in the LDP FIB by simply performing a longest prefix match with an aggregate prefix in the routing table (RIB). That way, the ABR is configured to summarize the /32 prefixes of PE routers. This method is compliant to RFC 5283, *LDP Extension for Inter-Area Label Switched Paths (LSPs)*.

3.20.1 LDP shortcut for BGP next hop resolution

LDP shortcut for BGP next-hop resolution shortcuts allow for the deployment of a ‘route-less core’ infrastructure on the 7750 SR and 7950 XRS. Many service providers either have or intend to remove the IBGP mesh from their network core, retaining only the mesh between routers connected to areas of the network that require routing to external routes.

Shortcuts are implemented by utilizing Layer 2 tunnels (that is, MPLS LSPs) as next hops for prefixes that are associated with the far end termination of the tunnel. By tunneling through the network core, the core routers forwarding the tunnel have no need to obtain external routing information and are immune to attack from external sources.

The tunnel table contains all available tunnels indexed by remote destination IP address. LSPs derived from received LDP /32 route FECs are automatically installed in the table associated with the advertising router-ID when IGP shortcuts are enabled.

Evaluating tunnel preference is based on the following order in descending priority:

1. LDP /32 route FEC shortcut
2. Actual IGP next-hop

If a higher priority shortcut is not available or is not configured, a lower priority shortcut is evaluated. When no shortcuts are configured or available, the IGP next-hop is always used. Shortcut and next-hop determination is event driven based on dynamic changes in the tunneling mechanisms and routing states.

See the *7450 ESS, 7750 SR, 7950 XRS, and VSR Unicast Routing Protocols Guide* for details on the use of LDP FEC and RSVP LSP for BGP Next-Hop Resolution.

3.20.2 LDP shortcut for IGP routes

The LDP shortcut for IGP route resolution feature allows forwarding of packets to IGP learned routes using an LDP LSP. When LDP shortcut is enabled globally, IP packets forwarded over a network IP interface are labeled with the label received from the next hop for the route and corresponding to the FEC-prefix matching the destination address of the IP packet. In such a case, the routing table has the shortcut next hop as the best route. If such a LDP FEC does not exist, then the routing table has the regular IP next hop and regular IP forwarding is performed on the packet.

An egress LER advertises and maintains a FEC, label binding for each IGP learned route. This is performed by the existing LDP fec-originate capability.

3.20.2.1 LDP shortcut configuration

The user enables the use of LDP shortcut for resolving IGP routes by entering the following global command:

- **MD-CLI**

```
configure router ldp ldp-shortcut
```

- **classic CLI**

```
configure router ldp-shortcut
```

This command enables forwarding of user IP packets and specified control IP packets using LDP shortcuts over all network interfaces in the system which participate in the IS-IS and OSPF routing protocols. The default is to disable the LDP shortcut across all interfaces in the system.

3.20.2.2 IGP route resolution

When LDP shortcut is enabled, LDP populates the RTM with next-hop entries corresponding to all prefixes for which it activated an LDP FEC. For a specified prefix, two route entries are populated in RTM. One corresponds to the LDP shortcut next hop and has an owner of LDP. The other one is the regular IP next hop. The LDP shortcut next hop always has preference over the regular IP next hop for forwarding user packets and specified control packets over a specified outgoing interface to the route next hop.

The prior activation of the FEC by LDP is done by performing an exact match with an IGP route prefix in RTM. It can also be done by performing a longest prefix-match with an IGP route in RTM if the aggregate-prefix-match option is enabled globally in LDP.

This feature is not restricted to /32 FEC prefixes. However only /32 FEC prefixes are populated in the CPM Tunnel Table for use as a tunnel by services.

All user packets and specified control packets for which the longest prefix match in RTM yields the FEC prefix are forwarded over the LDP LSP. Currently, the control packets that could be forwarded over the LDP LSP are ICMP ping and UDP-traceroute. The following is an example of the resolution process.

Assume the egress LER advertised a FEC for some /24 prefix using the following command.

```
configure router ldp fec-originate
```

At the ingress LER, LDP resolves the FEC by checking in RTM that an exact match exists for this prefix. After LDP activated the FEC, it programs the NHLFE in the egress datapath and the LDP tunnel information in the ingress datapath tunnel table.

Next, LDP provides the shortcut route to RTM which associates it with the same /24 prefix. There are two entries for this /24 prefix, the LDP shortcut next hop and the regular IP next hop. The latter was used by LDP to validate and activate the FEC. RTM then resolves all user prefixes which succeed a longest prefix match against the /24 route entry to use the LDP LSP.

Assume now the aggregate-prefix-match was enabled and that LDP found a /16 prefix in RTM to activate the FEC for the /24 FEC prefix. In this case, RTM adds a new more specific route entry of /24 and has the next hop as the LDP LSP but it still does not have a specific /24 IP route entry. RTM then resolves all user prefixes which succeed a longest prefix match against the /24 route entry to use the LDP LSP, while all other prefixes that succeed a longest prefix-match against the /16 route entry use the IP next hop.

3.20.2.3 LDP shortcut forwarding plane

After LDP activated a FEC for a specified prefix and programmed RTM, it also programs the ingress Tunnel Table in forwarding engine with the LDP tunnel information.

When an IPv4 packet is received on an ingress network interface, or a subscriber IES interface, or a regular IES interface, the lookup of the packet by the ingress forwarding engine results in the packet being sent labeled with the label stack corresponding to the NHLFE of the LDP LSP when the preferred RTM entry corresponds to an LDP shortcut.

If the preferred RTM entry corresponds to an IP next-hop, the IPv4 packet is forwarded unlabeled.

3.20.3 ECMP considerations

When ECMP is enabled and multiple equal-cost next hops exist for the IGP route, the ingress forwarding engine sprays the packets for this route based on hashing routine currently supported for IPv4 packets.

When the preferred RTM entry corresponds to an LDP shortcut route, spraying is performed across the multiple next hops for the LDP FEC. The FEC next hops can either be direct link LDP neighbors or T-LDP neighbors reachable over RSVP LSPs in the case of LDP-over-RSVP but not both. This is as per ECMP for LDP in existing implementation.

When the preferred RTM entry corresponds to a regular IP route, spraying is performed across regular IP next hops for the prefix.

3.20.4 Disabling TTL propagation in an LSP shortcut

This feature provides the option for disabling TTL propagation from a transit or a locally generated IP packet header into the LSP label stack when an LDP LSP is used as a shortcut for BGP next-hop resolution, a static-route next hop resolution, or for an IGP route resolution.

A transit packet is a packet received from an IP interface and forwarded over the LSP shortcut at ingress LER.

A locally-generated IP packet is any control plane packet generated from the CPM and forwarded over the LSP shortcut at ingress LER.

TTL handling can be configured for all LDP LSP shortcuts originating on an ingress LER using the following global commands.

```
configure router ldp shortcut-transit-ttl-propagate
configure router ldp shortcut-local-ttl-propagate
```

These commands apply to all LDP LSPs which are used to resolve static routes, BGP routes, and IGP routes.

When the following command is configured, TTL propagation is disabled on all locally generated IP packets, including ICMP ping, traceroute, and OAM packets that are destined for a route that is resolved to the LSP shortcut:

- **MD-CLI**

```
configure router ldp shortcut-local-ttl-propagate false
```

- **classic CLI**

```
configure router ldp no shortcut-local-ttl-propagate
```

In this case, a TTL of 255 is programmed onto the pushed label stack. This is referred to as pipe mode.

Similarly, when the following command is configured, TTL propagation is disabled on all IP packets received on any IES interface and destined for a route that is resolved to the LSP shortcut:

- **MD-CLI**

```
configure router ldp shortcut-transit-ttl-propagate false
```

- **classic CLI**

```
configure router ldp no shortcut-transit-ttl-propagate
```

In this case, a TTL of 255 is programmed onto the pushed label stack.

3.21 LDP graceful handling of resource exhaustion

This feature enhances the behavior of LDP when a datapath or a CPM resource required for the resolution of a FEC is exhausted. In prior releases, the LDP module shuts down. The user is required to fix the issue causing the FEC scaling to be exceeded and to restart the LDP module by executing the following command:

- **MD-CLI**

```
configure router ldp admin-state enable
```

- **classic CLI**

```
configure router ldp no shutdown
```

3.21.1 LDP base graceful handling of resources

This feature implements a base graceful handling capability by which the LDP interface to the peer, or the targeted peer in the case of Targeted LDP (T-LDP) session, is shutdown. If LDP tries to resolve a FEC over a link or a targeted LDP session and it runs out of data path or CPM resources, it brings down that interface or targeted peer which brings down the Hello adjacency over that interface to the resolved link LDP peer or to the targeted peer. The interface is brought down in LDP context only and is still available to other applications such as IP forwarding and RSVP LSP forwarding.

Depending of what type of resource was exhausted, the scope of the action taken by LDP is different. Some resource such as NHLFE have interface local impact, meaning that only the interface to the downstream LSR which advertised the label is shutdown. Some resources such as ILM have global impact, meaning that they impact every downstream peer or targeted peer which advertised the FEC to the node. The following are examples to illustrate this:

- For NHLFE exhaustion, one or more interfaces or targeted peers, if the FEC is ECMP, is shut down. ILM is maintained as long as there is at least one downstream for the FEC for which the NHLFE has been successfully programmed.
- For an exhaustion of an ILM for a unicast LDP FEC, all interfaces to peers or all target peers which sent the FEC are shut down. No deprogramming of datapath is required because FEC is not programmed.
- An exhaustion of ILM for an mLDP FEC can happen during primary ILM programming, MBB ILM programming, or multicast upstream FRR backup ILM programming. In all cases, the P2MP index for the mLDP tree is deprogrammed and the interfaces to each downstream peer that sent a Label Mapping message associated with this ILM are shut down.

After the user has taken action to free resources up, the user must manually unshut the interface or the targeted peer to bring it back into operation. This then re-establishes the Hello adjacency and resumes the resolution of FECs over the interface or to the targeted peer.

Detailed guidelines for using the feature and for troubleshooting a system which activated this feature are provided in the following sections.

This behavior is the default behavior and interoperates with the SR OS based LDP implementation and any other third party LDP implementation.

The following datapath resources can trigger this mechanism:

- NHLFE
- ILM
- Label-to-NHLFE (LTN)
- Tunnel Index
- P2MP Index

The Label allocation CPM resource can trigger this mechanism:

3.21.2 LDP enhanced graceful handling of resources

This feature is an enhanced graceful handling capability that is supported only among SR OS based implementations. If LDP tries to resolve a FEC over a link or a targeted session and it runs out of datapath or CPM resources, it puts the LDP/T-LDP session into overload state. As a result, it releases to its LDP peer the labels of the FECs which it could not resolve and also sends an LDP notification message

to all LDP peers with the new status load of overload for the FEC type which caused the overload. The notification of overload is per FEC type, that is, unicast IPv4, P2MP mLDP and so on, and not per individual FEC. The peer which caused the overload and all other peers stop sending any new FECs of that type until this node updates the notification stating that it is no longer in overload state for that FEC type. FECs of this type previously resolved and other FEC types to this peer and all other peers continues to forward traffic normally.

After the user has taken action to free resources up, the overload state of the LDP/T-LDP sessions toward its peers must be manually cleared.

The enhanced mechanism is enabled instead of the base mechanism only if both LSR nodes advertise this new LDP capability at the time the LDP session is initialized. Otherwise, they continue to use the base mechanism.

This feature operates among SR OS LSR nodes using a couple of private vendor LDP capabilities:

- The first one is the LSR Overload Status TLV to signal or clear the overload condition.
- The second one is the Overload Protection Capability Parameter, which allows LDP peers to negotiate the use of the overload notification feature and therefore the enhanced graceful handling mechanism.

When interoperating with an LDP peer which does not support the enhanced resource handling mechanism, the router reverts automatically to the default base resource handling mechanism.

The following are the details of the mechanism.

3.21.2.1 LSR overload notification

When an upstream LSR is overloaded for a FEC type, it notifies one or more downstream peer LSRs that it is overloaded for the FEC type.

When a downstream LSR receives overload status ON notification from an upstream LSR, it does not send further label mappings for the specified FEC type. When a downstream LSR receives overload OFF notification from an upstream LSR, it sends pending label mappings to the upstream LSR for the specified FEC type.

This feature introduces a new TLV referred to as LSR Overload Status TLV, shown below. This TLV is encoded using vendor proprietary TLV encoding as per RFC 5036. It uses a TLV type value of 0x3E02 and the Timetra OUI value of 0003FA.

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|U|F| Overload Status TLV Type  |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Timetra OUI  = 0003FA                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|S|                        Reserved                             |

where:
   U-bit: Unknown TLV bit, as described in RFC 5036. The value MUST
   be 1 which means if unknown to receiver then receiver should ignore

   F-bit: Forward unknown TLV bit, as described in RFC RFC5036. The value
   of this bit MUST be 1 since a LSR overload TLV is sent only between
   two immediate LDP peers, which are not forwarded.

   S-bit: The State Bit. It indicates whether the sender is setting the
   LSR Overload Status ON or OFF. The State Bit value is used as
   follows:
```

```
   1 - The TLV is indicating LSR overload status as ON.

   0 - The TLV is indicating LSR overload status as OFF.
```

When a LSR that implements the procedures defined in this document generates LSR overload status, it must send LSR Overload Status TLV in a LDP Notification Message accompanied by a FEC TLV. The FEC TLV must contain one Typed Wildcard FEC TLV that specifies the FEC type to which the overload status notification applies.

The feature in this document re-uses the Typed Wildcard FEC Element which is defined in RFC 5918.

3.21.2.2 LSR overload protection capability

To ensure backward compatibility with procedures in RFC 5036 an LSR supporting Overload Protection need means to determine whether a peering LSR supports overload protection or not.

An LDP speaker that supports the LSR Overload Protection procedures as defined in this document must inform its peers of the support by including a LSR Overload Protection Capability Parameter in its initialization message. The Capability parameter follows the guidelines and all Capability Negotiation Procedures as defined in RFC 5561. This TLV is encoded using vendor proprietary TLV encoding as per RFC 5036. It uses a TLV type value of 0x3E03 and the Timetra OUI value of 0003FA.

```
       0                   1                   2                   3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |U|F| LSR Overload Cap TLV Type |            Length             |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                  Timetra OUI = 0003FA                         |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |S| Reserved    |
      +-+-+-+-+-+-+-+-+
Where:

   U and F bits : MUST be 1 and 0 respectively as per section 3 of LDP
   Capabilities [RFC5561].

   S-bit : MUST be 1 (indicates that capability is being advertised).
```

3.21.2.3 Procedures for LSR overload protection

The procedures defined in this document apply only to LSRs that support Downstream Unsolicited (DU) label advertisement mode and Liberal Label Retention Mode. An LSR that implements the LSR overload protection follows the following procedures:

Note: An LSR must not use LSR overload notification procedures with a peer LSR that has not specified LSR Overload Protection Capability in Initialization Message received from the peer LSR.

1. When an upstream LSR detects that it is overloaded with a FEC type then it must initiate an LDP notification message with the S-bit ON in LSR Overload Status TLV and a FEC TLV containing the Typed Wildcard FEC Element for the specified FEC type. This message may be sent to one or more peers.

2. After it has notified peers of its overload status ON for a FEC type, the overloaded upstream LSR can send Label Release for a set of FEC elements to respective downstream LSRs to off load its LIB to below a specified watermark.
3. When an upstream LSR that was previously overloaded for a FEC type detects that it is no longer overloaded, it must send an LDP notification message with the S-bit OFF in LSR Overload Status TLV and FEC TLV containing the Typed Wildcard FEC Element for the specified FEC type.
4. When an upstream LSR has notified its peers that it is overloaded for a FEC type, then a downstream LSR must not send new label mappings for the specified FEC type to the upstream LSR.
5. When a downstream LSR receives LSR overload notification from a peering LSR with status OFF for a FEC type then the receiving LSR must send any label mappings for the FEC type which were pending to the upstream LSR for which are eligible to be sent now.
6. When an upstream LSR is overloaded for a FEC type and it receives Label Mapping for that FEC type from a downstream LSR then it can send Label Release to the downstream peer for the received Label Mapping with LDP Status Code as No_Label_Resources as defined in RFC 5036.

3.21.3 User guidelines and troubleshooting procedures

3.21.3.1 Common procedures

When troubleshooting a LDP resource exhaustion situation on an LSR, the user must first determine which of the LSR and its peers supports the enhanced handling of resources. This is done by checking if the local LSR or its peers advertised the LSR Overload Protection Capability by using the following command.

```
show router ldp status
```

Output example

```
===============================================================================
LDP Status for IPv4 LSR ID 0.0.0.0
               IPv6 LSR ID ::
===============================================================================
Created at         : 01/08/19 17:57:06
Last Change        : 01/08/19 17:57:06
Admin State        : Up
IPv4 Oper State    : Down                IPv6 Oper State      : Down
IPv4 Down Time     : 0d 00:12:58         IPv6 Down Time       : 0d 00:12:58
IPv4 Oper Down Rea*: systemIpDown        IPv6 Oper Down Reason: systemIpDown
IPv4 Oper Down Eve*: 0                   IPv6 Oper Down Events: 0
Tunn Down Damp Time: 3 sec               Weighted ECMP        : Disabled
Label Withdraw Del*: 0 sec               Implicit Null Label  : Disabled
Short. TTL Local   : Enabled             Short. TTL Transit   : Enabled
ConsiderSysIPInGep : Disabled
Imp Ucast Policies :                     Exp Ucast Policies   :
    pol1                                     none
Imp Mcast Policies :
    pol1
    policy2
    policy-3
    policy-four
    pol-five
Tunl Exp Policies  : None                Tunl Imp Policies    : None
FRR                : Disabled            Mcast Upstream FRR   : Disabled
```

```
Mcast Upst ASBR FRR: Disabled
```

3.21.3.2 Base resource handling procedures

Procedure

Step 1. If the peer or the local LSR does not support the Overload Protection Capability, it means that the associated adjacency [interface/peer] is brought down as part of the base resource handling mechanism.

The user can determine which interface or targeted peer was administratively disabled, by applying the following commands.

```
show router ldp interface resource-failures
show router ldp targ-peer resource-failures
```

Example

```
show router ldp interface resource-failures
===============================================================================
LDP Interface Resource Failures
===============================================================================
srl                                     srr
sru4                                    sr4-1-5-1
===============================================================================
```

```
show router ldp targ-peer resource-failures
===============================================================================
LDP Peers Resource Failures
===============================================================================
10.20.1.22                              192.168.1.3
===============================================================================
```

A trap is also generated for each interface or targeted peer:

```
16 2013/07/17 14:21:38.06 PST MINOR: LDP #2003 Base LDP Interface Admin State
"Interface instance state changed - vRtrID: 1, Interface sr4-1-5-1, administrati
ve state: inService, operational state: outOfService"

13 2013/07/17 14:15:24.64 PST MINOR: LDP #2003 Base LDP Interface Admin State
"Interface instance state changed - vRtrID: 1, Peer 10.20.1.22, administrative s
tate: inService, operational state: outOfService"
```

The user can then check that the base resource handling mechanism has been applied to a specific interface or peer by running the following show commands.

```
show router ldp interface detail
show router ldp targ-peer detail
```

Example

```
show router ldp interface detail
===============================================================================
LDP Interfaces (Detail)
===============================================================================
-------------------------------------------------------------------------------
```

```
Interface "sr4-1-5-1"
------------------------------------------------------------------------------
Admin State        : Up                  Oper State       : Down
Oper Down Reason   : noResources  <----- //link LDP resource exhaustion handled
Hold Time          : 45                  Hello Factor     : 3
Oper Hold Time     : 45
Hello Reduction    : Disabled            Hello Reduction *: 3
Keepalive Timeout  : 30                  Keepalive Factor : 3
Transport Addr     : System              Last Modified    : 07/17/13 14:21:38
Active Adjacencies : 0
Tunneling          : Disabled
Lsp Name           : None
Local LSR Type     : System
Local LSR          : None
BFD Status         : Disabled
Multicast Traffic  : Enabled
------------------------------------------------------------------------------
```

```
show router ldp discovery interface "sr4-1-5-1" detail
===============================================================================
LDP Hello Adjacencies (Detail)
===============================================================================
-------------------------------------------------------------------------------
Interface "sr4-1-5-1"
-------------------------------------------------------------------------------
Local Address      : 192.168.2.110      Peer Address        : 192.168.0.2
Adjacency Type     : Link               State               : Down
===============================================================================
```

```
show router ldp targ-peer detail
===============================================================================
LDP Peers (Detail)
===============================================================================
-------------------------------------------------------------------------------
Peer 10.20.1.22
-------------------------------------------------------------------------------
Admin State        : Up              Oper State           : Down
Oper Down Reason   : noResources     <----- // T-LDP resource exhaustion handled
Hold Time          : 45              Hello Factor         : 3
Oper Hold Time     : 45
Hello Reduction    : Disabled        Hello Reduction Fact*: 3
Keepalive Timeout  : 40              Keepalive Factor     : 4
Passive Mode       : Disabled        Last Modified        : 07/17/13 14:15:24
Active Adjacencies : 0               Auto Created         : No
Tunneling          : Enabled
Lsp Name           : None
Local LSR          : None
BFD Status         : Disabled
Multicast Traffic  : Disabled
-------------------------------------------------------------------------------
```

```
show router ldp discovery peer 10.20.1.22 detail
===============================================================================
LDP Hello Adjacencies (Detail)
===============================================================================
-------------------------------------------------------------------------------
Peer 10.20.1.22
-------------------------------------------------------------------------------
Local Address      : 192.168.1.110      Peer Address        : 10.20.1.22
Adjacency Type     : Targeted           State               : Down   <-----
//T-LDP resource exhaustion handled
```

```
===============================================================================
```

Step 2. Besides interfaces and targeted peer, locally originated FECs may also be put into overload. These are the following:

- unicast fec-originate pop
- multicast local static p2mp-fec type=1 [on leaf LSR]
- multicast local Dynamic p2mp-fec type=3 [on leaf LSR]

The user can check if only remote or local, or both FECs have been set in overload by the resource base resource exhaustion mechanism using the **tools dump router ldp instance** command.

The relevant part of the output is described below:

```
{...... snip......}
Num OLoad Interfaces:      4     <----- //#LDP interfaces resource in exhaustion
Num Targ Sessions:         72          Num Active Targ Sess:  62
Num OLoad Targ Sessions:   7     <----- //#T-LDP peers in resource exhaustion
Num Addr FECs Rcvd:        0           Num Addr FECs Sent:    0
Num Addr Fecs OLoad:       1     <----- //# of local/remote unicast FECs in Overload
Num Svc FECs Rcvd:         0           Num Svc FECs Sent:     0
Num Svc FECs OLoad:        0     <----- // # of local/
remote service Fecs in Overload
Num mcast FECs Rcvd:       0           Num Mcast FECs Sent:   0
Num mcast FECs OLoad:      0     <----- // # of local/
remote multicast Fecs in Overload
{...... snip......}
```

When at least one local FEC has been set in overload the following trap occurs:

```
23 2013/07/17 15:35:47.84 PST MINOR: LDP #2002 Base LDP Resources Exhausted
"Instance
 state changed - vRtrID: 1, administrative state: inService, operationa l state:
 inService"
```

Step 3. After the user has detected that at least, one link LDP or T-LDP adjacency has been brought down by the resource exhaustion mechanism, he/she must protect the router by applying one or more of the following to free resources up:

- Identify the source for the [unicast/multicast/service] FEC flooding.
- Configure the appropriate [import/export] policies and/or delete the excess [unicast/multicast/service] FECs that are not currently handled.

Step 4. Next, the user has to manually attempt to clear the overload (no resource) state and allow the router to attempt to restore the link and targeted sessions to its peer.

Note: Because of the dynamic nature of FEC distribution and resolution by LSR nodes, one cannot predict exactly which FECs and which interfaces or targeted peers are restored after performing the following commands if the LSR activates resource exhaustion again.

Use one of the following commands to clear the overload state:

- ```
  clear router ldp resource-failures
  ```
  ```

- clears the overload state and attempt to restore adjacency and session for LDP interfaces and peers
- clears the overload state for the local FECs

- ```
  clear router ldp interface
  ```

  or

  ```
  clear router ldp peer
  ```

  - clears the overload state and attempt to restore adjacency and session for LDP interfaces and peers
  - these two commands do not clear the overload state for the local FECs

3.21.3.3 Enhanced resource handling procedures

Procedure

Step 1. If the peer and the local LSR do support the Overload Protection Capability it means that the LSR signals the overload state for the FEC type that caused the resource exhaustion as part of the enhanced resource handling mechanism.

To verify if the local router has received or sent the overload status TLV, use the following command.

Example

```
show router ldp session 192.168.1.1 detail
-------------------------------------------------------------------------------
Session with Peer 192.168.1.1:0, Local 192.168.1.110:0
-------------------------------------------------------------------------------
Adjacency Type         : Both           State                  : Established
Up Time                : 0d 00:05:48
Max PDU Length         : 4096           KA/Hold Time Remaining : 24
Link Adjacencies       : 1              Targeted Adjacencies   : 1
Local Address          : 192.168.1.110  Peer Address           : 192.168.1.1
Local TCP Port         : 51063          Peer TCP Port          : 646
Local KA Timeout       : 30             Peer KA Timeout        : 45
Mesg Sent              : 442            Mesg Recv              : 2984
FECs Sent              : 16             FECs Recv              : 2559
Addrs Sent             : 17             Addrs Recv             : 1054
GR State               : Capable        Label Distribution     : DU
Nbr Liveness Time      : 0              Max Recovery Time      : 0
Number of Restart      : 0              Last Restart Time      : Never
P2MP                   : Capable        MP MBB                 : Capable
Dynamic Capability     : Not Capable    LSR Overload           : Capable
Advertise              : Address/Servi* BFD Operational Status : inService
Addr FEC OverLoad Sent : Yes            Addr FEC OverLoad Recv : No     <----
// this LSR sent overLoad for unicast FEC type to peer
Mcast FEC Overload Sent: No             Mcast FEC Overload Recv: No
Serv FEC Overload Sent : No             Serv FEC Overload Recv : No
-------------------------------------------------------------------------------
```

Example

```
show router ldp session 192.168.1.110 detail
```
```

```
-------------------------------------------------------------------------------
Session with Peer 192.168.1.110:0, Local 192.168.1.1:0
-------------------------------------------------------------------------------
Adjacency Type         : Both           State                 : Established
Up Time                : 0d 00:08:23
Max PDU Length         : 4096           KA/Hold Time Remaining : 21
Link Adjacencies       : 1              Targeted Adjacencies   : 1
Local Address          : 192.168.1.1    Peer Address           : 192.168.1.110
Local TCP Port         : 646            Peer TCP Port          : 51063
Local KA Timeout       : 45             Peer KA Timeout        : 30
Mesg Sent              : 3020           Mesg Recv              : 480
FECs Sent              : 2867           FECs Recv              : 16
Addrs Sent             : 1054           Addrs Recv             : 17
GR State               : Capable        Label Distribution     : DU
Nbr Liveness Time      : 0              Max Recovery Time      : 0
Number of Restart      : 0              Last Restart Time      : Never
P2MP                   : Capable        MP MBB                 : Capable
Dynamic Capability     : Not Capable    LSR Overload           : Capable
Advertise              : Address/Servi* BFD Operational Status : inService
Addr FEC OverLoad Sent : No             Addr FEC OverLoad Recv : Yes     <----
// this LSR received overLoad for unicast FEC type from peer
Mcast FEC Overload Sent: No             Mcast FEC Overload Recv: No
Serv FEC Overload Sent : No             Serv FEC Overload Recv : No
===============================================================================
```

A trap is also generated:

```
70002 2013/07/17 16:06:59.46 PST MINOR: LDP #2008 Base LDP Session State Change
"Session state is operational. Overload Notification message is sent to/from peer
  192.168.1.1:0 with overload state true for fec type prefixes"
```

Step 2. Besides interfaces and targeted peer, locally originated FECs may also be put into overload. These are the following:

- unicast fec-originate pop
- multicast local static p2mp-fec type=1 [on leaf LSR]
- multicast local Dynamic p2mp-fec type=3 [on leaf LSR]

The user can check if only remote or local, or both FECs have been set in overload by the resource enhanced resource exhaustion mechanism using the following command.

```
tools dump router ldp instance
```

The relevant part of the output is described below:

```
  Num Entities OLoad (FEC: Address Prefix  ):  Sent: 7           Rcvd: 0   <-----
// # of session in OvLd for fec-type=unicast
  Num Entities OLoad (FEC: PWE3            ):  Sent: 0           Rcvd: 0   <-----
// # of session in OvLd for fec-type=service
  Num Entities OLoad (FEC: GENPWE3         ):  Sent: 0           Rcvd: 0   <-----
// # of session in OvLd for fec-type=service
  Num Entities OLoad (FEC: P2MP            ):  Sent: 0           Rcvd: 0   <-----
// # of session in OvLd for fec-type=MulticastP2mp
  Num Entities OLoad (FEC: MP2MP UP        ):  Sent: 0           Rcvd: 0   <-----
// # of session in OvLd for fec-type=MulticastMP2mp
  Num Entities OLoad (FEC: MP2MP DOWN      ):  Sent: 0           Rcvd: 0   <-----
// # of session in OvLd for fec-type=MulticastMP2mp
  Num Active Adjacencies:    9
  Num Interfaces:            6           Num Active Interfaces: 6
  Num OLoad Interfaces:      0      <----- // link LDP interfaces in resource
```

```
 exhaustion
 should be zero when Overload Protection Capability is supported
  Num Targ Sessions:         72          Num Active Targ Sess:  67
  Num OLoad Targ Sessions:   0      <----- // T-LDP peers in resource exhaustion
 should be zero if Overload Protection Capability is supported
  Num Addr FECs Rcvd:        8667        Num Addr FECs Sent:    91
  Num Addr Fecs OLoad:       1                                    <-----
// # of local/remote unicast Fecs in Overload
  Num Svc FECs Rcvd:         3111        Num Svc FECs Sent:     0
  Num Svc FECs OLoad:        0                                    <-----
// # of local/remote service   Fecs in Overload
  Num mcast FECs Rcvd:       0           Num Mcast FECs Sent:   0
  Num mcast FECs OLoad:      0                                    <-----
// # of local/remote multicast Fecs in Overload
  Num MAC Flush Rcvd:        0           Num MAC Flush Sent:    0
```

When at least one local FEC has been set in overload the following trap occurs:

```
69999 2013/07/17 16:06:59.21 PST MINOR: LDP #2002 Base LDP Resources Exhausted
 "Instance state changed - vRtrID: 1, administrative state: inService, operational
 state: inService"
```

Step 3. After the user has detected that at least one overload status TLV has been sent or received by the LSR, he/she must protect the router by applying one or more of the following to free resources up:

- Identify the source for the [unicast/multicast/service] FEC flooding. This is most likely the LSRs which session received the overload status TLV.
- Configure the appropriate [import/export] policies and delete the excess [unicast/multicast/service] FECs from the FEC type in overload.

Step 4. Next, the user has to manually attempt to clear the overload state on the affected sessions and for the affected FEC types and allow the router to clear the overload status TLV to its peers.

Note: Because of the dynamic nature of FEC distribution and resolution by LSR nodes, one cannot predict exactly which sessions and which FECs are cleared after performing the following commands if the LSR activates overload again.

One of the following commands can be used depending on whether the user wants to clear all sessions in one step or one session at a time:

- `clear router ldp resource-failures`
  - clears the overload state for the affected sessions and FEC types
  - clears the overload state for the local FECs
- `clear router ldp session ip-address overload fec-type`
  - clears the overload state for the specified session and FEC type
  - clears the overload state for the local FECs

3.22 LDP-IGP synchronization

The SR OS supports the synchronization of an IGP and LDP based on a solution described in RFC 5443, which consists of setting the cost of a restored link to infinity to give both the IGP and LDP time to converge. When a link is restored after a failure, the IGP sets the link cost to infinity and advertises it. The actual value advertised in OSPF is 0xFFFF (65535). The actual value advertised in an IS-IS regular metric is 0x3F (63) and in IS-IS wide-metric is 0xFFFFFE (16777214). This synchronization feature is not supported on RIP interfaces.

When the LDP synchronization timer subsequently expires, the actual cost is put back and the IGP readvertises it and uses it at the next SPF computation. The LDP synchronization timer is configured using the following command:

- **MD-CLI**

```
configure router interface ldp-sync-timer seconds seconds
```

- **classic CLI**

```
configure router interface ldp-sync-timer seconds
```

The SR OS also supports an LDP End of LIB message, as defined in RFC 5919, that allows a downstream node to indicate to its upstream peer that it has advertised its entire label information base. The effect of this on the IGP-LDP synchronization timer is described below.

If an interface belongs to both IS-IS and OSPF, a physical failure causes both IGPs to advertise an infinite metric and to follow the IGP-LDP synchronization procedures. If only one IGP bounces on this interface or on the system, then only the affected IGP advertises the infinite metric and follows the IGP-LDP synchronization procedures.

Next, an LDP Hello adjacency is brought up with the neighbor. The LDP synchronization timer is started by the IGP when the LDP session to the neighbor is up over the interface. This is to allow time for the label-FEC bindings to be exchanged.

When the LDP synchronization timer expires, the link cost is restored and is readvertised. The IGP announces a new best next hop and LDP uses it if the label binding for the neighbor's FEC is available.

If the user changes the cost of an interface, the new value is advertised at the next flooding of link attributes by the IGP. However, if the LDP synchronization timer is still running, the new cost value is only advertised after the timer expires. The new cost value is also advertised after the user executes any of the following commands:

- **MD-CLI**

```
configure router isis ldp-sync false
configure router isis ldp-sync false
configure route ldp ldp-sync-timer delete seconds
tools perform router isis ldp-sync-exit
tools perform router ospf ldp-sync-exit
```

- **classic CLI**

```
configure router isis disable-ldp-sync
configure router isis disable-ldp-sync
configure router interface no ldp-sync-timer
tools perform router isis ldp-sync-exit
tools perform router ospf ldp-sync-exit
```

If the user changes the value of the LDP synchronization timer command option, the new value takes effect at the next synchronization event. If the timer is still running, it continues to use the previous value.

If parallel links exist to the same neighbor, then the bindings and services should remain up as long as there is one interface that is up. However, the user-configured LDP synchronization timer still applies on the interface that failed and was restored. In this case, the router only considers this interface for forwarding after the IGP readvertises its actual cost value.

The LDP End of LIB message is used by a node to signal completion of label advertisements, using a FEC TLV with the Typed Wildcard FEC element for all negotiated FEC types. This is done even if the system has no label bindings to advertise. The SR OS also supports the Unrecognized Notification TLV (RFC 5919) that indicates to a peer node that it ignores unrecognized status TLVs. This indicates to the peer node that it is safe to send End of LIB notifications even if the node is not configured to process them.

The behavior of a system that receives an End of LIB status notification is configured through the CLI on a per-interface basis as follows:

- **MD-CLI**

```
configure router interface ldp-sync-timer seconds seconds
configure router interface ldp-sync-timer end-of-lib
```

- **classic CLI**

```
configure router interface ldp-sync-timer seconds end-of-lib
```

If the **end-of lib** command option is not configured, then the LDP synchronization timer is started when the LDP Hello adjacency comes up over the interface, as described above. Any received End of LIB LDP messages are ignored.

If the **end-of-lib** command option is configured, then the system behaves as follows on the receive side:

- The **ldp-sync-timer** is started.
- If LDP End of LIB Typed Wildcard FEC messages are received for every FEC type negotiated for a specified session to an LDP peer for that IGP interface, the **ldp-sync-timer** is terminated and processing proceeds as if the timer had expired, that is, by restoring the IGP link cost.
- If the **ldp-sync-timer** expires before the LDP End of LIB messages are received for every negotiated FEC type, then the system restores the IGP link cost.
- The receive side drops any unexpected End of LIB messages.

If the **end-of-lib** command option is configured, then the system also sends out an End of LIB message for prefix and P2MP FECs after all FECs are sent for all peers that have advertised the Unrecognized Notification Capability TLV.

3.23 MLDP resolution using multicast RTM

When unicast services use IGP shortcuts, IGP shortcut next hops are installed in the RTM. Therefore, for multicast P2MP MLDP, the leaf node resolves the root using these IGP shortcuts. Currently MLDP cannot be resolved using IGP shortcuts. To avoid this, MLDP does a lookup in the multicast RTM. IGP shortcuts are not installed in MRTM. The following command forces MLDP do next-hop lookups in the RTM or MRTM.

```
configure router ldp resolve-root-using {ucast-rtm | mcast-rtm}
```

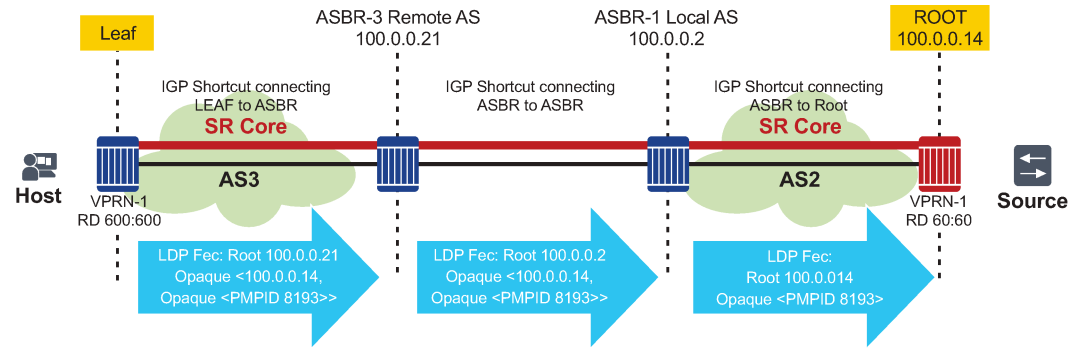
By default, the **resolve-root-using** command is set to the **ucast-rtm** command option and MLDP uses the unicast RTM for resolution of the FEC in all cases. When MLDP uses the unicast RTM to resolve the FEC, it does not resolve the FEC if its next hop is resolved using an IGP shortcut.

To force MLDP resolution to use the multicast RTM, use the **resolve-root-using mcast-rtm** command option. When this command is enabled:

- For FEC resolution using IGP, static or local, the ROOT in this FEC is resolved using the multicast RTM.
- A FEC being resolved using BGP is recursive, so the FEC next hop (ASBR/ABR) is resolved using the multicast RTM first and, if this fails, it is resolved using the unicast RTM. This next hop needs to be recursively resolved again using IGP/Static-Route or Local, this second resolution (recursive resolution) uses the multicast RTM only; see Figure 78: Recursive FEC behavior.
- When **resolve-root-using ucast-rtm** is set, MLDP uses the unicast RTM to resolve the FEC and does not resolve the FEC if its next hop is resolved using an IGP shortcut.

For inter-AS or intra-AS, IGP shortcuts are limited to each AS or area connecting LEAF to ASBR, ASBR to ASBR, or ASBR to ROOT.

Figure 78: Recursive FEC behavior



	LEAF	ASBR-3	ASBR-1
Inner Root 100.0.0.14 (First resolution using BGR to ASBR-3)	M-RTM first U-RTM second	M-RTM first U-RTM second	*
Inner Root recursive resolution of ASBR-3 100.0.0.21 for Inner Root	M-RTM		
Inner Root recursive resolution of ASBR-1 100.0.0.2 for Inner Root		M-RTM	
Outer Root 100.0.0.14			M-RTM

In Figure 78: Recursive FEC behavior, the FEC between LEAF and ASBR-3 is resolved using an IGP shortcut. When the **resolve-root-using mcast-rtm** is set, the inner Root 100.0.0.14 is resolved using the multicast RTM first. If the multicast RTM lookup fails, then a second lookup for 100.0.0.14 is done in the unicast RTM. Resolution of 100.0.0.14 results in a next hop of 100.0.0.21 which is ASBR-3, therefore ASBR-3 100.0.0.21 is resolved only using multicast RTM when **mcast-rtm** is enabled.

3.23.1 Other considerations for multicast RTM MLDP resolution

When the **configure ldp resolve-root-using** command is set to **mcast-rtm** and then changed to **ucast-rtm** there is traffic disruption. If MoFRR is enabled, by toggling from **mcast-rtm** to **ucast-rtm** (or the other way around) the MoFRR is not used. In fact, MoFRR is torn down and re-established using the new routing table.

The **mcast-rtm** only has a local effect. All MLDP routing calculations on this specific node use MRTM and not RTM.

If **mcast-rtm** is enabled, all MLDP functionality is based on MRTM. This includes MoFRR, ASBR-MoFRR, policy-based SPMSI, and non-segmented inter-AS.

3.24 Bidirectional forwarding detection for LDP LSPs

Bidirectional forwarding detection (BFD) for MPLS LSPs monitors the LSP between its LERs, irrespective of how many LSRs the LSP may traverse. This feature enables the detection of faults that are local to individual LSPs, irrespective of whether they also affect forwarding for other LSPs or IP packet flows. BFD for MPLS LSPs is ideal for monitoring LSPs that carry high-value services, and for which the quick detection of forwarding failures is critical. If an LSP BFD session goes down, the system raises an SNMP trap and indicates the BFD session state in the **show** and **tools dump** commands.

SR OS supports LSP BFD on RSVP and LDP LSPs. See MPLS and RSVP for information about using LSP BFD on RSVP LSPs. BFD packets are encapsulated in an MPLS label stack corresponding to the FEC that the BFD session is associated with, as described in RFC 5884, Section 7. SR OS does not support the monitoring of multiple ECMP paths that are associated with the same LDP FEC which is using multiple LSP BFD sessions simultaneously. However, LSP BFD still provides continuity checking for paths associated with a target FEC. LDP provides a single path to LSP BFD, corresponding with the first resolved lower interface index next-hop, and the first resolved lower TID index for LDP-over-RSVP cases. The path may potentially change over the lifetime of the FEC, based on resolution changes. The system tracks the changing path and maintains the LSP BFD session.

Because LDP LSPs are unidirectional, a routed return path is used for the BFD control packets traveling from the egress LER to the ingress LER.

3.24.1 Bootstrapping and maintaining LSP BFD sessions

A BFD session on an LSP is bootstrapped using LSP ping. LSP ping is used to exchange the local and remote discriminator values to use for the BFD session for a specific MPLS LSP or FEC.

The process for bootstrapping an LSP BFD session for LDP is the same as for RSVP, as described in Bidirectional forwarding detection for MPLS LSPs.

SR OS supports the sending of periodic LSP ping messages on an LSP for which LSP BFD has been configured, as specified in RFC 5884. The ping messages are sent, along with the bootstrap TLV, at a configurable interval for LSPs where **bfd-enable** is configured. The default interval is 60 s, with a maximum interval of 300 s. The LSP ping echo request message uses the system IP address as the default source address. An alternative source address consisting of any routable address that is local to the node may be configured and used if the local system IP address is not routable from the far-end node.

Note: SR OS does not take any action if a remote system fails to respond to a periodic LSP ping message. However, when the **show test-oam lsp-bfd** command is executed, it displays a return code of zero and a replying node address of 0.0.0.0 if the periodic LSP ping times out.

The periodic LSP ping interval is configured using the following command.

```
configure router ldp lsp-bfd lsp-ping-interval
```

Configuring an LSP ping interval of 0 disables periodic LSP ping for LDP FECs matching the specified prefix list. The **lsp-ping-interval** command has a default value of 60 s.

LSP BFD sessions are recreated after a high-availability switchover between active and standby CPMs. However, some disruption may occur to LSP ping as a result LSP BFD.

At the head end of an LSP, sessions are bootstrapped if the local and remote discriminators are not known. The sessions experience jitter at 0 to 25% of a retry time of 5 seconds. A side effect of the bootstrapping is that the following current information is lost from an active **show test-oam lsp-bfd** display:

- Replying Node
- Latest Return Code
- Latest Return SubCode
- Bootstrap Retry Count
- Tx Lsp Ping Requests
- Rx Lsp Ping Replies

If the local and remote discriminators are known, the system immediately begins generating periodic LSP pings. The pings experience jitter at 0 to 25% of the **lsp-ping-interval** time of 60 to 300 seconds. The **lsp-ping-interval** time is synchronized across by LSP BFD. A side effect of the bootstrapping is that the following current information is lost from an active **show test-oam lsp-bfd** display:

- Replying Node
- Latest Return Code
- Latest Return SubCode
- Bootstrap Retry Count
- Tx Lsp Ping Requests
- Rx Lsp Ping Replies

At the tail end of an LSP, sessions are recreated on the standby CPM following a switchover. The side effect of this is that the following current information is lost from an active **tools dump test-oam lsp-bfd tail** display:

- handle
- seqNum
- rc
- rsc

New, incoming bootstrap requests are dropped until the LSP BFD session is active. When the LSP BFD session is active, new bootstrap requests are considered.

3.24.2 BFD configuration on LDP LSPs

Use the commands under the following context to configure LSP BFD for LDP.

```
configure router ldp lsp-bfd
```

The **lsp-bfd** command creates the context for LSP BFD configuration for a set of LDP LSPs with a FEC matching the one defined by the *prefix-list-name*. The default is unconfigured. Using the following

command, for a specified prefix list, removes LSP BFD for all matching LDP FECs except those that also match another LSP BFD prefix list.

- **MD-CLI**

```
delete lsp-bfd
```

- **classic CLI**

```
no lsp-bfd
```

The *prefix-list-name* variable refers to a named prefix list configured in the following context:

- **MD-CLI**

```
configure policy-options
```

- **classic CLI**

```
configure router policy-options
```

Up to 16 instances of LSP BFD can be configured under LDP in the base router instance.

The following optional command configures a priority value that is used to order the processing if multiple prefix lists are configured.

```
configure router ldp lsp-bfd priority
```

The default value is 1.

If more than one prefix in a prefix list, or more than one prefix list, contains a prefix that corresponds to the same LDP FEC, then the system tests the prefix against the configured prefix lists in the following order:

1. numerically by priority level
2. alphabetically by prefix list name

The system uses the first matching configuration, if one exists.

If an LSP BFD is removed for a prefix list, but there remains another LSP BFD configuration with a prefix list match, then any FECs matched against that prefix is rematched against the remaining prefix list configurations in the same manner as described above.

A non-existent prefix list is equivalent to an empty prefix list. When a prefix list is created and populated with prefixes, LDP matches its FECs against that prefix list. It is not necessary to configure a named prefix list in the **configure router policy-options** context before specifying a prefix list using the following command.

```
configure router ldp lsp-bfd
```

If a prefix list contains a longest match corresponding to one or more LDP FECs, the BFD configuration is applied to all of the matching LDP LSPs.

Only /32 IPv4 and /128 IPv6 host prefix FECs is considered for BFD. BFD on PW FECs uses VCCV BFD.

The following command is used to configure the source address of periodic LSP ping packets and BFD control packets for LSP BFD sessions associated with LDP prefixes in the prefix list.

```
configure router ldp lsp-bfd source-address
```

The default value is the system IP address. If the system IP address is not routable from the far-end node of the BFD session, then an alternative routable IP address local to the source node should be used.

The system does not initialize an LSP BFD session if there is a mismatch between the address family of the source address and the address family of the prefix in the prefix list.

If the system has both IPv4 and IPv6 system IP addresses, and the **source-address** command is not configured, then the system uses a source address of the matching address family for IPv4 and IPv6 prefixes in the prefix list.

The following command applies the specified BFD template to the BFD sessions for LDP LSPs with FECs that match the prefix list.

```
configure router ldp lsp-bfd bfd-template
```

The default is **no bfd-template**. The named BFD template must first be configured using the following command before it can be referenced by LSP BFD, otherwise a CLI error is generated:

- **MD-CLI**

  ```
  configure bfd bfd-template
  ```

- **classic CLI**

  ```
  configure router bfd bfd-template
  ```

The minimum receive interval and transmit interval supported for LSP BFD on LDP LSPs is 1 second.

The **bfd-enable** command enables BFD on the LDP LSPs with FECs that match the prefix list.

3.25 LDP IPv6 control and data planes

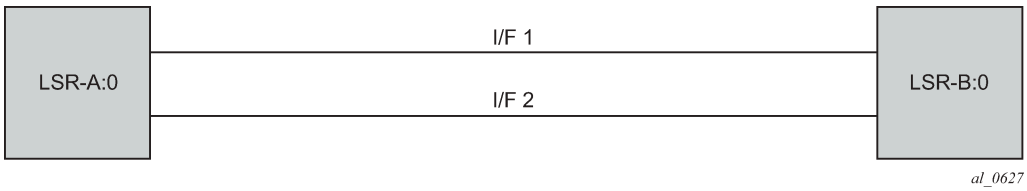
SR OS extends the LDP control plane and data plane to support LDP IPv6 adjacency and session using 128-bit LSR-ID.

The implementation allows for concurrent support of independent LDP IPv4 (32-bit LSR-ID) and IPv6 (128-bit LSR-ID) adjacencies and sessions between peer LSRs and over the same or different set of interfaces.

3.25.1 LDP operation in an IPv6 network

LDP IPv6 can be enabled on the SR OS interface. Figure 79: LDP adjacency and session over an IPv6 interface shows the LDP adjacency and session over an IPv6 interface.

Figure 79: LDP adjacency and session over an IPv6 interface



LSR-A and LSR-B have the following IPv6 LDP identifiers respectively:

- <LSR Id=A/128> : <label space id=0>
- <LSR Id=B/128> : <label space id=0>

By default, A/128 and B/128 use the system interface IPv6 address.

Note: Although the LDP control plane can operate using only the IPv6 system address, the user must configure the IPv4-formatted router ID for OSPF, IS-IS, and BGP to operate properly.

The following sections describe the behavior when LDP IPv6 is enabled on the interface.

3.25.2 Link LDP

The SR OS LDP IPv6 implementation uses a 128-bit LSR-ID as defined in *draft-pdutta-mpls-ldp-v2-00*. See LDP process overview for more information about interoperability of this implementation with 32-bit LSR-ID, as defined in RFC 7552.

Hello adjacency is brought up using link Hello packet with source IP address set to the interface link-local unicast address and a destination IP address set to the link-local multicast address FF02:0:0:0:0:0:0:2.

The transport address for the TCP connection, which is encoded in the Hello packet, is set to the LSR-ID of the LSR by default. It is set to the interface IPv6 address if the user enabled the interface option under one of the following contexts.

```
configure router ldp interface-parameters ipv6 transport-address
configure router ldp interface-parameters interface ipv6 transport-address
```

The interface global unicast address, meaning the primary IPv6 unicast address of the interface, is used.

The user can configure the local LSR ID option on the interface and change the value of the LSR-ID to either the local interface or to another interface name, loopback or not using the following command.

```
configure router ldp interface-parameters interface ipv6 local-lsr-id
```

The global unicast IPv6 address corresponding to the primary IPv6 address of the interface is used as the LSR-ID. If the user invokes an interface which does not have a global unicast IPv6 address in the configuration of the transport address or the configuration of the **local-lsr-id** command option, the session does not come up and an error message is displayed.

The LSR with the highest transport address bootstraps the IPv6 TCP connection and IPv6 LDP session.

Source and destination addresses of LDP/TCP session packets are the IPv6 transport addresses.

3.25.3 Targeted LDP

Source and destination addresses of targeted Hello packet are the LDP IPv6 LSR-IDs of systems A and B.

The user can configure the local LSR ID option on the targeted session and change the value of the LSR-ID to either the local interface or to some other interface name, loopback or not, by using the following command.

```
configure router ldp interface-parameters interface ipv6 local-lsr-id
```

The global unicast IPv6 address corresponding to the primary IPv6 address of the interface is used as the LSR-ID. If the user invokes an interface that does not have a global unicast IPv6 address in the

configuration of the transport address or the configuration of the **local-lsr-id** command option, the session does not come up and an error message is displayed. In all cases, the transport address for the LDP session and the source IP address of targeted Hello message are updated to the new LSR-ID value.

The LSR with the highest transport address (in this case, the LSR-ID) bootstraps the IPv6 TCP connection and IPv6 LDP session.

Source and destination IP addresses of LDP/TCP session packets are the IPv6 transport addresses (in this case, LDP LSR-IDs of systems A and B).

3.25.4 FEC resolution

LDP advertises and withdraws all interface IPv6 addresses using the Address/Address-Withdraw message. Both the link-local unicast address and the configured global unicast addresses of an interface are advertised.

All LDP FEC types can be exchanged over a LDP IPv6 LDP session like in LDP IPv4 session.

The LSR does not advertise a FEC for a link-local address and, if received, the LSR does not resolve it.

A IPv4 or IPv6 prefix FEC can be resolved to an LDP IPv6 interface in the same way as it is resolved to an LDP IPv4 interface. The outgoing interface and next-hop are looked up in RTM cache. The next-hop can be the link-local unicast address of the other side of the link or a global unicast address. The FEC is resolved to the LDP IPv6 interface of the downstream LDP IPv6 LSR that advertised the IPv4 or IPv6 address of the next hop.

An mLDP P2MP FEC with an IPv4 root LSR address, and carrying one or more IPv4 or IPv6 multicast prefixes in the opaque element, can be resolved to an upstream LDP IPv6 LSR by checking if the LSR advertised the next-hop for the IPv4 root LSR address. The upstream LDP IPv6 LSR then resolves the IPv4 P2MP FEC to one of the LDP IPV6 links to this LSR.

Note: Beginning in Release 13.0, a P2MP FEC with an IPv6 root LSR address, carrying one or more IPv4 or IPv6 multicast prefixes in the opaque element, is not supported. Manually configured mLDP P2MP LSP, NG-mVPN, and dynamic mLDP cannot operate in an IPv6-only network.

A PW FEC can be resolved to a targeted LDP IPv6 adjacency with an LDP IPv6 LSR if there is a context for the FEC with local spoke-SDP configuration or spoke-SDP auto-creation from a service such as BGP-AD VPLS, BGP-VPWS or dynamic MS-PW.

3.25.5 LDP session capabilities

LDP supports advertisement of all FEC types over an LDP IPv4 or an LDP IPv6 session. These FEC types are: IPv4 prefix FEC, IPv6 prefix FEC, IPv4 P2MP FEC, PW FEC 128, and PW FEC 129.

In addition, LDP supports signaling the enabling or disabling of the advertisement of the following subset of FEC types both during the LDP IPv4 or IPv6 session initialization phase, and subsequently when the session is already up.

- **IPv4 prefix FEC**

  This is performed using the State Advertisement Control (SAC) capability TLV as specified in RFC 7473. The SAC capability TLV includes the IPv4 SAC element having the D-bit (Disable-bit) set or reset to disable or enable this FEC type respectively. The LSR can send this TLV in the LDP Initialization message and subsequently in a LDP Capability message.

- **IPv6 prefix FEC**

  This is performed using the State Advertisement Control (SAC) capability TLV as specified in RFC 7473. The SAC capability TLV includes the IPv6 SAC element having the D-bit (Disable-bit) set or reset to disable or enable this FEC type respectively. The LSR can send this TLV in the LDP Initialization message and subsequently in a LDP Capability message to update the state of this FEC type.

- **P2MP FEC**

  This is performed using the P2MP capability TLV as specified in RFC 6388. The P2MP capability TLV has the S-bit (State-bit) with a value of set or reset to enable or disable this FEC type respectively. Unlike the IPv4 SAC and IPv6 SAC capabilities, the P2MP capability does not distinguish between IPv4 and IPv6 P2MP FEC. The LSR can send this TLV in the LDP Initialization message and, subsequently, in a LDP Capability message to update the state of this FEC type.

During LDP session initialization, each LSR indicates to its peers which FEC type it supports by including the capability TLV for it in the LDP Initialization message. The SR OS implementation enables the above FEC types by default and sends the corresponding capability TLVs in the LDP initialization message. If one or both peers advertise the disabling of a capability in the LDP Initialization message, no FECs of the corresponding FEC type are exchanged between the two peers for the lifetime of the LDP session unless a Capability message is sent subsequently to explicitly enable it. The same behavior applies if no capability TLV for a FEC type is advertised in the LDP initialization message, except for the IPv4 prefix FEC which is assumed to be supported by all implementations by default.

Dynamic Capability, as defined in RFC 5561, allows all above FEC types to update the enabled or disabled state after the LDP session initialization phase. An LSR informs its peer that it supports the Dynamic Capability by including the Dynamic Capability Announcement TLV in the LDP Initialization message. If both LSRs advertise this capability, the user is allowed to enable or disable any of the above FEC types while the session is up and the change takes effect immediately. The LSR then sends a SAC Capability message with the IPv4 or IPv6 SAC element having the D-bit (Disable-bit) set or reset, or the P2MP capability TLV in a Capability message with the S-bit (State-bit) set or reset. Each LSR then takes the consequent action of withdrawing or advertising the FECs of that type to the peer LSR. If one or both LSRs did not advertise the Dynamic Capability Announcement TLV in the LDP Initialization message, any change to the enabled or disabled FEC types only takes effect at the next time the LDP session is restarted.

The user can enable a specific FEC type for a specific LDP session to a peer by using the following commands.

```
configure router ldp session-parameters peer fec-type-capability p2mp
configure router ldp session-parameters peer fec-type-capability prefix-ipv4
configure router ldp session-parameters peer fec-type-capability prefix-ipv6
```

3.25.6 LDP adjacency capabilities

Adjacency-level FEC-type capability advertisement is defined in *draft-pdutta-mpls-ldp-adj-capability*. By default, all FEC types supported by the LSR are advertised in the LDP IPv4 or IPv6 session initialization; see LDP session capabilities for more information. If a specific FEC type is enabled at the session level, it can be disabled over a specified LDP interface at the IPv4 or IPv6 adjacency level for all IPv4 or IPv6 peers over that interface. If a specific FEC type is disabled at the session level, then FECs are not advertised and enabling that FEC type at the adjacency level does not have any effect. The LDP adjacency capability can be configured on link Hello adjacency only and does not apply to targeted Hello adjacency.

The LDP adjacency capability TLV is advertised in the Hello message with the D-bit (Disable-bit) set or reset to disable or enable the resolution of this FEC type over the link of the Hello adjacency. It is used to restrict which FECs can be resolved over a specified interface to a peer. This provides the ability to dedicate links and datapath resources to specific FEC types. For IPv4 and IPv6 prefix FECs, a subset of ECMP links to a LSR peer may be each be configured to carry one of the two FEC types. An mLDP P2MP FEC can exclude specific links to a downstream LSR from being used to resolve this type of FEC.

Like the LDP session-level FEC-type capability, the adjacency FEC-type capability is negotiated for both directions of the adjacency. If one or both peers advertise the disabling of a capability in the LDP Hello message, no FECs of the corresponding FEC type are resolved by either peer over the link of this adjacency for the lifetime of the LDP Hello adjacency, unless one or both peers sends the LDP adjacency capability TLV subsequently to explicitly enable it.

The user can enable a FEC type for a specified LDP interface to a peer by using the following commands.

```
configure router ldp interface-parameters interface ipv4 fec-type-capability p2mp-ipv4
configure router ldp interface-parameters interface ipv4 fec-type-capability p2mp-ipv6
configure router ldp interface-parameters interface ipv4 fec-type-capability prefix-ipv4
configure router ldp interface-parameters interface ipv4 fec-type-capability prefix-ipv6

configure router ldp interface-parameters interface ipv6 fec-type-capability p2mp-ipv4
configure router ldp interface-parameters interface ipv6 fec-type-capability p2mp-ipv6
configure router ldp interface-parameters interface ipv6 fec-type-capability prefix-ipv4
configure router ldp interface-parameters interface ipv6 fec-type-capability prefix-ipv6
```

Unlike the session-level capability, these commands can disable multicast FEC for IPv4 and IPv6 separately.

The encoding of the adjacency capability TLV uses a PRIVATE Vendor TLV. It is used only in a Hello message to negotiate a set of capabilities for a specific LDP IPv4 or IPv6 Hello adjacency.

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1|0| ADJ_CAPABILITY_TLV        |      Length                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           VENDOR_OUI                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|S|  Reserved   |                                               |
+-+-+-+-+-+-+-+-+                                               +
|                 Adjacency capability elements                 |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The value of the U-bit for the TLV is set to 1 so that a receiver must silently ignore if the TLV is deemed unknown.

The value of the F-bit is 0. After being advertised, this capability cannot be withdrawn; the S-bit is set to 1 in a Hello message.

Adjacency capability elements are encoded as follows:

```
0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|D|  CapFlag    |
+-+-+-+-+-+-+-+-+
```

D bit

controls the capability state

1

disable capability

0

enable capability

CapFlag

the adjacency capability

1

prefix IPv4 forwarding

2

prefix IPv6 forwarding

3

P2MP IPv4 forwarding

4

P2MP IPv6 forwarding

5

MP2MP IPv4 forwarding

6

MP2MP IPv6 forwarding

Each CapFlag appears no more than once in the TLV. If duplicates are found, the D-bit of the first element is used. For forward compatibility, if the CapFlag is unknown, the receiver must silently discard the element and continue processing the rest of the TLV.

3.25.7 Address and FEC distribution

After an LDP LSR initializes the LDP session to the peer LSR and the session comes up, local IPv4 and IPv6 interface addresses are exchanged using the Address and Address Withdraw messages. Similarly, FECs are exchanged using Label Mapping messages.

By default, IPv6 address distribution is determined by whether the Dual-stack capability TLV, which is defined in RFC 7552, is present in the Hello message from the peer. This coupling is introduced because of interoperability issues found with existing third-party LDP IPv4 implementations.

The following is the detailed behavior:

- If the peer sent the dual-stack capability TLV in the Hello message, then IPv6 local addresses are sent to the peer. The user can configure a new address export policy to further restrict which local IPv6 interface addresses to send to the peer. If the peer explicitly stated enabling of LDP IPv6 FEC type by including the IPv6 SAC TLV with the D-bit (Disable-bit) set to 0 in the initialization message, then IPv6 FECs are sent to the peer. FEC prefix export policies can be used to restrict which LDP IPv6 FEC can be sent to the peer.
- If the peer sent the dual-stack capability TLV in the Hello message, but explicitly stated disabling of LDP IPv6 FEC type by including the IPv6 SAC TLV with the D-bit (Disable-bit) set to 1 in the initialization message, then IPv6 FECs are not sent but IPv6 local addresses are sent to the peer. A CLI is provided to allow the configuration of an address export policy to further restrict which local IPv6 interface

addresses to send to the peer. FEC prefix export policy has no effect because the peer explicitly requested disabling the IPv6 FEC type advertisement.

- If the peer did not send the dual-stack capability TLV in the Hello message, then no IPv6 addresses or IPv6 FECs are sent to that peer, regardless of the presence or not of the IPv6 SAC TLV in the initialization message. This case is added to prevent interoperability issues with existing third-party LDP IPv4 implementations. The user can override this by explicitly configuring an address export policy and a FEC export policy to select which addresses and FECs to send to the peer.

The above behavior applies to LDP IPv4 and IPv6 addresses and FECs. The procedure is summarized in the flowchart diagrams in Figure 80: LDP IPv6 address and FEC distribution procedure and Figure 81: LDP IPv6 address and FEC distribution procedure.

Figure 80: LDP IPv6 address and FEC distribution procedure

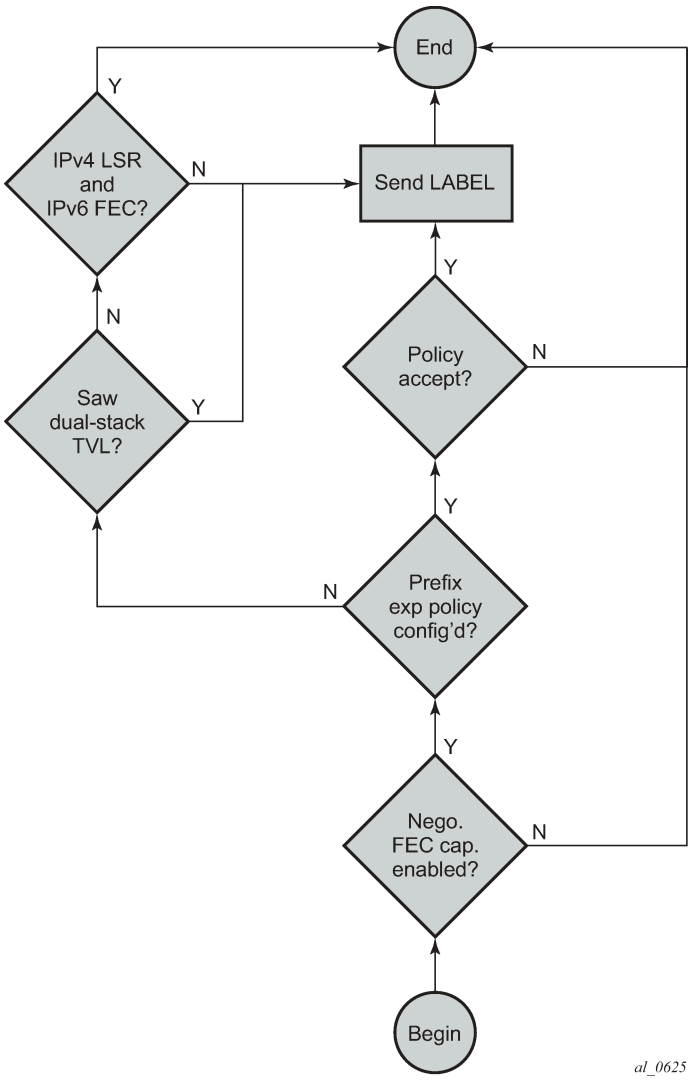
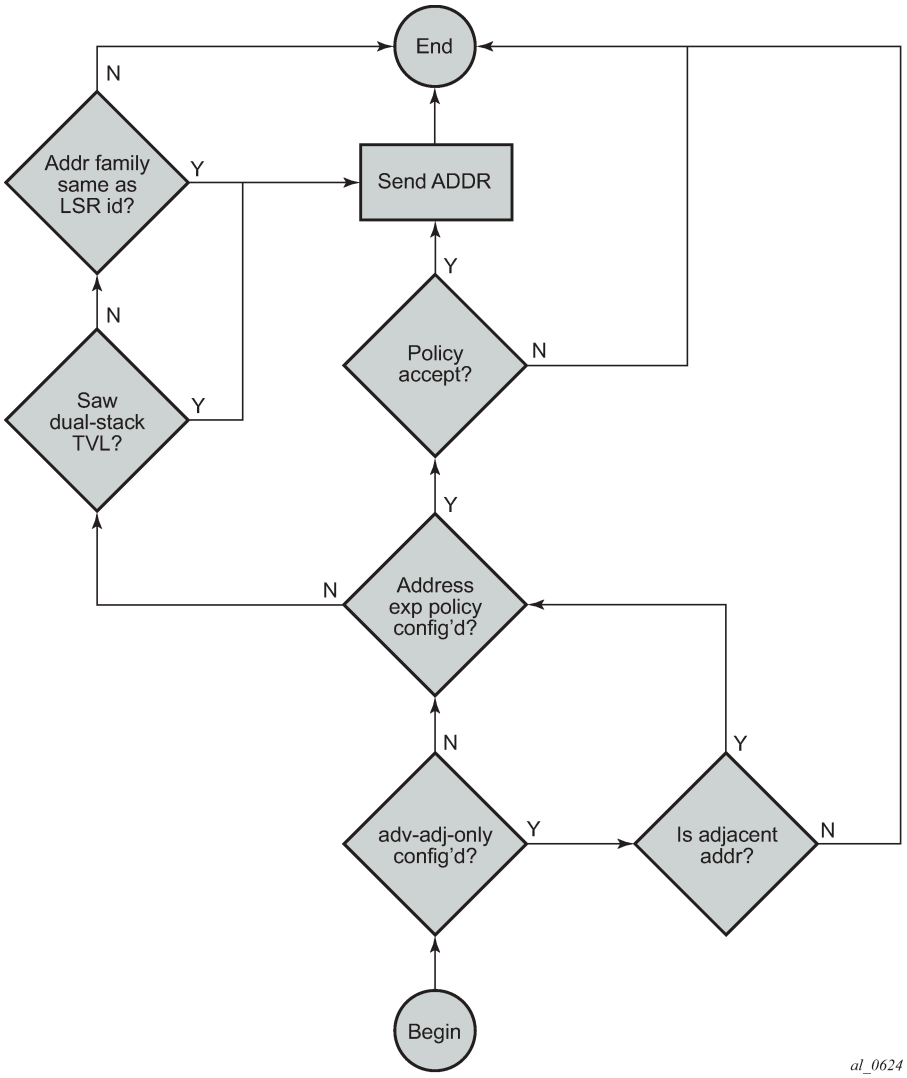


Figure 81: LDP IPv6 address and FEC distribution procedure



3.25.8 Controlling IPv6 FEC distribution during an upgrade to SR OS supporting LDP IPv6

A FEC for each of the IPv4 and IPv6 system interface addresses is advertised and resolved automatically by the LDP peers when the LDP session comes up, regardless of whether the session is IPv4 or IPv6.

To avoid the automatic advertisement and resolution of IPv6 system FEC when the LDP session is IPv4, the following procedure must be followed before and after the upgrade to the SR OS version which introduces support of LDP IPv6.

Note: Before the upgrade, implement a global prefix policy which rejects prefix [::0/0 longer] to prevent IPv6 FECs from being installed after the upgrade.

- In MISSU case:

  - If new IPv4 sessions are created on the node, the per-peer FEC-capabilities must be configured to filter out IPv6 FECs.
  - Until an existing IPv4 session is flapped, FEC-capabilities have no effect on filtering out IPv6 FECs. The import global policy must remain configured in place until the session flaps. Alternatively, a per-peer-import-policy [::0/0 longer] can be associated with this peer.
- In cold upgrade case:
  - If new IPv4 sessions are created on the node, the per-peer FEC-capabilities must be configured to filter out IPv6 FECs.
  - On older, pre-existing IPv4 sessions, the per-peer FEC-capabilities must be configured to filter out IPv6 FECs.
- When all LDP IPv4 sessions have dynamic capabilities enabled, with per-peer FEC-capabilities for IPv6 FECs disabled, then the GLOBAL IMPORT policy can be removed.

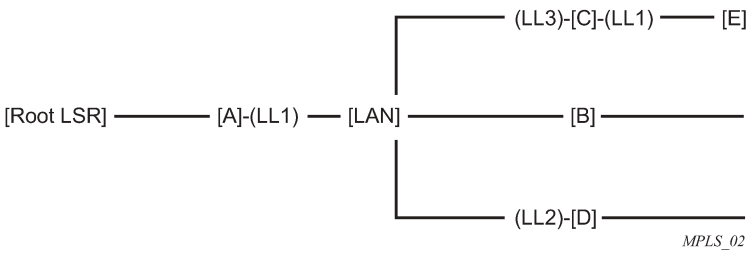
3.25.9 Handling of duplicate link-local IPv6 addresses in FEC resolution

Link-local IPv6 addresses are scoped to a link and duplicate addresses can be used on different links to the same or different peer LSR. When the duplicate addresses exist on the same LAN, routing detects them and block one of them. In all other cases, duplicate links are valid because they are scoped to the local link.

In this section, LLn refers to Link-Local address (n).

Figure 82: FEC resolution in LAN shows FEC resolution in a LAN.

Figure 82: FEC resolution in LAN



LSR B resolves a mLDP FEC with the root node being Root LSR. The route lookup shows that best route to loopback of Root LSR is {interface if-B and next-hop LL1}.

However, LDP finds that both LSR A and LSR C advertised address LL1 and that there are Hello adjacencies (IPv4 or IPv6) to both A and C. In this case, a change is made so that an LSR only advertises link-local IPv6 addresses to a peer for the links over which it established a Hello adjacency to that peer. In this case, LSR C advertises LL1 to LSR E but not to LSRs A, B, and D. This behavior applies with both P2P and broadcast interfaces.

Ambiguity also exists with prefix FEC (unicast FEC); the above solution also applies.

FEC Resolution over P2P links

---------(LL1)-[C]------

|

[Root LSR]-------[A]-(LL1)-----[B] ------(LL4)-[D]------

| |

|-(LL2)---------|

| |

|-(LL3)---------|

LSR B resolves an mLDP FEC with root node being Root LSR. The route lookup shows that best route to loopback of Root LSR is {interface if-B and next-hop LL1}.

- **case 1**

  LDP is enabled on all links. This case has no ambiguity. LDP only selects LSR A because the address LL1 from LSR C is discovered over a different interface. This case also applies to prefix FEC (unicast FEC) and there is no ambiguity in the resolution.

- **case 2**

  LDP is disabled on link A-B with next-hop LL1; LSR B can still select one of the two other interfaces to upstream LSR A as long as LSR A advertised LL1 address in the LDP session.

3.25.10 IGP and static route synchronization with LDP

The IGP-LDP synchronization and the static route to LDP synchronization features are modified to operate on a dual-stack IPv4/IPv6 LDP interface as follows:

- If the router interface goes down or both LDP IPv4 and LDP IPv6 sessions go down, IGP sets the interface metric to maximum value and all static routes with the following command enabled and resolved on this interface are deactivated.

  ```
  configure router static-route-entry next-hop ldp-sync
  ```

- If the router interface is up and only one of the LDP IPv4 or LDP IPv6 interfaces goes down, no action is taken.
- When the router interface comes up from a down state, and one of either the LDP IPv4 or LDP IPv6 sessions comes up, IGP starts the sync timer at the expiry of which the interface metric is restored to its configured value. All static routes with the **ldp-sync** command option enabled are also activated at the expiry of the timer.

Because of the above behavior, it is recommended that the user configures the sync timer to a value which allows enough time for both the LDP IPv4 and LDP IPv6 sessions to come up.

3.25.11 BFD operation

The operation of BFD over a LDP interface tracks the next-hop of prefix IPv4 and prefix IPv6 in addition to tracking of the LDP peer address of the Hello adjacency over that link. This tracking is required as LDP can now resolve both IPv4 and IPv6 prefix FECs over a single IPv4 or IPv6 LDP session and therefore the next-hop of a prefix does not necessarily match the LDP peer source address of the Hello adjacency. The failure of either or both of the BFD session tracking the FEC next-hop and the one tracking the Hello adjacency causes the LFA backup NHLFE for the FEC to be activated, or the FEC to be re-resolved if there is no FRR backup.

The following commands allow the user to decide if they want to track only with an IPv4 BFD session, only with an IPv6 BFD session, or both:

- **MD-CLI**

```
configure router ldp interface-parameters interface bfd-liveness ipv4
configure router ldp interface-parameters interface bfd-liveness ipv6
```

- **classic CLI**

```
configure router ldp interface-parameters interface bfd-enable ipv4
configure router ldp interface-parameters interface bfd-enable ipv6
```

This command provides the flexibility required in case the user does not need to track both Hello adjacency and next-hops of FECs. For example, if the user configures **ipv6** only to save on the number of BFD sessions, then LDP tracks the IPv6 Hello adjacency and the next-hops of IPv6 prefix FECs. LDP does not track next-hops of IPv4 prefix FECs resolved over the same LDP IPv6 adjacency. If the IPv4 data plane encounters errors and the IPv6 Hello adjacency is not affected and remains up, traffic for the IPv4 prefix FECs resolved over that IPv6 adjacency is black-holed. If the BFD tracking the IPv6 Hello adjacency times out, then all IPv4 and IPv6 prefix FECs is updated.

The tracking of a mLDP FEC has the following behavior:

- IPv4 and IPv6 mLDP FECs are only tracked with the Hello adjacency because they do not have the concept of downstream next-hop.
- The upstream LSR peer for an mLDP FEC supports the multicast upstream FRR procedures, and the upstream peer is tracked using the Hello adjacency on each link or the IPv6 transport address if there is a T-LDP session.
- The tracking of a targeted LDP peer with BFD does not change with the support of IPv6 peers. BFD tracks the transport address conveyed by the Hello adjacency which bootstrapped the LDP IPv6 session.

3.25.12 Services using SDP with an LDP IPv6 FEC

The SDP LDP type configured using **configure service sdp ldp** is supported using IPv6 addresses with the following commands.

Use the following command to configure the system IP address of the far-end destination router for the SDP that is the termination point for a service:

- **MD-CLI**

```
configure service sdp far-end ip-address
```

- **classic CLI**

```
configure service sdp far-end
```

Use the following command to specify an SDP tunnel destination address that is different from the configuration of the SDP far-end option.

```
configure service sdp tunnel-far-end
```

The addresses need not be of the same family (IPv6 or IPv4) for the SDP configuration to be allowed. The user can have an SDP with an IPv4 (or IPv6) control plane for the T-LDP session and an IPv6 (or IPv4) LDP FEC as the tunnel.

Because IPv6 LSP is only supported with LDP, the use of a far-end IPv6 address is not allowed with a BGP or RSVP/MPLS LSP. In addition, the CLI does not allow an SDP with a combination of an IPv6 LDP LSP and an IPv4 LSP of a different control plane. As a result, the following commands are blocked within the SDP configuration context when the far-end is an IPv6 address:

```
configure service sdp bgp-tunnel
configure service sdp lsp
configure service sdp mixed-lsp-mode
```

SDP admin groups are not supported with an SDP using an LDP IPv6 FEC, and the attempt to assign them is blocked in CLI.

Services that use LDP control plane (such as T-LDP VPLS and R-VPLS, VLL, and IES/VPRN spoke interface) have the spoke SDP (PW) signaled with an IPv6 T-LDP session when the **far-end** command option is configured to an IPv6 address. The spoke SDP for these services binds by default to an SDP that uses a LDP IPv6 FEC, which prefix matches the far end address. The spoke SDP can use a different LDP IPv6 FEC or a LDP IPv4 FEC as the tunnel by configuring the **tunnel-far-end** command option. In addition, the IPv6 PW control word is supported with both data plane packets and VCCV OAM packets. Hash label is also supported with the above services, including the signaling and negotiation of hash label support using T-LDP (Flow sub-TLV) with the LDP IPv6 control plane. Finally, network domains are supported in VPLS.

3.25.13 Mirror services and lawful intercept

The user can configure a spoke SDP bound to an LDP IPv6 LSP to forward mirrored packets from a mirror source to a remote mirror destination. In the configuration of the mirror destination service at the destination node, the following command must use a spoke SDP with a VC-ID that matches the one that is configured in the mirror destination service at the mirror source node.

```
configure mirror mirror-dest remote-source
```

The following command is not supported with an IPv6 address.

```
configure mirror mirror-dest remote-source far-end
```

This also applies to the configuration of the mirror destination for a LI source.

3.25.13.1 Configuration at mirror source node

Note: This section applies to the classic CLI.

Use the following rules to configure at the mirror source node:

- The *sdp-id* must match an SDP which uses LDP IPv6 FEC.
- Configuring *egress-vc-label* is optional.

  configure mirror mirror-dest 10

The following example shows an optional vc-label configuration.

Example: MD-CLI

```
[ex:/configure mirror mirror-dest "10"]
A:admin@node-2# info
    spoke-sdp 2:1 {
        egress {
            vc-label 16
        }
    }
```

Example: classic CLI

```
A:node-2>config>mirror>mirror-dest$ info
----------------------------------------------
            shutdown
            spoke-sdp 2:1 create
                egress
                    vc-label 16
                exit
                no shutdown
            exit
----------------------------------------------
```

3.25.13.2 Configuration at mirror destination node

Use the following rules to configure at the mirror destination node.

- The following command is not supported with LDP IPv6 transport tunnel. The user must reference a spoke SDP using a LDP IPv6 SDP coming from mirror source node:
  - **MD-CLI**

    ```
    configure mirror mirror-dest remote-source far-end far-end-addr
    ```

  - **classic CLI**

    ```
    configure mirror mirror-dest remote-source far-end
    ```

- Use the following command to configure a spoke SDP for the remote source.

  ```
  configure mirror mirror-dest remote-source spoke-sdp
  ```

  The *vc-id* should match that of the configured spoke SDP in the mirror-destination context at mirror source node.

  ```
  configure mirror mirror-dest spoke-sdp
  ```

- Configuring *ingress-vc-label* is optional; both static and t-ldp are supported in the following command.

  ```
  configure mirror mirror-dest 10 remote-source
  ```

The following example shows an optional vc-label configuration.

Example: MD-CLI

```
[ex:/configure mirror mirror-dest "10" remote-source]
```

```
A:admin@node-2# info
    far-end 10.10.10.5 {
    }
    spoke-sdp 2:1 {
        ingress {
            vc-label 33
        }
    }
```

Example: classic CLI

```
A:node-2>config>mirror>mirror-dest>remote-source$ info
----------------------------------------------
            far-end 10.10.10.5

            spoke-sdp 2:1 create
                ingress
                    vc-label 33
                exit
                no shutdown
----------------------------------------------
```

Mirroring and LI is also supported with the PW redundancy feature when the endpoint spoke SDP, including the ICB, is using a LDP IPv6 tunnel.

3.25.14 Static route resolution to a LDP IPv6 FEC

An LDP IPv6 FEC can be used to resolve a static IPv6 route with an indirect next hop matching the FEC prefix. Use the following command to configure a resolution filter to specify the LDP tunnel type to be selected from TTM:

- **MD-CLI**

```
configure router static-routes route indirect tunnel-next-hop resolution-filter
```

- **classic CLI**

```
configure router static-route-entry indirect tunnel-next-hop resolution-filter
```

A static route of an IPv6 prefix cannot be resolved to an indirect next hop using a LDP IPv4 FEC. An IPv6 prefix can only be resolved to an IPv4 next hop using the 6-over-4 encapsulation by which the outer IPv4 header uses system IPv4 address as source and the next hop as a destination. So the following example returns an error:

```
A:node-2>config>router# static-route-entry 3ffe::30/128 indirect 192.168.1.1 tunnel-
next-hop resolution-filter ldp

INFO: PIP #2209 Tunnel parameters cannot be used on 6over4 static-routes
```

3.25.15 IGP route resolution to a LDP IPv6 FEC

LDP IPv6 shortcut for IGP IPv6 prefix is supported. The following commands allow a user to select if shortcuts must be enabled for IPv4 prefixes only, for IPv6 prefixes only, or for both:

- **MD-CLI**

```
configure router ldp ldp-shortcut ipv4
configure router ldp ldp-shortcut ipv6
```

- **classic CLI**

```
configure router ldp-shortcut [ipv4] [ipv6]
```

This CLI command has the following behaviors:

- When executing a pre-Release 13.0 config file, the existing command is converted as follows: **configure router ldp-shortcut** changed to **configure router ldp-shortcut ipv4**
- If the user enters the command without the command options in the CLI, it defaults to enabling shortcuts for IPv4 IGP prefixes.
- When the user enters both IPv4 and IPv6 command options in the CLI, shortcuts for both IPv4 and IPv6 prefixes are enabled.

3.25.16 OAM support with LDP IPv6

The following MPLS OAM tools are updated to operate with LDP IPv6:

- **MD-CLI**

```
oam lsp-ping ldp prefix [path-destination] [source-ip-address]
oam lsp-trace ldp prefix [path-destination] [source-ip-address]
```

- **classic CLI**

```
oam lsp-ping ldp prefix [path-destination] [src-ip-address]
oam lsp-trace ldp prefix [path-destination] [src-ip-address]
```

These MPLS OAM tools support the following:

- use of IPv6 addresses in the echo request and echo reply messages, including in DSMAP TLV, as per RFC 8029
- use of LDP IPv6 prefix target FEC stack TLV as per RFC 8029
- use of IPv6 addresses in the DDMAP TLV and FEC stack change sub-TLV, as per RFC 6424
- use of 127/8 IPv4 mapped IPv6 address; that is, in the range ::ffff:127/104, as the destination address of the echo request message, as per RFC 8029
- use of 127/8 IPv4 mapped IPv6 address; that is, in the range ::ffff:127/104, as the **path-destination** address when the user wants to exercise a specific LDP ECMP path

The behavior at the sender and receiver nodes is updated to support both LDP IPv4 and IPv6 target FEC stack TLVs. Specifically:

- The IP family (IPv4/IPv6) of the UDP/IP echo request message always matches the family of the LDP target FEC stack TLV as entered by the user in the **prefix** command option.
- The **source-ip-address** command option is extended to accept IPv6 address of the sender node. If the user did not enter a source IP address, the system IPv6 address is used. If the user entered a source IP address of a different family than the LDP target FEC stack TLV, an error is returned and the test command is aborted.

- The IP family of the UDP/IP echo reply message must match that of the received echo request message.
- For **lsp-trace**, the downstream information in DSMAP/DDMAP is encoded as the same family as the LDP control plane of the link LDP or targeted LDP session to the downstream peer.
- The sender node inserts the experimental value of 65503 in the Router Alert Option in the echo request packet's IPv6 header as per RFC 5350. When a value is allocated by IANA for MPLS OAM as part of *draft-ietf-mpls-oam-ipv6-rao*, it is updated.

Finally, for classic CLI, the **oam vccv-ping** and **oam vccv-trace** commands for a single-hop PW are updated to support IPv6 PW FEC 128 and FEC 129 as per RFC 6829. These two commands only apply to classic CLI. In addition, the PW OAM control word is supported with VCCV packets when the control word option is enabled on the spoke-SDP configuration. The value of the Channel Type field is set to 0x57, which indicates that the Associated Channel carries an IPv6 packet, as per RFC 4385.

3.25.17 LDP IPv6 interoperability considerations

3.25.17.1 Interoperability with implementations compliant with RFC 7552

The SR OS implementation uses a 128-bit LSR-ID, as defined in RFC 7552, to establish an LDP IPv6 Hello adjacency and session with a peer LSR. This allows a routable system IPv6 address to be used by default to bring up the LDP task on the router and establish link LDP and T-LDP sessions to other LSRs, as is the common practice with LDP IPv4 in existing customer deployments. More importantly, this allows for the establishment of control plane independent LDP IPv4 and LDP IPv6 sessions between two LSRs over the same interface or set of interfaces. The SR OS implementation allows for multiple separate LDP IPv4 and LDP IPv6 sessions between two routers over the same interface or a set of interfaces, as long as each session uses a unique LSR-ID (32-bit for IPv4 and 128-bit for IPv6).

The SR OS LDP IPv6 implementation complies with the control plane procedures defined in RFC 7552 for establishing an LDP IPv6 Hello adjacency and LDP session. However, the implementation does not interoperate, by default, with third-party implementations of this standard because the latter encode a 32-bit LSR-ID in the IPv6 Hello message while SR OS encodes a 128-bit LSR-ID.

To assure interoperability in deployments strictly adhering to RFC 7552, SR OS provides the option for configuring and encoding a 32-bit LSR-ID in the LDP IPv6 Hello message. When this option is enabled, an SR OS LSR establishes an LDP IPv6 Hello adjacency and an LDP IPv6 session with an RFC 7552 compliant peer or targeted peer LSR, using a 32-bit LSR-ID and a 128-bit transport address. See LDP IPv6 32-bit LSR-ID for more information.

In a dual-stack IPv4/IPV6 interface environment, the SR OS based LSR does not originate both IPv6 and IPv4 Hello messages with the configured 32-bit LSR-ID value when both IPv4 and IPv6 contexts are enabled on the same LDP interface. This behavior is allowed in RFC 7552 for migration purposes. However, the SR OS implements separate IPv4 and IPv6 Hello adjacencies and LDP sessions with different LSR-ID values for the LDP IPv4 (32-bit value) and LDP IPv6 (32-bit or 128-bit value) Hello adjacencies. Therefore, the LDP IPv4 and LDP IPv6 sessions are independent in the control plane.

However, if the peer LSR sends both IPv4 and IPv6 Hello messages using the same 32-bit LSR-ID value, as allowed in RFC 7552, only a single LDP session with the local 32-bit LSR-ID comes up toward that peer LSR-ID, depending on which of the IPv4 or IPv6 adjacencies came up first.

The dual-stack capability TLV, in the Hello message, is used by an LSR to inform its peer that it is capable of establishing either an LDP IPv4 or LDP IPv6 session, and the IP family preference for the LDP Hello adjacency for the resulting LDP session.

Finally, the SR OS LDP implementation inter-operates with an implementation using a 32-bit LSR-ID, as defined in RFC 7552, to establish an IPv4 LDP session and to resolve both IPv4 and IPv6 prefix FECs. In this case, the dual-stack capability TLV indicates implicitly the LSR support for resolving IPv6 FECs over an IPv4 LDP session.

3.25.17.2 LDP IPv6 32-bit LSR-ID

The SR OS implementation provides the option for configuring and encoding a 32-bit LSR-ID in the LDP IPv6 Hello message to achieve interoperability in deployments strictly adhering to RFC 7552.

The LSR-ID of an LDP Label Switched Router (LSR) is a 32-bit integer used to uniquely identify it in a network. SR OS also supports LDP IPv6 in both the control plane and data plane. However, the implementation uses a 128-bit LSR-ID, as defined in *draft-pdutta-mpls-ldp-v2* to establish an LDP IPv6 Hello adjacency and session with a peer LSR.

The SR OS LDP IPv6 implementation complies with the control plane procedures defined in RFC 7552 for establishing an LDP IPv6 Hello adjacency and LDP session. However, the SR OS LDP IPv6 implementation does not interoperate with third-party implementations of this standard, because the latter encode a 32-bit LSR-ID in the IPv6 Hello message, while SR OS encodes a 128-bit LSR-ID.

When this feature is enabled, an SR OS LSR is able to establish an LDP IPv6 Hello adjacency and an LDP IPv6 session with an RFC 7552 compliant peer or targeted peer LSR, using a 32-bit LSR-ID and a 128-bit transport address.

3.25.17.2.1 Feature configuration

This user configures the 32-bit LSR-ID on a LDP peer or targeted peer using the following commands:

- **MD-CLI**

```
configure router ldp interface-parameters interface ipv6 local-lsr-id format-32bit
configure router ldp interface-parameters interface ipv6 local-lsr-id format-32bit
```

- **classic CLI**

```
configure router ldp interface-parameters interface ipv6 local-lsr-id interface [32bit-
format]
configure router ldp interface-parameters interface ipv6 local-lsr-id [32bit-format]
configure router ldp targeted-session peer local-lsr-id [32bit-format]
```

When the **local-lsr-id** command is enabled with the 32 bit formatting, an SR OS LSR is able to establish a LDP IPv6 Hello adjacency and a LDP IPv6 session with a RFC 7552 compliant peer or targeted peer LSR using a 32-bit LSR-ID set to the value of the IPv4 address of the specified local LSR-ID interface and a 128-bit transport address set to the value of the IPv6 address of the specified local LSR-ID interface.

Note: The system interface cannot be used as a local LSR-ID with the 32 bit formatting enabled as it is the default LSR-ID and transport address for all LDP sessions to peers and targeted peers on this LSR. This configuration is blocked in CLI.

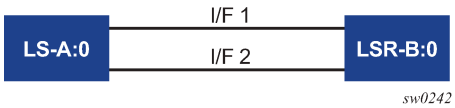
If the user enables the 32 bit formatting in the IPv6 context of a running LDP interface or in the targeted session peer context of a running IPv6 peer, the already established LDP IPv6 Hello adjacency and LDP IPv6 session is brought down and re-established with the new 32-bit LSR-ID value.

The detailed control plane procedures are provided in LDP LSR IPv6 operation with 32-bit LSR-ID.

3.25.17.2.2 LDP LSR IPv6 operation with 32-bit LSR-ID

Consider the setup shown in Figure 83: LDP adjacency and session over IPv6 interface.

Figure 83: LDP adjacency and session over IPv6 interface



LSR A and LSR B have the following LDP command options.

LSR A

- Interface I/F1 : link local address = fe80::a1
- Interface I/F2 : link local address = fe80::a2
- Interface LoA1: IPv4 address = <A1/32>; primary IPv6 unicast address = <A2/128>
- Interface LoA2: IPv4 address = <A3/32>; primary IPv6 unicast address = <A4/128>
- local-lsr-id = interface LoA1; 32 bit formatting option enabled

  Use the following commands to configure the interface and enable 32 bit formatting:

  – **MD-CLI**

  ```
  configure router ldp interface-parameters interface ipv6 local-lsr-id interface-name LoA1
  configure router ldp interface-parameters interface ipv6 local-lsr-id format-32bit
  ```

  – **classic CLI**

  ```
  configure router ldp interface-parameters interface ipv6 local-lsr-id LoA1 32bit-format
  ```

  LDP identifier = {<LSR Id=A1/32> : <label space id=0>}; transport address = <A2/128>
- local-lsr-id = interface LoA2; 32 bit formatting option enabled

  Use the following commands to configure the interface and enable 32 bit formatting:

  – **MD-CLI**

  ```
  configure router ldp targeted-session peer local-lsr-id interface-name LoA2
  configure router ldp targeted-session peer local-lsr-id format-32bit
  ```

  – **classic CLI**

  ```
  configure router ldp targeted-session peer local-lsr-id LoA2 32bit-format
  ```

  LDP identifier = {<LSR Id=A3/32> : <label space id=0>}; transport address = <A4/128>

LSR B

- Interface I/F1 : link local address = fe80::b1
- Interface I/F2 : link local address = fe80::b2
- Interface LoB1: IPv4 address = <B1/32>; primary IPv6 unicast address = <B2/128>
- Interface LoB2: IPv4 address = <B3/32>; primary IPv6 unicast address = <B4/128>

- local-lsr-id = interface LoB1; 32 bit formatting option enabled

  Use the following commands to configure the interface and enable 32 bit formatting:

  – **MD-CLI**

  ```
  configure router ldp interface-parameters interface ipv6 local-lsr-id interface-name LoB1
  configure router ldp interface-parameters interface ipv6 local-lsr-id format-32bit
  ```

  – **classic CLI**

  ```
  configure router ldp interface-parameters interface ipv6 local-lsr-id LoB1 32bit-format
  ```

  LDP identifier = {<LSR Id=B1/32> : <label space id=0>}; transport address = <B2/128>

- local-lsr-id = interface LoB2; 32 bit formatting option enabled

  Use the following commands to configure the interface and enable 32 bit formatting:

  – **MD-CLI**

  ```
  configure router ldp targeted-session peer local-lsr-id interface-name LoB2
  configure router ldp targeted-session peer local-lsr-id format-32bit
  ```

  – **classic CLI**

  ```
  configure router ldp targeted-session peer local-lsr-id LoB2 32bit-format
  ```

  LDP identifier = {<LSR Id=B3/32> : <label space id=0>}; transport address = <B4/128>

3.25.17.2.2.1 Link LDP

When the IPv6 context of interfaces I/F1 and I/F2 are brought up, the following procedures are performed.

1. LSR A (LSR B) sends a IPv6 Hello message with source IP address set to the link-local unicast address of the specified local LSR ID interface, for example, fe80::a1 (fe80::a2), and a destination IP address set to the link-local multicast address ff02:0:0:0:0:0:0:2.
2. LSR A (LSR B) sets the LSR-ID in LDP identifier field of the common LDP PDU header to the 32-bit IPv4 address of the specified local LSR-ID interface LoA1 (LoB1), for example, A1/32 (B1/32).

   If the specified local LSR-ID interface is unnumbered or does not have an IPv4 address configured, the adjacency does not come up and an error is returned (lsrInterfaceNoValidIp [17]) in the output of the following command.

   ```
   show router ldp interface detail
   ```

3. LSR A (LSR B) sets the transport address TLV in the Hello message to the IPv6 address of the specified local LSR-ID interface LoA1 (LoB1), for example, A2/128 (B2/128).

   If the specified local LSR-ID interface is unnumbered or does not have an IPv6 address configured, the adjacency does not come up and an error is returned (interfaceNoValidIp [16]) in the output of the following command.

   ```
   show router ldp interface detail
   ```

4. LSR A (LSR B) includes in each IPv6 Hello message the dual-stack TLV with the transport connection preference set to IPv6 family.

- If the peer is a third-party LDP IPv6 implementation and does not include the dual-stack TLV, then LSR A (LSR B) resolves IPv6 FECs only because IPv6 addresses are not advertised in Address messages as per RFC 7552 [ldp-ipv6-rfc].
- If the peer is a third-party LDP IPv6 implementation and includes the dual-stack TLV with transport connection preference set to IPv4, LSR A (LSR B) does not bring up the Hello adjacency and discards the Hello message. If the LDP session was already established, then LSRA(B) sends a fatal Notification message with status code of 'Transport Connection Mismatch' (0x00000032)' and restart the LDP session [ldp-ipv6-rfc]. In both cases, a new counter for the transport connection mismatches is incremented in the output of the following command.

```
show router ldp statistics
```

5. The LSR with highest transport address takes on the active role and initiates the TCP connection for the LDP IPv6 session using the corresponding source and destination IPv6 transport addresses.

3.25.17.2.2.2 Targeted LDP

Similarly, when the new option is invoked on a targeted IPv6 peer, the router sends a IPv6 targeted Hello message with source IP address set to the global unicast IPv6 address corresponding to the primary IPv6 address of the specified interface and a destination IP address set to configured IPv6 address of the peer. The LSR-ID field in the LDP identifier in the common LDP PDU header is set the 32-bit address of the specified interface. If the specified interface does not have an IPv4 address configured the adjacency does not come up. Any subsequent adjacency or session level messages is sent with the common LDP PDU header set as above.

When the targeted IPv6 peer contexts are brought up, the following procedures are performed:

1. LSR A (LSR B) sends a IPv6 Hello message with source IP address set to the primary IPv6 unicast address of the specified local LSR ID interface LoA2(LoB2), for example, A4/128 (B4/128), and a destination IP address set to the peer address B4/128(A4/128).
2. LSR A (LSR B) sets the LSR-ID in LDP identifier field of the common LDP PDU header to the 32-bit IPv4 address of the specified local LSR-ID interface LoA2(LoB2), for example, A3/32 (B3/32).

   If the specified local LSR-ID interface is unnumbered or does not have an IPv4 address configured, the adjacency does not come up and an error is returned.
3. LSR A (LSR B) sets the transport address TLV in the Hello message to the IPv6 address of the specified local LSR-ID interface LoA2 (LoB2), for example, A4/128 (B4/128).

   If the specified local LSR-ID interface is unnumbered or does not have an IPv6 address configured, the adjacency does not come up and an error is returned.
4. LSR A (LSR B) includes in each IPv6 Hello message the dual-stack TLV with the preference set to IPv6 family.
   - If the peer is a third-party LDP IPv6 implementation and does not include the dual-stack TLV, then LSR A (LSR B) resolves IPv6 FECs only because IPv6 addresses are not advertised in Address messages as per RFC 7552 [ldp-ipv6-rfc].
   - If the peer is a third-party LDP IPv6 implementation and includes the dual-stack TLV with transport connection preference set to IPv4, LSR A (LSR B) does not bring up the Hello adjacency and discards the Hello message. If the LDP session was already established, then LSRA(B) sends a fatal Notification message with status code of 'Transport Connection Mismatch' (0x00000032)' and

restarts the LDP session [ldp-ipv6-rfc]. In both cases, a new counter for the transport connection mismatches is incremented in the output of the following command.

```
show router ldp statistics
```

5. The LSR with highest transport address takes on the active role and initiates the TCP connection for the LDP IPv6 session using the corresponding source and destination IPv6 transport addresses.

3.25.17.2.2.3 Link and targeted LDP feature interaction

The following describes feature interactions:

- LSR A (LSR B) do not originate both IPv6 and IPv4 Hello messages with the configured 32-bit LSR-ID value when both IPv4 and IPv6 contexts are enabled on the same LDP interface (dual-stack LDP IPv4/IPv6). This behavior is allowed in RFC 7552 for migration purposes but SR OS implements separate IPv4 and IPv6 Hello adjacencies and LDP sessions with different LSR-ID values. Therefore, an IPv6 context that uses a 32-bit LSR-ID address matching that of the IPv4 context on the same interface is not allowed to be brought up and the other way around.

  Furthermore, an IPv6 context of any interface or targeted peer that uses a 32-bit LSR-ID address matching that of an IPv4 context of any other interface, an IPv6 context of any other interface using 32-bit LSR-ID, a targeted IPv4 peer, a targeted IPv6 peer using 32-bit LSR-ID, or an auto T-LDP IPv4 template on the same router is not allowed to be brought up and the other way around.
- With the introduction of a 32-bit LSR-ID for a IPv6 LDP interface or peer, it is possible to configure the same IPv6 transport address for an IPv4 LSR-ID and an IPv6 LSR-ID on the same node. For instance, assume the following configuration:
  - **interface I/F1**
    - local-lsr-id = interface LoA1; option 32 bit-format enabled.

      Use the following commands to configure the interface and enable the 32 bit-format:
      - **MD-CLI**

        ```
        configure router ldp interface-parameters interface ipv6 local-lsr-id interface-name
         LoA1
        configure router ldp interface-parameters interface ipv6 local-lsr-id format-32bit
        ```
      - **classic CLI**

        ```
        configure router ldp interface-parameters interface ipv6 local-lsr-id LoA1 32bit-
        format
        ```
    - LDP identifier = {<LSR Id=A1/32> : <label space id=0>}; transport address = <A2/128>
  - **interface I/F2**
    - local-lsr-id = interface LoA1

      Use the following command to configure the interface:
      - **MD-CLI**

        ```
        configure router ldp interface-parameters interface ipv6 local-lsr-id interface-name
         LoA1
        ```

– **classic CLI**

```
configure router ldp interface-parameters interface ipv6 local-lsr-id LoA1
```

- LDP identifier = {<LSR Id=A2/128> : <label space id=0>}; transport address = <A2/128>

– **targeted session**

- local-lsr-id = interface LoA1

  Use the following command to configure the interface:

  – **MD-CLI**

  ```
  configure router ldp targeted-session peer local-lsr-id interface-name LoA1
  ```

  – **classic CLI**

  ```
  configure router ldp targeted-session peer local-lsr-id LoA1
  ```

- LDP identifier = {<LSR Id=A2/128> : <label space id=0>}; transport address = <A2/128>

The above configuration results in two interfaces and a targeted session with the same local end transport IPv6 address but the local LSR-ID for interface I/F1 is different.

If an IPv6 Hello adjacency over interface I/F1 toward a specified peer comes up first and initiates an IPv6 LDP session, then the other two Hello adjacencies to the same peer do not come up.

If one of the IPv6 Hello adjacencies of interface I/F2 or Targeted Session 1 comes up first to a peer, it triggers an IPv6 LDP session shared by both these adjacencies and the Hello adjacency over interface I/F1 to the same peer does not come up.

3.25.17.2.3 Migration considerations

3.25.17.2.3.1 Migrating services from LDP IPv4 session to 32-bit LSR-ID LDP IPv6 session

Assume the user deploys on a SR OS based LSR a service bound to a SDP which auto-creates the IPv4 targeted LDP session to a peer LSR running a third party LDP implementation. In this case, the auto-created T-LDP session uses the system interface IPv4 address as the local LSR-ID and as the local transport address because there is no targeted session configured in LDP to set these command options away from default values.

When both LSR nodes are being migrated to using LDP IPv6 with a 32-bit LSR-ID, the user must configure the IPv6 context of the local LDP interfaces to use a local LSR-ID interface different than the system interface and with the 32bit-format option enabled. Similarly, the user must configure a new Targeted session in LDP with that same local LSR-ID interface and with the 32bit-format option enabled. This results in a LDP IPv6 session triggered by the link LDP IPv6 Hello adjacency or the targeted IPv6 Hello adjacency which came up first. This LDP IPv6 session uses the IPv4 address and the IPv6 address of the configured local LSR-ID interface as the LSR-ID and transport address respectively.

The user must then modify the service configuration on both ends to use a far-end address matching the far-end IPv6 transport address of the LDP IPv6 session. On the SR OS based LSR, this can be done by creating a new IPv6 SDP of type LDP with the far-end address matching the far-end IPv6 transport address.

If the service enabled PW redundancy, the migration may be eased by creating a standby backup PW bound to the IPv6 SDP and adding it to the same VLL or VPLS endpoint the spoke SDP bound to the IPv4 SDP belongs to. Then, activate the backup PW using the following command.

```
tools perform service id endpoint force-switchover
```

This make the spoke SDP bound to the IPv6 SDP the primary PW. Finally, the spoke SDP bound to the IPv4 SDP can be deleted.

3.25.17.3 Interoperability with implementations compliant with RFC 5036 for IPv4 LDP control plane only

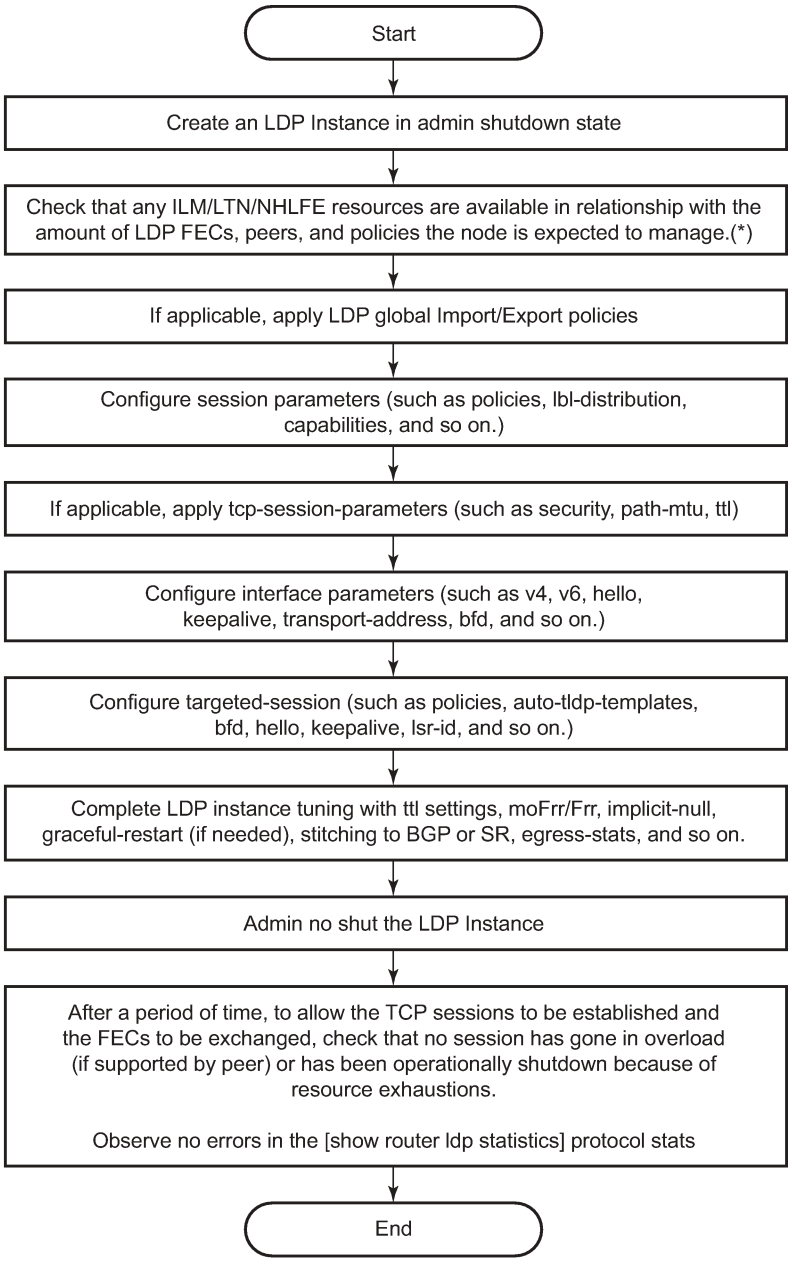
The SR OS implementation supports advertising and resolving IPv6 prefix FECs over an LDP IPv4 session using a 32-bit LSR-ID, in compliance with RFC 7552. When introducing an LSR based on the SR OS in a LAN with a broadcast interface, it can peer with third-party LSR implementations that support RFC 7552 and LSRs that do not. When it peers, using an IPv4 LDP control plane, with a third-party LSR implementation that does not support it, the advertisement of IPv6 addresses or IPv6 FECs to that peer may cause it to bring down the IPv4 LDP session.

That is, there are deployed third-party LDP implementations that are compliant with RFC 5036 for LDP IPv4, but that are not compliant with RFC 5036 for handling IPv6 address or IPv6 FECs over an LDP IPv4 session. To resolve this issue, RFC 7552 modifies RFC 5036 by requiring implementations complying with RFC 7552 to check for the dual-stack capability TLV in the IPv4 Hello message from the peer. Without the peer advertising this TLV, an LSR must not send IPv6 addresses and FECs to that peer. The SR OS implementation supports this requirement.

3.26 LDP process overview

Figure 84: LDP configuration and implementation displays the process to provision basic LDP.

Figure 84: LDP configuration and implementation



(*) if some of the needed resources are not available consider implementing stricter import-policies and/or enabling the per-peer fec-limit functionality.

MPLS_01

3.27 Configuring LDP with CLI

This section provides information to configure LDP using the command line interface.

3.27.1 LDP configuration overview

When the implementation of LDP is instantiated, the protocol is in the no shutdown state. In addition, targeted sessions are then enabled. The default command options for LDP are set to the documented values for targeted sessions in *draft-ietf-mpls-ldp-mib-09.txt* .

LDP must be enabled in order for signaling to be used to obtain the ingress and egress labels in frames transmitted and received on the service distribution path (SDP). When signaling is off, labels must be manually configured when the SDP is bound to a service.

3.27.2 Basic LDP configuration

Use this section to configure LDP and remove configuration examples of common configuration tasks.

The LDP protocol instance is created in the enabled state.

The following example displays the default LDP configuration.

Example: MD-CLI

```
[ex:/configure router "Base" ldp]
A:admin@node-2# info detail
...
    import-pmsi-routes {
        mvpn false
        mvpn-no-export-community false
    }
 ## fec-originate
    egress-statistics {
     ## fec-prefix
    }
 ## lsp-bfd
    session-parameters {
     ## peer
    }
    tcp-session-parameters {
     ## authentication-keychain
     ## authentication-key
     ## peer-transport
    }
    interface-parameters {
        ipv4 {
            transport-address system
            hello {
                timeout 15
                factor 3
            }
            keepalive {
                timeout 30
                factor 3
            }
        }
        ipv6 {
            transport-address system
            hello {
                timeout 15
                factor 3
            }
            keepalive {
```

```
                timeout 30
                factor 3
            }
        }
     ## interface
    }
    targeted-session {
        sdp-auto-targeted-session true
     ## export-prefixes
     ## import-prefixes
        resolve-v6-prefix-over-shortcut false
        ipv4 {
            hello {
                timeout 45
                factor 3
            }
            keepalive {
                timeout 40
                factor 4
            }
            hello-reduction {
                admin-state disable
                factor 3
            }
        }
        ipv6 {
            hello {
                timeout 45
                factor 3
            }
            keepalive {
                timeout 40
                factor 4
            }
            hello-reduction {
                admin-state disable
                factor 3
            }
        }
  ...
```

Example: classic CLI

```
A:node-2>config>router>ldp$ info detail
----------------------------------------------
...
            import-pmsi-routes
                no mvpn
                no mvpn-no-export-community
            exit
            tcp-session-parameters
                no auth-keychain
                no authentication-key
            exit
            interface-parameters
                ipv4
                    no hello
                    no keepalive
                    no transport-address
                exit
                ipv6
                    no hello
                    no keepalive
```

```
                    no transport-address
                exit
            exit
            targeted-session
                no disable-targeted-session
                no import-prefixes
                no export-prefixes
                ipv4
                    no hello
                    no keepalive
                    no hello-reduction
                exit
                ipv6
                    no hello
                    no keepalive
                    no hello-reduction
                exit
                auto-tx
                    ipv4
                        shutdown
                        no tunneling
                    exit
                exit
                auto-rx
                    ipv4
                        shutdown
                        no tunneling
                    exit
                exit
                no resolve-v6-prefix-over-shortcut
            exit
            no shutdown
-----------------------------------------------
```

3.27.3 Common configuration tasks

This section provides an overview of the tasks to configure LDP and provides the CLI commands.

3.27.3.1 Enabling LDP

Note: This section applies for the classic CLI.

LDP must be enabled in order for the protocol to be active. MPLS is enabled in the **configure router mpls** context.

Use the following command to enable LDP on a router:

```
configure router ldp
```

The following displays the enabled LDP configuration.

Example: classic CLI

```
A:node-2>config>router# info
...
#--------------------------------------------------
```

```
echo "LDP Configuration"
#------------------------------------------------
        ldp
            import-pmsi-routes
            exit
            tcp-session-parameters
            exit
            interface-parameters
            exit
            targeted-session
            exit
            no shutdown
        exit
----------------------------------------------
```

3.27.3.2 Configuring FEC originate

A FEC can be added to the LDP IP prefix database with a specific label operation on the node. Permitted operations are pop or swap. For a swap operation, an incoming label can be swapped with a label in the range of 16 to 1048575. If a swap-label is not configured then the default value is 3.

A route-table entry is required for a FEC with a pop operation to be advertised. For a FEC with a swap operation, a route-table entry must exist and user configured next-hop for swap operation must match one of the next-hops in route-table entry.

Use the commands in the following context to configure FEC originate.

```
configure router ldp fec-originate
```

The following example displays a FEC originate configuration.

Example: MD-CLI

```
[ex:/configure router "Base" ldp]
A:admin@node-2# info
    fec-originate 10.1.1.1/32 {
        pop true
    }
    fec-originate 10.1.2.1/32 {
        advertised-label 1000
        next-hop 10.10.1.2
    }
    fec-originate 10.1.3.1/32 {
        advertised-label 1001
        next-hop 10.10.2.3
        swap-label 131071
    }
```

Example: classic CLI

```
A:node-2>config>router# info

//#------------------------------------------------
echo "LDP Configuration"
#------------------------------------------------
        ldp
            fec-originate 10.1.1.1/32 pop
            fec-originate 10.1.2.1/32 advertised-label 1000 next-hop 10.10.1.2
```

```
            fec-originate 10.1.3.1/32 advertised-label 1001 next-hop 10.10.2.3 swap-label
 131071
            import-pmsi-routes
            exit
            tcp-session-parameters
            exit
            interface-parameters
            exit
            targeted-session
            exit
            no shutdown
        exit
-------------------------------------------
```

3.27.3.3 Configuring the graceful-restart helper

Graceful-restart helper advertises to its LDP neighbors by carrying the fault tolerant (FT) session TLV in the LDP initialization message, assisting the LDP in preserving its IP forwarding state across the restart. Nokia's recovery is self-contained and relies on information stored internally to self-heal. This feature is only used to help third-party routers without a self-healing capability to recover.

Maximum recovery time is the time (in seconds) the sender of the TLV would like the receiver to wait, after detecting the failure of LDP communication with the sender.

Neighbor liveness time is the time (in seconds) the LSR is willing to retain its MPLS forwarding state. The time should be long enough to allow the neighboring LSRs to re-sync all the LSPs in a graceful manner, without creating congestion in the LDP control plane.

Use the commands in the following context to configure graceful-restart.

```
configure router ldp graceful-restart
```

3.27.3.4 Applying export and import policies

Both inbound and outbound label binding filtering are supported. Inbound filtering allows a route policy to control the label bindings an LSR accepts from its peers. An import policy can accept or reject label bindings received from LDP peers.

Label bindings can be filtered based on:

- neighbor (match on bindings received from the specified peer)
- prefix-list (match on bindings with the specified prefix/prefixes)

Outbound filtering allows a route policy to control the set of LDP label bindings advertised by the LSR. An export policy can control the set of LDP label bindings advertised by the router. By default, label bindings for only the system address are advertised and propagate all FECs that are received. All other local interface FECs can be advertised using policies.

Note: Static FECs cannot be blocked using an export policy.

Matches can be based on:

- all (all local subnets)
- match (match on bindings with the specified prefix/prefixes)

Use the commands in the following contexts to apply import and export policies.

```
configure router ldp export
configure router ldp import
```

The following example displays the export and import policy configuration.

Example: MD-CLI

```
[ex:/configure router "Base"]
A:admin@node-2# info
  ldp {
        import-policy ["LDP-import"]
        export-policy ["LDP-export"]
        fec-originate 192.168.2.1/32 {
            advertised-label 1000
            next-hop 10.10.1.2
        }
        fec-originate 192.168.1.1/32 {
            pop true
        }
    }
```

Example: classic CLI

```
A:node-2>config>router# info
#--------------------------------------------------
echo "LDP Configuration"
#--------------------------------------------------
        ldp
            export "LDP-export"
            import "LDP-import"
            fec-originate 192.168.1.1/32 pop
            fec-originate 192.168.2.1/32 advertised-label 1000 next-hop 10.10.1.2
            import-pmsi-routes
            exit
            tcp-session-parameters
            exit
            interface-parameters
            exit
            targeted-session
            exit
            no shutdown
        exit
```

3.27.3.5 Targeted session command options

Use the commands in the following context to specify **targeted-session** command options.

```
configure router ldp targeted-session
```

The following example displays an LDP configuration.

Example: MD-CLI

```
[ex:/configure router "Base" ldp]
A:admin@node-2# info
    targeted-session {
```

```
        ipv4 {
            hello {
                timeout 120
            }
            keepalive {
                timeout 120
                factor 3
            }
        }
        peer 10.10.10.104 {
            hello {
                timeout 240
                factor 3
            }
            keepalive {
                timeout 240
                factor 3
            }
        }
    }
```

Example: classic CLI

```
A:node-2>config>router>ldp# info
----------------------------------------------
...
            targeted-session
                ipv4
                    hello 120 3
                    keepalive 120 3
                exit
                peer 10.10.10.104
                    hello 240 3
                    keepalive 240 3
                exit
            exit
----------------------------------------------
```

3.27.3.6 Configuring the LDP interface

Use the commands in the following context to configure the interface.

```
configure router ldp interface-parameters
```

The following example displays an LDP interface configuration.

Example: MD-CLI

```
[ex:/configure router "Base" ldp]
A:admin@node-2# info
 ...
    interface-parameters {
        interface "to-DUT1" {
            ipv4 {
                hello {
                    timeout 240
                    factor 3
                }
                keepalive {
```

```
                    timeout 240
                    factor 3
                }
            }
        }
    }
```

Example: classic CLI

```
A:node-2>config>router>ldp# info
----------------------------------------------
 ...
            interface-parameters
                interface "to-DUT1" dual-stack
                    ipv4
                        hello 240 3
                        keepalive 240 3
                        no shutdown
                    exit
                    no shutdown
                exit
            exit
----------------------------------------------
```

3.27.3.7 Configuring the LDP session parameters

Use the commands in the following contexts to specify session parameters.

```
configure router ldp session-parameters
configure router ldp tcp-session-parameters
```

The following example displays an LDP session parameter configuration.

Example: MD-CLI

```
[ex:/configure router "Base" ldp]
A:admin@node-2# info
    session-parameters {
        peer 10.1.1.1 {
        }
        peer 10.10.10.104 {
        }
    }
    tcp-session-parameters {
        peer-transport 10.10.10.104 {
            authentication-key "McTNkSePNJMVFysxyZa4yw8iLZbb7ys= hash2"
        }
    }
```

Example: classic CLI

```
A:node-2>config>router>ldp# info
----------------------------------------------
            import-pmsi-routes
            exit
            session-parameters
```

```
                peer 10.1.1.1
                exit
                peer 10.10.10.104
                exit
            exit
            tcp-session-parameters
                peer-transport 10.10.10.104
                    authentication-key "McTNkSePNJMVFysxyZa4yw8iLZbb7ys=" hash2
                exit
            exit
            interface-parameters
            exit
            targeted-session
            exit
            no shutdown
-----------------------------------------------
```

3.27.3.8 LDP signaling and services

When LDP is enabled, targeted sessions can be established to create remote adjacencies with nodes that are not directly connected. When service distribution paths (SDPs) are configured, extended discovery mechanisms enable LDP to send periodic targeted hello messages to the SDP far-end point. The exchange of LDP hellos trigger session establishment. The SDP signaling default enables targeted LDP (T-LDP).

```
configure service sdp signaling tldp
```

The service SDP uses the targeted-session configured in the following context.

```
configure router ldp targeted-session
```

The SDP LDP and LSP commands are mutually exclusive; either one LSP can be specified or LDP can be enabled. If LDP is already enabled on an MPLS SDP, then an LSP cannot be specified on the SDP. If an LSP is specified on an MPLS SDP, then LDP cannot be enabled on the SDP.

For more information about configuring SDPs, see the *7450 ESS, 7750 SR, 7950 XRS, and VSR Services Overview Guide*.

Use the commands in the following contexts to configure LDP on an MPLS SDP.

```
configure service sdp ldp
configure service sdp signaling
```

The following example displays an SDP configuration showing the signaling default tldp enabled.

Example: MD-CLI

```
[ex:/configure service sdp 1]
A:admin@node-2# info detail
 ...
    description "MPLS: to-99"
    path-mtu 4462
    signaling tldp
    far-end {
        ip-address 10.10.10.99
    }
...
```

Example: classic CLI

In the classic CLI, you must remove the LSP from the configuration using the **no lsp lsp-name** command to enable LDP on the SDP when an LSP is already specified.

```
A:node-2>config>service>sdp# info detail
----------------------------------------------
...
            description "MPLS: to-99"
            far-end 10.10.10.99
            signaling tldp
            path-mtu 4462
...
           ----------------------------------------------
```

The following shows a working configuration of LDP over RSVP-TE (1) where tunnels look like the second example (2):

Example 1 — LDP over RSVP-TE

Example: MD-CLI

```
[ex:/configure router "Base" ldp]
A:admin@node-2# info
    prefer-tunnel-in-tunnel false
    interface-parameters {
        interface "LDP-test" {
        }
    }
    targeted-session {
        peer 10.51.0.1 {
            admin-state disable
            tunneling {
                lsp "to_P_1" { }
            }
        }
        peer 10.51.0.17 {
            admin-state disable
            tunneling {
                lsp "to_P_6" { }
            }
        }
    }
```

Example: classic CLI

```
A:node-2>config>router>ldp# info
----------------------------------------------
            prefer-tunnel-in-tunnel
            interface-parameters
                interface "port-1/1/3"
                exit
                interface "port-lag-1"
                exit
            exit
            targeted-session
                peer 10.51.0.1
                    shutdown
                    tunneling
```

```
                        lsp "to_P_1"
                    exit
                exit
                peer 10.51.0.17
                    shutdown
                    tunneling
                        lsp "to_P_6"
                    exit
                exit
            exit
-----------------------------------------------
```

Example 2 — Tunnels

Example: MD-CLI

```
[ex:/configure router "Base" interface "LDP-test" if-attribute]
A:admin@node-2# info
    admin-group ["1" "2"]

[ex:/configure router "Base" mpls]
A:admin@node-2# info
    admin-state enable
    resignal-timer 30
    path "dyn" {
        admin-state enable
    }
    lsp "to_P_1" {
        admin-state enable
        type p2p-rsvp
        to 10.51.0.1
        fast-reroute {
            frr-method facility
        }
        primary "dyn" {
        }
    }
    lsp "to_P_6" {
        admin-state enable
        type p2p-rsvp
        to 10.51.0.17
        fast-reroute {
            frr-method facility
        }
        primary "dyn" {
        }
    }
```

Example: classic CLI

```
A:node-2>config>router>if-attr# info
-----------------------------------------------

admin-group "lower" value 2
admin-group "upper" value 1
-----------------------------------------------
*A:ALA-1>config>router>mpls# info
-----------------------------------------------
            resignal-timer 30
            interface "system"
            exit
            interface "port-1/1/3"
```

```
            exit
            interface "port-lag-1"
            exit
            path "dyn"
                no shutdown
            exit
            lsp "to_P_1"
                to 10.51.0.1
                cspf
                fast-reroute facility
                exit
                primary "dyn"
                exit
                no shutdown
            exit
            lsp "to_P_6"
                to 10.51.0.17
                cspf
                fast-reroute facility
                exit
                primary "dyn"
                exit
                no shutdown
            exit
            no shutdown
-------------------------------------------
```

3.28 LDP configuration management tasks

This section discusses LDP configuration management tasks.

3.28.1 Disabling LDP

The following command disables the LDP protocol on the router. All command options revert to the default settings.

Use the following commands to disable LDP:

- **MD-CLI**

```
configure router ldp admin-state disable
```

- **classic CLI**
  In the classic CLI, LDP must be shut down before it can be disabled.

```
configure router ldp shutdown
configure router no ldp
```

3.28.2 Modifying targeted session command options

The modification of LDP targeted session command options does not take effect until the next time the session goes down and is re-established. Individual command options cannot be deleted. Different defaults can be configured for IPv4 and IPv6 LDP targeted Hello adjacencies.

The following example displays the default values.

Example: MD-CLI

```
[ex:/configure router "Base" ldp targeted-session]
A:admin@node-2# info detail
    sdp-auto-targeted-session true
 ## export-prefixes
 ## import-prefixes
    resolve-v6-prefix-over-shortcut false
    ipv4 {
        hello {
            timeout 45
            factor 3
        }
        keepalive {
            timeout 40
            factor 4
        }
        hello-reduction {
            admin-state disable
            factor 3
        }
    }
    ipv6 {
        hello {
            timeout 45
            factor 3
        }
        keepalive {
            timeout 40
            factor 4
        }
        hello-reduction {
            admin-state disable
            factor 3
        }
    }
 ## peer
 ...
```

Example: classic CLI

```
A:node-2>config>router>ldp>targ-session# info detail
----------------------------------------------
                no disable-targeted-session
                no import-prefixes
                no export-prefixes
                ipv4
                    no hello
                    no keepalive
                    no hello-reduction
                exit
                ipv6
                    no hello
                    no keepalive
                    no hello-reduction
                exit
                ...
----------------------------------------------
```

3.28.3 Modifying interface parameters

Individual parameters cannot be deleted. The modification of LDP targeted session parameters does not take effect until the next time the session goes down and is re-establishes.

The following example displays the default values.

Example: MD-CLI

```
!*[pr:/configure router "Base" ldp interface-parameters]
A:admin@node-2# info detail
    ipv4 {
        transport-address system
        hello {
            timeout 15
            factor 3
        }
        keepalive {
            timeout 30
            factor 3
        }
    }
    ipv6 {
        transport-address system
        hello {
            timeout 15
            factor 3
        }
        keepalive {
            timeout 30
            factor 3
        }
    }
    interface "LDP-test" {
     ## apply-groups
     ## apply-groups-exclude
        admin-state enable
     ## load-balancing-weight
        bfd-liveness {
            ipv4 false
            ipv6 false
        }
     ## ipv4
     ## ipv6
    }
```

Example: classic CLI

In the classic CLI, the **no** form of an **interface-parameters interface** command reverts modified values back to the defaults.

```
A:node-2>config>router>ldp>if-params>if$ info detail
----------------------------------------------
                    no bfd-enable
                    no load-balancing-weight
                    ipv4
                        no hello
                        no keepalive
                        no local-lsr-id
                        fec-type-capability
                            prefix-ipv4 enable
```

```
                            prefix-ipv6 enable
                            p2mp-ipv4 enable
                            p2mp-ipv6 enable
                        exit
                        no transport-address
                        no shutdown
                    exit
                    no shutdown
-----------------------------------------------
```

4 Standards and protocol support

Note:
The information provided in this chapter is subject to change without notice and may not apply to all platforms.

Nokia assumes no responsibility for inaccuracies.

4.1 Access Node Control Protocol (ANCP)

draft-ietf-ancp-protocol-02, *Protocol for Access Node Control Mechanism in Broadband Networks*

RFC 5851, *Framework and Requirements for an Access Node Control Mechanism in Broadband Multi-Service Networks*

4.2 Bidirectional Forwarding Detection (BFD)

draft-ietf-lsr-ospf-bfd-strict-mode-10, *OSPF BFD Strict-Mode*

RFC 5880, *Bidirectional Forwarding Detection (BFD)*

RFC 5881, *Bidirectional Forwarding Detection (BFD) IPv4 and IPv6 (Single Hop)*

RFC 5882, *Generic Application of Bidirectional Forwarding Detection (BFD)*

RFC 5883, *Bidirectional Forwarding Detection (BFD) for Multihop Paths*

RFC 7130, *Bidirectional Forwarding Detection (BFD) on Link Aggregation Group (LAG) Interfaces*

RFC 7880, *Seamless Bidirectional Forwarding Detection (S-BFD)*

RFC 7881, *Seamless Bidirectional Forwarding Detection (S-BFD) for IPv4, IPv6, and MPLS*

RFC 7883, *Advertising Seamless Bidirectional Forwarding Detection (S-BFD) Discriminators in IS-IS*

RFC 7884, *OSPF Extensions to Advertise Seamless Bidirectional Forwarding Detection (S-BFD) Target Discriminators*

RFC 9247, *BGP - Link State (BGP-LS) Extensions for Seamless Bidirectional Forwarding Detection (S-BFD)*

4.3 Border Gateway Protocol (BGP)

draft-gredler-idr-bgplu-epe-14, *Egress Peer Engineering using BGP-LU*

draft-hares-idr-update-attrib-low-bits-fix-01, *Update Attribute Flag Low Bits Clarification*

draft-ietf-idr-add-paths-guidelines-08, *Best Practices for Advertisement of Multiple Paths in IBGP*

draft-ietf-idr-best-external-03, *Advertisement of the best external route in BGP*

draft-ietf-idr-bgp-flowspec-oid-03, *Revised Validation Procedure for BGP Flow Specifications*

draft-ietf-idr-bgp-gr-notification-01, *Notification Message support for BGP Graceful Restart*

draft-ietf-idr-bgp-ls-app-specific-attr-16, *Application-Specific Attributes Advertisement with BGP Link-State*

draft-ietf-idr-bgp-ls-flex-algo-06, *Flexible Algorithm Definition Advertisement with BGP Link-State*

draft-ietf-idr-bgp-optimal-route-reflection-10, *BGP Optimal Route Reflection (BGP-ORR)*

draft-ietf-idr-error-handling-03, *Revised Error Handling for BGP UPDATE Messages*

draft-ietf-idr-flowspec-interfaceset-03, *Applying BGP flowspec rules on a specific interface set*

draft-ietf-idr-flowspec-path-redirect-05, *Flowspec Indirection-id Redirect* – localised ID

draft-ietf-idr-flowspec-redirect-ip-02, *BGP Flow-Spec Redirect to IP Action*

draft-ietf-idr-link-bandwidth-03, *BGP Link Bandwidth Extended Community*

draft-ietf-idr-long-lived-gr-00, *Support for Long-lived BGP Graceful Restart*

RFC 1772, *Application of the Border Gateway Protocol in the Internet*

RFC 1997, *BGP Communities Attribute*

RFC 2385, *Protection of BGP Sessions via the TCP MD5 Signature Option*

RFC 2439, *BGP Route Flap Damping*

RFC 2545, *Use of BGP-4 Multiprotocol Extensions for IPv6 Inter-Domain Routing*

RFC 2858, *Multiprotocol Extensions for BGP-4*

RFC 2918, *Route Refresh Capability for BGP-4*

RFC 4271, *A Border Gateway Protocol 4 (BGP-4)*

RFC 4360, *BGP Extended Communities Attribute*

RFC 4364, *BGP/MPLS IP Virtual Private Networks (VPNs)*

RFC 4456, *BGP Route Reflection: An Alternative to Full Mesh Internal BGP (IBGP)*

RFC 4486, *Subcodes for BGP Cease Notification Message*

RFC 4659, *BGP-MPLS IP Virtual Private Network (VPN) Extension for IPv6 VPN*

RFC 4684, *Constrained Route Distribution for Border Gateway Protocol/MultiProtocol Label Switching (BGP/MPLS) Internet Protocol (IP) Virtual Private Networks (VPNs)*

RFC 4724, *Graceful Restart Mechanism for BGP* – helper mode

RFC 4760, *Multiprotocol Extensions for BGP-4*

RFC 4798, *Connecting IPv6 Islands over IPv4 MPLS Using IPv6 Provider Edge Routers (6PE)*

RFC 5004, *Avoid BGP Best Path Transitions from One External to Another*

RFC 5065, *Autonomous System Confederations for BGP*

RFC 5291, *Outbound Route Filtering Capability for BGP-4*

RFC 5396, *Textual Representation of Autonomous System (AS) Numbers* – asplain

RFC 5492, *Capabilities Advertisement with BGP-4*

RFC 5668, *4-Octet AS Specific BGP Extended Community*

RFC 6286, *Autonomous-System-Wide Unique BGP Identifier for BGP-4*

RFC 6368, *Internal BGP as the Provider/Customer Edge Protocol for BGP/MPLS IP Virtual Private Networks (VPNs)*

RFC 6793, *BGP Support for Four-Octet Autonomous System (AS) Number Space*

RFC 6810, *The Resource Public Key Infrastructure (RPKI) to Router Protocol*

RFC 6811, *Prefix Origin Validation*

RFC 6996, *Autonomous System (AS) Reservation for Private Use*

RFC 7311, *The Accumulated IGP Metric Attribute for BGP*

RFC 7606, *Revised Error Handling for BGP UPDATE Messages*

RFC 7607, *Codification of AS 0 Processing*

RFC 7674, *Clarification of the Flowspec Redirect Extended Community*

RFC 7752, *North-Bound Distribution of Link-State and Traffic Engineering (TE) Information Using BGP*

RFC 7854, *BGP Monitoring Protocol (BMP)*

RFC 7911, *Advertisement of Multiple Paths in BGP*

RFC 7999, *BLACKHOLE Community*

RFC 8092, *BGP Large Communities Attribute*

RFC 8097, *BGP Prefix Origin Validation State Extended Community*

RFC 8212, *Default External BGP (EBGP) Route Propagation Behavior without Policies*

RFC 8277, *Using BGP to Bind MPLS Labels to Address Prefixes*

RFC 8571, *BGP - Link State (BGP-LS) Advertisement of IGP Traffic Engineering Performance Metric Extensions*

RFC 8950, *Advertising IPv4 Network Layer Reachability Information (NLRI) with an IPv6 Next Hop*

RFC 8955, *Dissemination of Flow Specification Rules*

RFC 8956, *Dissemination of Flow Specification Rules for IPv6*

RFC 9086, *Border Gateway Protocol - Link State (BGP-LS) Extensions for Segment Routing BGP Egress Peer Engineering*

4.4 Bridging and management

IEEE 802.1AB, *Station and Media Access Control Connectivity Discovery*

IEEE 802.1ad, *Provider Bridges*

IEEE 802.1ag, *Connectivity Fault Management*

IEEE 802.1ah, *Provider Backbone Bridges*

IEEE 802.1ak, *Multiple Registration Protocol*

IEEE 802.1aq, *Shortest Path Bridging*

IEEE 802.1AX, *Link Aggregation*

IEEE 802.1D, *MAC Bridges*

IEEE 802.1p, *Traffic Class Expediting*

IEEE 802.1Q, *Virtual LANs*

IEEE 802.1s, *Multiple Spanning Trees*

IEEE 802.1w, *Rapid Reconfiguration of Spanning Tree*

IEEE 802.1X, *Port Based Network Access Control*

4.5 Broadband Network Gateway (BNG) Control and User Plane Separation (CUPS)

3GPP TS 23.003, *Numbering, addressing and identification*

3GPP TS 23.007, *Restoration procedures*

3GPP TS 23.402, *Architecture enhancements for non-3GPP accesses* – S2a roaming based on GPRS

3GPP TS 23.501, *System architecture for the 5G System (5GS)*

3GPP TS 23.502, *Procedures for the 5G System (5GS)*

3GPP TS 23.503, *Policy and charging control framework for the 5G System (5GS)*

3GPP TS 24.501, *Non-Access-Stratum (NAS) protocol for 5G System (5GS)*

3GPP TS 29.244, *Interface between the Control Plane and the User Plane nodes*

3GPP TS 29.281, *General Packet Radio System (GPRS) Tunnelling Protocol User Plane (GTPv1-U)*

3GPP TS 29.500, *Technical Realization of Service Based Architecture*

3GPP TS 29.501, *Principles and Guidelines for Services Definition*

3GPP TS 29.502, *Session Management Services*

3GPP TS 29.503, *Unified Data Management Services*

3GPP TS 29.512, *Session Management Policy Control Service*

3GPP TS 29.518, *Access and Mobility Management Services*

3GPP TS 32.255, *5G data connectivity domain charging*

3GPP TS 32.290, *Services, operations and procedures of charging using Service Based Interface (SBI)*

3GPP TS 32.291, *5G system, charging service*

BBF TR-459, *Control and User Plane Separation for a Disaggregated BNG*

BBF TR-459.2, *Multi-Service Disaggregated BNG with CUPS: Integrated Carrier Grade NAT function*

RFC 8300, *Network Service Header (NSH)*

RFC 8910, *Captive-Portal Identification in DHCP and Router Advertisements (RAs)*

4.6 Certificate management

RFC 4210, *Internet X.509 Public Key Infrastructure Certificate Management Protocol (CMP)*

RFC 4211, *Internet X.509 Public Key Infrastructure Certificate Request Message Format (CRMF)*

RFC 5280, *Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile*

RFC 6712, *Internet X.509 Public Key Infrastructure -- HTTP Transfer for the Certificate Management Protocol (CMP)*

RFC 7030, *Enrollment over Secure Transport*

RFC 7468, *Textual Encodings of PKIX, PKCS, and CMS Structures*

4.7 Circuit emulation

RFC 4553, *Structure-Agnostic Time Division Multiplexing (TDM) over Packet (SAToP)*

RFC 5086, *Structure-Aware Time Division Multiplexed (TDM) Circuit Emulation Service over Packet Switched Network (CESoPSN)*

RFC 5287, *Control Protocol Extensions for the Setup of Time-Division Multiplexing (TDM) Pseudowires in MPLS Networks*

4.8 Ethernet

IEEE 802.3ah, *Media Access Control Parameters, Physical Layers, and Management Parameters for Subscriber Access Networks*

IEEE 802.3x, *Ethernet Flow Control*

ITU-T G.8031/Y.1342, *Ethernet Linear Protection Switching*

ITU-T G.8032/Y.1344, *Ethernet Ring Protection Switching*

ITU-T Y.1731, *OAM functions and mechanisms for Ethernet based networks*

4.9 Ethernet VPN (EVPN)

draft-ietf-bess-bgp-srv6-args-00, *SRv6 Argument Signaling for BGP Services*

draft-ietf-bess-evpn-ip-aliasing-00, *EVPN Support for L3 Fast Convergence and Aliasing/Backup Path* – IP Prefix routes

draft-ietf-bess-evpn-ipvpn-interworking-06, *EVPN Interworking with IPVPN*

draft-ietf-bess-evpn-irb-mcast-09, *EVPN Optimized Inter-Subnet Multicast (OISM) Forwarding* – ingress replication and mLDP

draft-ietf-bess-evpn-pref-df-06, *Preference-based EVPN DF Election*

draft-ietf-bess-evpn-unequal-lb-16, *Weighted Multi-Path Procedures for EVPN Multi-Homing* – section 9

draft-ietf-bess-evpn-virtual-eth-segment-06, *EVPN Virtual Ethernet Segment*

draft-ietf-bess-pbb-evpn-isid-cmacflush-00, *PBB-EVPN ISID-based CMAC-Flush*

draft-sr-bess-evpn-vpws-gateway-03, *Ethernet VPN Virtual Private Wire Services Gateway Solution*

RFC 7432, *BGP MPLS-Based Ethernet VPN*

RFC 7623, *Provider Backbone Bridging Combined with Ethernet VPN (PBB-EVPN)*

RFC 8214, *Virtual Private Wire Service Support in Ethernet VPN*

RFC 8317, *Ethernet-Tree (E-Tree) Support in Ethernet VPN (EVPN) an Provider Backbone Bridging EVPN (PBB-EVPN)*

RFC 8365, *A Network Virtualization Overlay Solution Using Ethernet VPN (EVPN)*

RFC 8560, *Seamless Integration of Ethernet VPN (EVPN) with Virtual Private LAN Service (VPLS) and Their Provider Backbone Bridge (PBB) Equivalents*

RFC 8584, *DF Election and AC-influenced DF Election*

RFC 9047, *Propagation of ARP/ND Flags in an Ethernet Virtual Private Network (EVPN)*

RFC 9135, *Integrated Routing and Bridging in Ethernet VPN (EVPN)* – Asymmetric IRB Procedures and Mobility Procedure

RFC 9136, *IP Prefix Advertisement in Ethernet VPN (EVPN)*

RFC 9161, *Operational Aspects of Proxy ARP/ND in Ethernet Virtual Private Networks*

RFC 9251, *Internet Group Management Protocol (IGMP) and Multicast Listener Discovery (MLD) Proxies for Ethernet VPN (EVPN)*

4.10 gRPC Remote Procedure Calls (gRPC)

cert.proto version 0.1.0, *gRPC Network Operations Interface (gNOI) Certificate Management Service*

file.proto version 0.1.0, *gRPC Network Operations Interface (gNOI) File Service*

gnmi.proto version 0.8.0, *gRPC Network Management Interface (gNMI) Service Specification*

PROTOCOL-HTTP2, *gRPC over HTTP2*

system.proto Version 1.0.0, *gRPC Network Operations Interface (gNOI) System Service*

4.11 Intermediate System to Intermediate System (IS-IS)

draft-ietf-isis-mi-02, *IS-IS Multi-Instance*

draft-ietf-lsr-igp-ureach-prefix-announce-01, *IGP Unreachable Prefix Announcement* – without U-Flag and UP-Flag

draft-kaplan-isis-ext-eth-02, *Extended Ethernet Frame Size Support*

ISO/IEC 10589:2002 Second Edition, *Intermediate system to Intermediate system intra-domain routeing information exchange protocol for use in conjunction with the protocol for providing the connectionless-mode Network Service (ISO 8473)*

RFC 1195, *Use of OSI IS-IS for Routing in TCP/IP and Dual Environments*

RFC 2973, *IS-IS Mesh Groups*

RFC 3359, *Reserved Type, Length and Value (TLV) Codepoints in Intermediate System to Intermediate System*

RFC 3719, *Recommendations for Interoperable Networks using Intermediate System to Intermediate System (IS-IS)*

RFC 3787, *Recommendations for Interoperable IP Networks using Intermediate System to Intermediate System (IS-IS)*

RFC 5120, *M-ISIS: Multi Topology (MT) Routing in IS-IS*

RFC 5130, *A Policy Control Mechanism in IS-IS Using Administrative Tags*

RFC 5301, *Dynamic Hostname Exchange Mechanism for IS-IS*

RFC 5302, *Domain-wide Prefix Distribution with Two-Level IS-IS*

RFC 5303, *Three-Way Handshake for IS-IS Point-to-Point Adjacencies*

RFC 5304, *IS-IS Cryptographic Authentication*

RFC 5305, *IS-IS Extensions for Traffic Engineering TE*

RFC 5306, *Restart Signaling for IS-IS* – helper mode

RFC 5308, *Routing IPv6 with IS-IS*

RFC 5309, *Point-to-Point Operation over LAN in Link State Routing Protocols*

RFC 5310, *IS-IS Generic Cryptographic Authentication*

RFC 6119, *IPv6 Traffic Engineering in IS-IS*

RFC 6213, *IS-IS BFD-Enabled TLV*

RFC 6232, *Purge Originator Identification TLV for IS-IS*

RFC 6233, *IS-IS Registry Extension for Purges*

RFC 6329, *IS-IS Extensions Supporting IEEE 802.1aq Shortest Path Bridging*

RFC 7775, *IS-IS Route Preference for Extended IP and IPv6 Reachability*

RFC 7794, *IS-IS Prefix Attributes for Extended IPv4 and IPv6 Reachability* – sections 2.1 and 2.3

RFC 7981, *IS-IS Extensions for Advertising Router Information*

RFC 7987, *IS-IS Minimum Remaining Lifetime*

RFC 8202, *IS-IS Multi-Instance* – single topology

RFC 8570, *IS-IS Traffic Engineering (TE) Metric Extensions* – Min/Max Unidirectional Link Delay metric for flex-algo, RSVP, SR-TE

RFC 8919, *IS-IS Application-Specific Link Attributes*

4.12 Internet Protocol (IP) Fast Reroute (FRR)

draft-ietf-rtgwg-lfa-manageability-08, *Operational management of Loop Free Alternates*

RFC 5286, *Basic Specification for IP Fast Reroute: Loop-Free Alternates*

RFC 7431, *Multicast-Only Fast Reroute*

RFC 7490, *Remote Loop-Free Alternate (LFA) Fast Reroute (FRR)*

RFC 8518, *Selection of Loop-Free Alternates for Multi-Homed Prefixes*

4.13 Internet Protocol (IP) general

draft-grant-tacacs-02, *The TACACS+ Protocol*

RFC 768, *User Datagram Protocol*

RFC 793, *Transmission Control Protocol*

RFC 854, *Telnet Protocol Specifications*

RFC 1350, *The TFTP Protocol (revision 2)*

RFC 2347, *TFTP Option Extension*

RFC 2348, *TFTP Blocksize Option*

RFC 2349, *TFTP Timeout Interval and Transfer Size Options*

RFC 2428, *FTP Extensions for IPv6 and NATs*

RFC 2617, *HTTP Authentication: Basic and Digest Access Authentication*

RFC 2784, *Generic Routing Encapsulation (GRE)*

RFC 2818, *HTTP Over TLS*

RFC 2890, *Key and Sequence Number Extensions to GRE*

RFC 3164, *The BSD syslog Protocol*

RFC 4250, *The Secure Shell (SSH) Protocol Assigned Numbers*

RFC 4251, *The Secure Shell (SSH) Protocol Architecture*

RFC 4252, *The Secure Shell (SSH) Authentication Protocol* – publickey, password

RFC 4253, *The Secure Shell (SSH) Transport Layer Protocol*

RFC 4254, *The Secure Shell (SSH) Connection Protocol*

RFC 4511, *Lightweight Directory Access Protocol (LDAP): The Protocol*

RFC 4513, *Lightweight Directory Access Protocol (LDAP): Authentication Methods and Security Mechanisms* – TLS

RFC 4632, *Classless Inter-domain Routing (CIDR): The Internet Address Assignment and Aggregation Plan*

RFC 5082, *The Generalized TTL Security Mechanism (GTSM)*

RFC 5246, *The Transport Layer Security (TLS) Protocol Version 1.2* – TLS client, RSA public key

RFC 5425, *Transport Layer Security (TLS) Transport Mapping for Syslog* – RFC 3164 with TLS

RFC 5656, *Elliptic Curve Algorithm Integration in the Secure Shell Transport Layer* – ECDSA

RFC 5925, *The TCP Authentication Option*

RFC 5926, *Cryptographic Algorithms for the TCP Authentication Option (TCP-AO)*

RFC 6398, *IP Router Alert Considerations and Usage* – MLD

RFC 6528, *Defending against Sequence Number Attacks*

RFC 7011, *Specification of the IP Flow Information Export (IPFIX) Protocol for the Exchange of Flow Information*

RFC 7012, *Information Model for IP Flow Information Export*

RFC 7230, *Hypertext Transfer Protocol (HTTP/1.1): Message Syntax and Routing*

RFC 7231, *Hypertext Transfer Protocol (HTTP/1.1): Semantics and Content*

RFC 7232, *Hypertext Transfer Protocol (HTTP/1.1): Conditional Requests*

RFC 7301, *Transport Layer Security (TLS) Application Layer Protocol Negotiation Extension*

RFC 7616, *HTTP Digest Access Authentication*

RFC 8446, *The Transport Layer Security (TLS) Protocol Version 1.3*

4.14 Internet Protocol (IP) multicast

cisco-ipmulticast/pim-autorp-spec01, *Auto-RP: Automatic discovery of Group-to-RP mappings for IP multicast* – version 1

draft-ietf-bier-pim-signaling-08, *PIM Signaling Through BIER Core*

draft-ietf-idmr-traceroute-ipm-07, *A "traceroute" facility for IP Multicast*

draft-ietf-l2vpn-vpls-pim-snooping-07, *Protocol Independent Multicast (PIM) over Virtual Private LAN Service (VPLS)*

RFC 1112, *Host Extensions for IP Multicasting*

RFC 2236, *Internet Group Management Protocol, Version 2*

RFC 2365, *Administratively Scoped IP Multicast*

RFC 2375, *IPv6 Multicast Address Assignments*

RFC 2710, *Multicast Listener Discovery (MLD) for IPv6*

RFC 3306, *Unicast-Prefix-based IPv6 Multicast Addresses*

RFC 3376, *Internet Group Management Protocol, Version 3*

RFC 3446, *Anycast Rendevous Point (RP) mechanism using Protocol Independent Multicast (PIM) and Multicast Source Discovery Protocol (MSDP)*

RFC 3590, *Source Address Selection for the Multicast Listener Discovery (MLD) Protocol*

RFC 3618, *Multicast Source Discovery Protocol (MSDP)*

RFC 3810, *Multicast Listener Discovery Version 2 (MLDv2) for IPv6*

RFC 3956, *Embedding the Rendezvous Point (RP) Address in an IPv6 Multicast Address*

RFC 3973, *Protocol Independent Multicast - Dense Mode (PIM-DM): Protocol Specification (Revised)* – auto-RP groups

RFC 4541, *Considerations for Internet Group Management Protocol (IGMP) and Multicast Listener Discovery (MLD) Snooping Switches*

RFC 4604, *Using Internet Group Management Protocol Version 3 (IGMPv3) and Multicast Listener Discovery Protocol Version 2 (MLDv2) for Source-Specific Multicast*

RFC 4607, *Source-Specific Multicast for IP*

RFC 4608, *Source-Specific Protocol Independent Multicast in 232/8*

RFC 4610, *Anycast-RP Using Protocol Independent Multicast (PIM)*

RFC 4611, *Multicast Source Discovery Protocol (MSDP) Deployment Scenarios*

RFC 5059, *Bootstrap Router (BSR) Mechanism for Protocol Independent Multicast (PIM)*

RFC 5186, *Internet Group Management Protocol Version 3 (IGMPv3) / Multicast Listener Discovery Version 2 (MLDv2) and Multicast Routing Protocol Interaction*

RFC 5384, *The Protocol Independent Multicast (PIM) Join Attribute Format*

RFC 5496, *The Reverse Path Forwarding (RPF) Vector TLV*

RFC 6037, *Cisco Systems' Solution for Multicast in MPLS/BGP IP VPNs*

RFC 6512, *Using Multipoint LDP When the Backbone Has No Route to the Root*

RFC 6513, *Multicast in MPLS/BGP IP VPNs*

RFC 6514, *BGP Encodings and Procedures for Multicast in MPLS/IP VPNs*

RFC 6515, *IPv4 and IPv6 Infrastructure Addresses in BGP Updates for Multicast VPNs*

RFC 6516, *IPv6 Multicast VPN (MVPN) Support Using PIM Control Plane and Selective Provider Multicast Service Interface (S-PMSI) Join Messages*

RFC 6625, *Wildcards in Multicast VPN Auto-Discover Routes*

RFC 6826, *Multipoint LDP In-Band Signaling for Point-to-Multipoint and Multipoint-to-Multipoint Label Switched Path*

RFC 7246, *Multipoint Label Distribution Protocol In-Band Signaling in a Virtual Routing and Forwarding (VRF) Table Context*

RFC 7385, *IANA Registry for P-Multicast Service Interface (PMSI) Tunnel Type Code Points*

RFC 7716, *Global Table Multicast with BGP Multicast VPN (BGP-MVPN) Procedures*

RFC 7761, *Protocol Independent Multicast - Sparse Mode (PIM-SM): Protocol Specification (Revised)*

RFC 8279, *Multicast Using Bit Index Explicit Replication (BIER)*

RFC 8296, *Encapsulation for Bit Index Explicit Replication (BIER) in MPLS and Non-MPLS Networks* – MPLS encapsulation

RFC 8401, *Bit Index Explicit Replication (BIER) Support via IS-IS*

RFC 8444, *OSPFv2 Extensions for Bit Index Explicit Replication (BIER)*

RFC 8487, *Mtrace Version 2: Traceroute Facility for IP Multicast*

RFC 8534, *Explicit Tracking with Wildcard Routes in Multicast VPN* – (C-*,C-*) wildcard

RFC 8556, *Multicast VPN Using Bit Index Explicit Replication (BIER)*

4.15 Internet Protocol (IP) version 4

RFC 791, *Internet Protocol*

RFC 792, *Internet Control Message Protocol*

RFC 826, *An Ethernet Address Resolution Protocol*

RFC 951, *Bootstrap Protocol (BOOTP)* – relay

RFC 1034, *Domain Names - Concepts and Facilities*

RFC 1035, *Domain Names - Implementation and Specification*

RFC 1191, *Path MTU Discovery* – router specification

RFC 1519, *Classless Inter-Domain Routing (CIDR): an Address Assignment and Aggregation Strategy*

RFC 1534, *Interoperation between DHCP and BOOTP*

RFC 1542, *Clarifications and Extensions for the Bootstrap Protocol*

RFC 1812, *Requirements for IPv4 Routers*

RFC 1918, *Address Allocation for Private Internets*

RFC 2003, *IP Encapsulation within IP*

RFC 2131, *Dynamic Host Configuration Protocol*

RFC 2132, *DHCP Options and BOOTP Vendor Extensions*

RFC 2401, *Security Architecture for Internet Protocol*

RFC 3021, *Using 31-Bit Prefixes on IPv4 Point-to-Point Links*

RFC 3046, *DHCP Relay Agent Information Option (Option 82)*

RFC 3768, *Virtual Router Redundancy Protocol (VRRP)*

RFC 4884, *Extended ICMP to Support Multi-Part Messages* – ICMPv4 and ICMPv6 Time Exceeded

4.16 Internet Protocol (IP) version 6

RFC 2464, *Transmission of IPv6 Packets over Ethernet Networks*

RFC 2529, *Transmission of IPv6 over IPv4 Domains without Explicit Tunnels*

RFC 3122, *Extensions to IPv6 Neighbor Discovery for Inverse Discovery Specification*

RFC 3315, *Dynamic Host Configuration Protocol for IPv6 (DHCPv6)*

RFC 3587, *IPv6 Global Unicast Address Format*

RFC 3596, *DNS Extensions to Support IP version 6*

RFC 3633, *IPv6 Prefix Options for Dynamic Host Configuration Protocol (DHCP) version 6*

RFC 3646, *DNS Configuration options for Dynamic Host Configuration Protocol for IPv6 (DHCPv6)*

RFC 3736, *Stateless Dynamic Host Configuration Protocol (DHCP) Service for IPv6*

RFC 3971, *SEcure Neighbor Discovery (SEND)*

RFC 3972, *Cryptographically Generated Addresses (CGA)*

RFC 4007, *IPv6 Scoped Address Architecture*

RFC 4191, *Default Router Preferences and More-Specific Routes* – Default Router Preference

RFC 4193, *Unique Local IPv6 Unicast Addresses*

RFC 4291, *Internet Protocol Version 6 (IPv6) Addressing Architecture*

RFC 4443, *Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6) Specification*

RFC 4861, *Neighbor Discovery for IP version 6 (IPv6)*

RFC 4862, *IPv6 Stateless Address Autoconfiguration* – router functions

RFC 4890, *Recommendations for Filtering ICMPv6 Messages in Firewalls*

RFC 4941, *Privacy Extensions for Stateless Address Autoconfiguration in IPv6*

RFC 5007, *DHCPv6 Leasequery*

RFC 5095, *Deprecation of Type 0 Routing Headers in IPv6*

RFC 5722, *Handling of Overlapping IPv6 Fragments*

RFC 5798, *Virtual Router Redundancy Protocol (VRRP) Version 3 for IPv4 and IPv6* – IPv6

RFC 5952, *A Recommendation for IPv6 Address Text Representation*

RFC 6092, *Recommended Simple Security Capabilities in Customer Premises Equipment (CPE) for Providing Residential IPv6 Internet Service* – Internet Control and Management, Upper-Layer Transport Protocols, UDP Filters, IPsec and Internet Key Exchange (IKE), TCP Filters

RFC 6106, *IPv6 Router Advertisement Options for DNS Configuration*

RFC 6164, *Using 127-Bit IPv6 Prefixes on Inter-Router Links*

RFC 6221, *Lightweight DHCPv6 Relay Agent*

RFC 6437, *IPv6 Flow Label Specification*

RFC 6603, *Prefix Exclude Option for DHCPv6-based Prefix Delegation*

RFC 8021, *Generation of IPv6 Atomic Fragments Considered Harmful*

RFC 8200, *Internet Protocol, Version 6 (IPv6) Specification*

RFC 8201, *Path MTU Discovery for IP version 6*

4.17 Internet Protocol Security (IPsec)

draft-ietf-ipsec-isakmp-mode-cfg-05, *The ISAKMP Configuration Method*

draft-ietf-ipsec-isakmp-xauth-06, *Extended Authentication within ISAKMP/Oakley (XAUTH)*

RFC 2401, *Security Architecture for the Internet Protocol*

RFC 2403, *The Use of HMAC-MD5-96 within ESP and AH*

RFC 2404, *The Use of HMAC-SHA-1-96 within ESP and AH*

RFC 2405, *The ESP DES-CBC Cipher Algorithm With Explicit IV*

RFC 2406, *IP Encapsulating Security Payload (ESP)*

RFC 2407, *IPsec Domain of Interpretation for ISAKMP (IPsec DoI)*

RFC 2408, *Internet Security Association and Key Management Protocol (ISAKMP)*

RFC 2409, *The Internet Key Exchange (IKE)*

RFC 2410, *The NULL Encryption Algorithm and Its Use With IPsec*

RFC 2560, *X.509 Internet Public Key Infrastructure Online Certificate Status Protocol - OCSP*

RFC 3526, *More Modular Exponential (MODP) Diffie-Hellman group for Internet Key Exchange (IKE)*

RFC 3566, *The AES-XCBC-MAC-96 Algorithm and Its Use With IPsec*

RFC 3602, *The AES-CBC Cipher Algorithm and Its Use with IPsec*

RFC 3706, *A Traffic-Based Method of Detecting Dead Internet Key Exchange (IKE) Peers*

RFC 3947, *Negotiation of NAT-Traversal in the IKE*

RFC 3948, *UDP Encapsulation of IPsec ESP Packets*

RFC 4106, *The Use of Galois/Counter Mode (GCM) in IPsec ESP*

RFC 4109, *Algorithms for Internet Key Exchange version 1 (IKEv1)*

RFC 4301, *Security Architecture for the Internet Protocol*

RFC 4303, *IP Encapsulating Security Payload*

RFC 4307, *Cryptographic Algorithms for Use in the Internet Key Exchange Version 2 (IKEv2)*

RFC 4308, *Cryptographic Suites for IPsec*

RFC 4434, *The AES-XCBC-PRF-128 Algorithm for the Internet Key Exchange Protocol (IKE)*

RFC 4543, *The Use of Galois Message Authentication Code (GMAC) in IPsec ESP and AH*

RFC 4754, *IKE and IKEv2 Authentication Using the Elliptic Curve Digital Signature Algorithm (ECDSA)*

RFC 4835, *Cryptographic Algorithm Implementation Requirements for Encapsulating Security Payload (ESP) and Authentication Header (AH)*

RFC 4868, *Using HMAC-SHA-256, HMAC-SHA-384, and HMAC-SHA-512 with IPsec*

RFC 4945, *The Internet IP Security PKI Profile of IKEv1/ISAKMP, IKEv2 and PKIX*

RFC 5019, *The Lightweight Online Certificate Status Protocol (OCSP) Profile for High-Volume Environments*

RFC 5282, *Using Authenticated Encryption Algorithms with the Encrypted Payload of the IKEv2 Protocol*

RFC 5903, *ECP Groups for IKE and IKEv2*

RFC 5996, *Internet Key Exchange Protocol Version 2 (IKEv2)*

RFC 5998, *An Extension for EAP-Only Authentication in IKEv2*

RFC 6379, *Suite B Cryptographic Suites for IPsec*

RFC 6380, *Suite B Profile for Internet Protocol Security (IPsec)*

RFC 6960, *X.509 Internet Public Key Infrastructure Online Certificate Status Protocol - OCSP*

RFC 7296, *Internet Key Exchange Protocol Version 2 (IKEv2)*

RFC 7321, *Cryptographic Algorithm Implementation Requirements and Usage Guidance for Encapsulating Security Payload (ESP) and Authentication Header (AH)*

RFC 7383, *Internet Key Exchange Protocol Version 2 (IKEv2) Message Fragmentation*

RFC 7427, *Signature Authentication in the Internet Key Exchange Version 2 (IKEv2)*

4.18 Label Distribution Protocol (LDP)

draft-pdutta-mpls-ldp-adj-capability-00, *LDP Adjacency Capabilities*

draft-pdutta-mpls-ldp-v2-00, *LDP Version 2*

draft-pdutta-mpls-mldp-up-redundancy-00, *Upstream LSR Redundancy for Multi-point LDP Tunnels*

draft-pdutta-mpls-multi-ldp-instance-00, *Multiple LDP Instances*

draft-pdutta-mpls-tldp-hello-reduce-04, *Targeted LDP Hello Reduction*

RFC 3037, *LDP Applicability*

RFC 3478, *Graceful Restart Mechanism for Label Distribution Protocol* – helper mode

RFC 5036, *LDP Specification*

RFC 5283, *LDP Extension for Inter-Area Label Switched Paths (LSPs)*

RFC 5443, *LDP IGP Synchronization*

RFC 5561, *LDP Capabilities*

RFC 5919, *Signaling LDP Label Advertisement Completion*

RFC 6388, *Label Distribution Protocol Extensions for Point-to-Multipoint and Multipoint-to-Multipoint Label Switched Paths*

RFC 6512, *Using Multipoint LDP When the Backbone Has No Route to the Root*

RFC 6826, *Multipoint LDP in-band signaling for Point-to-Multipoint and Multipoint-to-Multipoint Label Switched Paths*

RFC 7032, *LDP Downstream-on-Demand in Seamless MPLS*

RFC 7473, *Controlling State Advertisements of Non-negotiated LDP Applications*

RFC 7552, *Updates to LDP for IPv6*

4.19 Layer Two Tunneling Protocol (L2TP) Network Server (LNS)

draft-mammoliti-l2tp-accessline-avp-04, *Layer 2 Tunneling Protocol (L2TP) Access Line Information Attribute Value Pair (AVP) Extensions*

RFC 2661, *Layer Two Tunneling Protocol "L2TP"*

RFC 2809, *Implementation of L2TP Compulsory Tunneling via RADIUS*

RFC 3438, *Layer Two Tunneling Protocol (L2TP) Internet Assigned Numbers: Internet Assigned Numbers Authority (IANA) Considerations Update*

RFC 3931, *Layer Two Tunneling Protocol - Version 3 (L2TPv3)*

RFC 4719, *Transport of Ethernet Frames over Layer 2 Tunneling Protocol Version 3 (L2TPv3)*

RFC 4951, *Fail Over Extensions for Layer 2 Tunneling Protocol (L2TP) "failover"*

4.20 Multiprotocol Label Switching (MPLS)

draft-ietf-mpls-lsp-ping-ospfv3-codepoint-02, *OSPFv3 CodePoint for MPLS LSP Ping*

RFC 3031, *Multiprotocol Label Switching Architecture*

RFC 3032, *MPLS Label Stack Encoding*

RFC 3270, *Multi-Protocol Label Switching (MPLS) Support of Differentiated Services* – E-LSP

RFC 3443, *Time To Live (TTL) Processing in Multi-Protocol Label Switching (MPLS) Networks*

RFC 4023, *Encapsulating MPLS in IP or Generic Routing Encapsulation (GRE)*

RFC 4182, *Removing a Restriction on the use of MPLS Explicit NULL*

RFC 4950, *ICMP Extensions for Multiprotocol Label Switching*

RFC 5332, *MPLS Multicast Encapsulations*

RFC 5884, *Bidirectional Forwarding Detection (BFD) for MPLS Label Switched Paths (LSPs)*

RFC 6374, *Packet Loss and Delay Measurement for MPLS Networks* – Delay Measurement, Channel Type 0x000C

RFC 6424, *Mechanism for Performing Label Switched Path Ping (LSP Ping) over MPLS Tunnels*

RFC 6425, *Detecting Data Plane Failures in Point-to-Multipoint Multiprotocol Label Switching (MPLS) - Extensions to LSP Ping*

RFC 6790, *The Use of Entropy Labels in MPLS Forwarding*

RFC 7308, *Extended Administrative Groups in MPLS Traffic Engineering (MPLS-TE)*

RFC 7510, *Encapsulating MPLS in UDP*

RFC 7746, *Label Switched Path (LSP) Self-Ping*

RFC 7876, *UDP Return Path for Packet Loss and Delay Measurement for MPLS Networks* – Delay Measurement

RFC 8029, *Detecting Multiprotocol Label Switched (MPLS) Data-Plane Failures*

4.21 Multiprotocol Label Switching - Transport Profile (MPLS-TP)

RFC 5586, *MPLS Generic Associated Channel*

RFC 5921, *A Framework for MPLS in Transport Networks*

RFC 5960, *MPLS Transport Profile Data Plane Architecture*

RFC 6370, *MPLS Transport Profile (MPLS-TP) Identifiers*

RFC 6378, *MPLS Transport Profile (MPLS-TP) Linear Protection*

RFC 6426, *MPLS On-Demand Connectivity and Route Tracing*

RFC 6427, *MPLS Fault Management Operations, Administration, and Maintenance (OAM)*

RFC 6428, *Proactive Connectivity Verification, Continuity Check and Remote Defect indication for MPLS Transport Profile*

RFC 6478, *Pseudowire Status for Static Pseudowires*

RFC 7213, *MPLS Transport Profile (MPLS-TP) Next-Hop Ethernet Addressing*

4.22 Network Address Translation (NAT)

draft-ietf-behave-address-format-10, *IPv6 Addressing of IPv4/IPv6 Translators*

draft-ietf-behave-v6v4-xlate-23, *IP/ICMP Translation Algorithm*

draft-miles-behave-l2nat-00, *Layer2-Aware NAT*

draft-nishitani-cgn-02, *Common Functions of Large Scale NAT (LSN)*

RFC 4787, *Network Address Translation (NAT) Behavioral Requirements for Unicast UDP*

RFC 5382, *NAT Behavioral Requirements for TCP*

RFC 5508, *NAT Behavioral Requirements for ICMP*

RFC 6146, *Stateful NAT64: Network Address and Protocol Translation from IPv6 Clients to IPv4 Servers*

RFC 6333, *Dual-Stack Lite Broadband Deployments Following IPv4 Exhaustion*

RFC 6334, *Dynamic Host Configuration Protocol for IPv6 (DHCPv6) Option for Dual-Stack Lite*

RFC 6887, *Port Control Protocol (PCP)*

RFC 6888, *Common Requirements For Carrier-Grade NATs (CGNs)*

RFC 7753, *Port Control Protocol (PCP) Extension for Port-Set Allocation*

RFC 7915, *IP/ICMP Translation Algorithm*

4.23 Network Configuration Protocol (NETCONF)

RFC 5277, *NETCONF Event Notifications*

RFC 6020, *YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF)*

RFC 6022, *YANG Module for NETCONF Monitoring*

RFC 6241, *Network Configuration Protocol (NETCONF)*

RFC 6242, *Using the NETCONF Protocol over Secure Shell (SSH)*

RFC 6243, *With-defaults Capability for NETCONF*

RFC 8342, *Network Management Datastore Architecture (NMDA)* – Startup, Candidate, Running and Intended datastores

RFC 8525, *YANG Library*

RFC 8526, *NETCONF Extensions to Support the Network Management Datastore Architecture* – <get-data> operation

4.24 Open Shortest Path First (OSPF)

RFC 1765, *OSPF Database Overflow*

RFC 2328, *OSPF Version 2*

RFC 3101, *The OSPF Not-So-Stubby Area (NSSA) Option*

RFC 3509, *Alternative Implementations of OSPF Area Border Routers*

RFC 3623, *Graceful OSPF Restart Graceful OSPF Restart* – helper mode

RFC 3630, *Traffic Engineering (TE) Extensions to OSPF Version 2*

RFC 4222, *Prioritized Treatment of Specific OSPF Version 2 Packets and Congestion Avoidance*

RFC 4552, *Authentication/Confidentiality for OSPFv3*

RFC 4576, *Using a Link State Advertisement (LSA) Options Bit to Prevent Looping in BGP/MPLS IP Virtual Private Networks (VPNs)*

RFC 4577, *OSPF as the Provider/Customer Edge Protocol for BGP/MPLS IP Virtual Private Networks (VPNs)*

RFC 5185, *OSPF Multi-Area Adjacency*

RFC 5187, *OSPFv3 Graceful Restart* – helper mode

RFC 5243, *OSPF Database Exchange Summary List Optimization*

RFC 5250, *The OSPF Opaque LSA Option*

RFC 5309, *Point-to-Point Operation over LAN in Link State Routing Protocols*

RFC 5340, *OSPF for IPv6*

RFC 5642, *Dynamic Hostname Exchange Mechanism for OSPF*

RFC 5709, *OSPFv2 HMAC-SHA Cryptographic Authentication*

RFC 5838, *Support of Address Families in OSPFv3*

RFC 6549, *OSPFv2 Multi-Instance Extensions*

RFC 6987, *OSPF Stub Router Advertisement*

RFC 7471, *OSPF Traffic Engineering (TE) Metric Extensions* – Min/Max Unidirectional Link Delay metric for flex-algo, RSVP, SR-TE

RFC 7684, *OSPFv2 Prefix/Link Attribute Advertisement*

RFC 7770, *Extensions to OSPF for Advertising Optional Router Capabilities*

RFC 8362, *OSPFv3 Link State Advertisement (LSA) Extensibility*

RFC 8920, *OSPF Application-Specific Link Attributes*

4.25 OpenFlow

TS-007 Version 1.3.1, *OpenFlow Switch Specification* – OpenFlow-hybrid switches

4.26 Path Computation Element Protocol (PCEP)

draft-alvarez-pce-path-profiles-04, *PCE Path Profiles*

draft-dhs-spring-pce-sr-p2mp-policy-00, *PCEP extensions for p2mp sr policy*

draft-ietf-pce-binding-label-sid-15, *Carrying Binding Label/Segment Identifier (SID) in PCE-based Networks.* – MPLS binding SIDs

draft-ietf-pce-pceps-tls13-04, *Updates for PCEPS: TLS Connection Establishment Restrictions*

RFC 5440, *Path Computation Element (PCE) Communication Protocol (PCEP)*

RFC 8231, *Path Computation Element Communication Protocol (PCEP) Extensions for Stateful PCE*

RFC 8253, *PCEPS: Usage of TLS to Provide a Secure Transport for the Path Computation Element Communication Protocol (PCEP)*

RFC 8281, *PCEP Extensions for PCE-initiated LSP Setup in a Stateful PCE Model*

RFC 8408, *Conveying Path Setup Type in PCE Communication Protocol (PCEP) Messages*

RFC 8664, *Path Computation Element Communication Protocol (PCEP) Extensions for Segment Routing*

4.27 Point-to-Point Protocol (PPP)

RFC 1332, *The PPP Internet Protocol Control Protocol (IPCP)*

RFC 1990, *The PPP Multilink Protocol (MP)*

RFC 1994, *PPP Challenge Handshake Authentication Protocol (CHAP)*

RFC 2516, *A Method for Transmitting PPP Over Ethernet (PPPoE)*

RFC 4638, *Accommodating a Maximum Transit Unit/Maximum Receive Unit (MTU/MRU) Greater Than 1492 in the Point-to-Point Protocol over Ethernet (PPPoE)*

RFC 5072, *IP Version 6 over PPP*

4.28 Policy management and credit control

3GPP TS 29.212 Release 11, *Policy and Charging Control (PCC); Reference points* – Gx support as it applies to wireline environment (BNG)

RFC 4006, *Diameter Credit-Control Application*

RFC 6733, *Diameter Base Protocol*

4.29 Pseudowire (PW)

draft-ietf-l2vpn-vpws-iw-oam-04, *OAM Procedures for VPWS Interworking*

MFA Forum 12.0.0, *Multiservice Interworking - Ethernet over MPLS*

MFA Forum 13.0.0, *Fault Management for Multiservice Interworking v1.0*

MFA Forum 16.0.0, *Multiservice Interworking - IP over MPLS*

RFC 3916, *Requirements for Pseudo-Wire Emulation Edge-to-Edge (PWE3)*

RFC 3985, *Pseudo Wire Emulation Edge-to-Edge (PWE3)*

RFC 4385, *Pseudo Wire Emulation Edge-to-Edge (PWE3) Control Word for Use over an MPLS PSN*

RFC 4446, *IANA Allocations for Pseudowire Edge to Edge Emulation (PWE3)*

RFC 4447, *Pseudowire Setup and Maintenance Using the Label Distribution Protocol (LDP)*

RFC 4448, *Encapsulation Methods for Transport of Ethernet over MPLS Networks*

RFC 5085, *Pseudowire Virtual Circuit Connectivity Verification (VCCV): A Control Channel for Pseudowires*

RFC 5659, *An Architecture for Multi-Segment Pseudowire Emulation Edge-to-Edge*

RFC 5885, *Bidirectional Forwarding Detection (BFD) for the Pseudowire Virtual Circuit Connectivity Verification (VCCV)*

RFC 6073, *Segmented Pseudowire*

RFC 6310, *Pseudowire (PW) Operations, Administration, and Maintenance (OAM) Message Mapping*

RFC 6391, *Flow-Aware Transport of Pseudowires over an MPLS Packet Switched Network*

RFC 6575, *Address Resolution Protocol (ARP) Mediation for IP Interworking of Layer 2 VPNs*

RFC 6718, *Pseudowire Redundancy*

RFC 6829, *Label Switched Path (LSP) Ping for Pseudowire Forwarding Equivalence Classes (FECs) Advertised over IPv6*

RFC 6870, *Pseudowire Preferential Forwarding Status bit*

RFC 7023, *MPLS and Ethernet Operations, Administration, and Maintenance (OAM) Interworking*

RFC 7267, *Dynamic Placement of Multi-Segment Pseudowires*

RFC 7392, *Explicit Path Routing for Dynamic Multi-Segment Pseudowires* – ER-TLV and ER-HOP IPv4 Prefix

RFC 8395, *Extensions to BGP-Signaled Pseudowires to Support Flow-Aware Transport Labels*

4.30 Quality of Service (QoS)

RFC 2430, *A Provider Architecture for Differentiated Services and Traffic Engineering (PASTE)*

RFC 2474, *Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers*

RFC 2597, *Assured Forwarding PHB Group*

RFC 3140, *Per Hop Behavior Identification Codes*

RFC 3246, *An Expedited Forwarding PHB (Per-Hop Behavior)*

4.31 Remote Authentication Dial In User Service (RADIUS)

draft-oscca-cfrg-sm3-02, *The SM3 Cryptographic Hash Function*

RFC 2865, *Remote Authentication Dial In User Service (RADIUS)*

RFC 2866, *RADIUS Accounting*

RFC 2867, *RADIUS Accounting Modifications for Tunnel Protocol Support*

RFC 2868, *RADIUS Attributes for Tunnel Protocol Support*

RFC 2869, *RADIUS Extensions*

RFC 3162, *RADIUS and IPv6*

RFC 4818, *RADIUS Delegated-IPv6-Prefix Attribute*

RFC 5176, *Dynamic Authorization Extensions to RADIUS*

RFC 6613, *RADIUS over TCP* – with TLS

RFC 6614, *Transport Layer Security (TLS) Encryption for RADIUS*

RFC 6929, *Remote Authentication Dial-In User Service (RADIUS) Protocol Extensions*

RFC 6911, *RADIUS attributes for IPv6 Access Networks*

4.32 Resource Reservation Protocol - Traffic Engineering (RSVP-TE)

draft-newton-mpls-te-dynamic-overbooking-00, *A Diffserv-TE Implementation Model to dynamically change booking factors during failure events*

RFC 2702, *Requirements for Traffic Engineering over MPLS*

RFC 2747, *RSVP Cryptographic Authentication*

RFC 2961, *RSVP Refresh Overhead Reduction Extensions*

RFC 3097, *RSVP Cryptographic Authentication -- Updated Message Type Value*

RFC 3209, *RSVP-TE: Extensions to RSVP for LSP Tunnels*

RFC 3477, *Signalling Unnumbered Links in Resource ReSerVation Protocol - Traffic Engineering (RSVP-TE)*

RFC 3564, *Requirements for Support of Differentiated Services-aware MPLS Traffic Engineering*

RFC 3906, *Calculating Interior Gateway Protocol (IGP) Routes Over Traffic Engineering Tunnels*

RFC 4090, *Fast Reroute Extensions to RSVP-TE for LSP Tunnels*

RFC 4124, *Protocol Extensions for Support of Diffserv-aware MPLS Traffic Engineering*

RFC 4125, *Maximum Allocation Bandwidth Constraints Model for Diffserv-aware MPLS Traffic Engineering*

RFC 4127, *Russian Dolls Bandwidth Constraints Model for Diffserv-aware MPLS Traffic Engineering*

RFC 4561, *Definition of a Record Route Object (RRO) Node-Id Sub-Object*

RFC 4875, *Extensions to Resource Reservation Protocol - Traffic Engineering (RSVP-TE) for Point-to-Multipoint TE Label Switched Paths (LSPs)*

RFC 5712, *MPLS Traffic Engineering Soft Preemption*

RFC 5817, *Graceful Shutdown in MPLS and Generalized MPLS Traffic Engineering Networks*

4.33 Routing Information Protocol (RIP)

RFC 1058, *Routing Information Protocol*

RFC 2080, *RIPng for IPv6*

RFC 2082, *RIP-2 MD5 Authentication*

RFC 2453, *RIP Version 2*

4.34 Segment Routing (SR)

draft-ietf-bess-mvpn-evpn-sr-p2mp-07, *Multicast and Ethernet VPN with Segment Routing P2MP and Ingress Replication* – MVPN

draft-bashandy-rtgwg-segment-routing-uloop-15, *Loop avoidance using Segment Routing*

draft-filsfils-spring-net-pgm-extension-srv6-usid-15, *Network Programming extension: SRv6 uSID instruction*

draft-filsfils-spring-srv6-net-pgm-insertion-08, *SRv6 NET-PGM extension: Insertion*

draft-ietf-idr-bgpls-srv6-ext-14, *BGP Link State Extensions for SRv6*

draft-ietf-idr-segment-routing-te-policy-23, *Advertising Segment Routing Policies in BGP*

draft-ietf-idr-ts-flowspec-srv6-policy-03, *Traffic Steering using BGP FlowSpec with SR Policy*

draft-ietf-pim-p2mp-policy-ping-03, *P2MP Policy Ping*

draft-ietf-pim-sr-p2mp-policy-06, *Segment Routing Point-to-Multipoint Policy* – MPLS

draft-ietf-rtgwg-segment-routing-ti-lfa-11, *Topology Independent Fast Reroute using Segment Routing*

draft-ietf-spring-conflict-resolution-05, *Segment Routing MPLS Conflict Resolution*

draft-ietf-spring-sr-replication-segment-16, *SR Replication segment for Multi-point Service Delivery* – MPLS

draft-ietf-spring-srv6-srh-compression-xx, *Compressed SRv6 Segment List Encoding in SRH*

draft-voyer-6man-extension-header-insertion-10, *Deployments With Insertion of IPv6 Segment Routing Headers*

RFC 8287, *Label Switched Path (LSP) Ping/Traceroute for Segment Routing (SR) IGP-Prefix and IGP-Adjacency Segment Identifiers (SIDs) with MPLS Data Planes*

RFC 8426, *Recommendations for RSVP-TE and Segment Routing (SR) Label Switched Path (LSP) Coexistence*

RFC 8476, *Signaling Maximum SID Depth (MSD) Using OSPF* – node MSD

RFC 8491, *Signaling Maximum SID Depth (MSD) Using IS-IS* – node MSD

RFC 8660, *Segment Routing with the MPLS Data Plane*

RFC 8661, *Segment Routing MPLS Interworking with LDP*

RFC 8663, *MPLS Segment Routing over IP* – BGP SR with SR-MPLS-over-UDP/IP

RFC 8665, *OSPF Extensions for Segment Routing*

RFC 8666, *OSPFv3 Extensions for Segment Routing*

RFC 8667, *IS-IS Extensions for Segment Routing*

RFC 8669, *Segment Routing Prefix Segment Identifier Extensions for BGP*

RFC 8754, *IPv6 Segment Routing Header (SRH)*

RFC 8814, *Signaling Maximum SID Depth (MSD) Using the Border Gateway Protocol - Link State*

RFC 8986, *Segment Routing over IPv6 (SRv6) Network Programming*

RFC 9085, *Border Gateway Protocol - Link State (BGP-LS) Extensions for Segment Routing*

RFC 9088, *Signaling Entropy Label Capability and Entropy Readable Label Depth Using IS-IS* – advertising ELC

RFC 9089, *Signaling Entropy Label Capability and Entropy Readable Label Depth Using OSPF* – advertising ELC

RFC 9252, *BGP Overlay Services Based on Segment Routing over IPv6 (SRv6)*

RFC 9256, *Segment Routing Policy Architecture*

RFC 9259, *Operations, Administration, and Maintenance (OAM) in Segment Routing over IPv6 (SRv6)*

RFC 9350, *IGP Flexible Algorithm*

RFC 9352, *IS-IS Extensions to Support Segment Routing over the IPv6 Data Plane*

4.35 Simple Network Management Protocol (SNMP)

draft-blumenthal-aes-usm-04, *The AES Cipher Algorithm in the SNMP's User-based Security Model* – CFB128-AES-192 and CFB128-AES-256

draft-ietf-isis-wg-mib-06, *Management Information Base for Intermediate System to Intermediate System (IS-IS)*

draft-ietf-mboned-msdp-mib-01, *Multicast Source Discovery protocol MIB*

draft-ietf-mpls-ldp-mib-07, *Definitions of Managed Objects for the Multiprotocol Label Switching, Label Distribution Protocol (LDP)*

draft-ietf-mpls-lsr-mib-06, *Multiprotocol Label Switching (MPLS) Label Switching Router (LSR) Management Information Base Using SMIv2*

draft-ietf-mpls-te-mib-04, *Multiprotocol Label Switching (MPLS) Traffic Engineering Management Information Base*

draft-ietf-ospf-mib-update-08, *OSPF Version 2 Management Information Base*

draft-ietf-vrrp-unified-mib-06, *Definitions of Managed Objects for the VRRP over IPv4 and IPv6* – IPv6

ESO-CONSORTIUM-MIB revision 200406230000Z, *esoConsortiumMIB*

IANA-ADDRESS-FAMILY-NUMBERS-MIB revision 200203140000Z, *ianaAddressFamilyNumbers*

IANAifType-MIB revision 200505270000Z, *ianaifType*

IANA-RTPROTO-MIB revision 200009260000Z, *ianaRtProtoMIB*

IEEE8021-CFM-MIB revision 200706100000Z, *ieee8021CfmMib*

IEEE8021-PAE-MIB revision 200101160000Z, *ieee8021paeMIB*

IEEE8023-LAG-MIB revision 200006270000Z, *lagMIB*

LLDP-MIB revision 200505060000Z, *lldpMIB*

RFC 1157, *A Simple Network Management Protocol (SNMP)*

RFC 1212, *Concise MIB Definitions*

RFC 1215, *A Convention for Defining Traps for use with the SNMP*

RFC 1724, *RIP Version 2 MIB Extension*

RFC 1901, *Introduction to Community-based SNMPv2*

RFC 2021, *Remote Network Monitoring Management Information Base Version 2 using SMIv2*

RFC 2206, *RSVP Management Information Base using SMIv2*

RFC 2213, *Integrated Services Management Information Base using SMIv2*

RFC 2494, *Definitions of Managed Objects for the DS0 and DS0 Bundle Interface Type*

RFC 2578, *Structure of Management Information Version 2 (SMIv2)*

RFC 2579, *Textual Conventions for SMIv2*

RFC 2580, *Conformance Statements for SMIv2*

RFC 2787, *Definitions of Managed Objects for the Virtual Router Redundancy Protocol*

RFC 2819, *Remote Network Monitoring Management Information Base*

RFC 2856, *Textual Conventions for Additional High Capacity Data Types*

RFC 2863, *The Interfaces Group MIB*

RFC 2864, *The Inverted Stack Table Extension to the Interfaces Group MIB*

RFC 2933, *Internet Group Management Protocol MIB*

RFC 3014, *Notification Log MIB*

RFC 3165, *Definitions of Managed Objects for the Delegation of Management Scripts*

RFC 3231, *Definitions of Managed Objects for Scheduling Management Operations*

RFC 3273, *Remote Network Monitoring Management Information Base for High Capacity Networks*

RFC 3410, *Introduction and Applicability Statements for Internet Standard Management Framework*

RFC 3411, *An Architecture for Describing Simple Network Management Protocol (SNMP) Management Frameworks*

RFC 3412, *Message Processing and Dispatching for the Simple Network Management Protocol (SNMP)*

RFC 3413, *Simple Network Management Protocol (SNMP) Applications*

RFC 3414, *User-based Security Model (USM) for version 3 of the Simple Network Management Protocol (SNMPv3)*

RFC 3415, *View-based Access Control Model (VACM) for the Simple Network Management Protocol (SNMP)*

RFC 3416, *Version 2 of the Protocol Operations for the Simple Network Management Protocol (SNMP)*

RFC 3417, *Transport Mappings for the Simple Network Management Protocol (SNMP)* – SNMP over UDP over IPv4

RFC 3418, *Management Information Base (MIB) for the Simple Network Management Protocol (SNMP)*

RFC 3419, *Textual Conventions for Transport Addresses*

RFC 3498, *Definitions of Managed Objects for Synchronous Optical Network (SONET) Linear Automatic Protection Switching (APS) Architectures*

RFC 3584, *Coexistence between Version 1, Version 2, and Version 3 of the Internet-standard Network Management Framework*

RFC 3592, *Definitions of Managed Objects for the Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) Interface Type*

RFC 3593, *Textual Conventions for MIB Modules Using Performance History Based on 15 Minute Intervals*

RFC 3635, *Definitions of Managed Objects for the Ethernet-like Interface Types*

RFC 3637, *Definitions of Managed Objects for the Ethernet WAN Interface Sublayer*

RFC 3826, *The Advanced Encryption Standard (AES) Cipher Algorithm in the SNMP User-based Security Model*

RFC 3877, *Alarm Management Information Base (MIB)*

RFC 3895, *Definitions of Managed Objects for the DS1, E1, DS2, and E2 Interface Types*

RFC 3896, *Definitions of Managed Objects for the DS3/E3 Interface Type*

RFC 4001, *Textual Conventions for Internet Network Addresses*

RFC 4022, *Management Information Base for the Transmission Control Protocol (TCP)*

RFC 4113, *Management Information Base for the User Datagram Protocol (UDP)*

RFC 4220, *Traffic Engineering Link Management Information Base*

RFC 4273, *Definitions of Managed Objects for BGP-4*

RFC 4292, *IP Forwarding Table MIB*

RFC 4293, *Management Information Base for the Internet Protocol (IP)*

RFC 4631, *Link Management Protocol (LMP) Management Information Base (MIB)*

RFC 4878, *Definitions and Managed Objects for Operations, Administration, and Maintenance (OAM) Functions on Ethernet-Like Interfaces*

RFC 7420, *Path Computation Element Communication Protocol (PCEP) Management Information Base (MIB) Module*

RFC 7630, *HMAC-SHA-2 Authentication Protocols in the User-based Security Model (USM) for SNMPv3*

SFLOW-MIB revision 200309240000Z, *sFlowMIB*

4.36 Timing

GR-1244-CORE Issue 3, *Clocks for the Synchronized Network: Common Generic Criteria*

GR-253-CORE Issue 3, *SONET Transport Systems: Common Generic Criteria*

IEEE 1588-2008, *IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*

ITU-T G.781, *Synchronization layer functions*

ITU-T G.811, *Timing characteristics of primary reference clocks*

ITU-T G.813, *Timing characteristics of SDH equipment slave clocks (SEC)*

ITU-T G.8261, *Timing and synchronization aspects in packet networks*

ITU-T G.8262, *Timing characteristics of synchronous Ethernet equipment slave clock (EEC)*

ITU-T G.8262.1, *Timing characteristics of an enhanced synchronous Ethernet equipment slave clock (eEEC)*

ITU-T G.8264, *Distribution of timing information through packet networks*

ITU-T G.8265.1, *Precision time protocol telecom profile for frequency synchronization*

ITU-T G.8272 , *Timing characteristics of primary reference time clocks* – PRTC-A, PRTC-B

ITU-T G.8275.1, *Precision time protocol telecom profile for phase/time synchronization with full timing support from the network*

ITU-T G.8275.2, *Precision time protocol telecom profile for phase/time synchronization with partial timing support from the network*

RFC 3339, *Date and Time on the Internet: Timestamps*

RFC 5905, *Network Time Protocol Version 4: Protocol and Algorithms Specification*

RFC 8573, *Message Authentication Code for the Network Time Protocol*

4.37 Two-Way Active Measurement Protocol (TWAMP)

RFC 5357, *A Two-Way Active Measurement Protocol (TWAMP)* – server, unauthenticated mode

RFC 5938, *Individual Session Control Feature for the Two-Way Active Measurement Protocol (TWAMP)*

RFC 6038, *Two-Way Active Measurement Protocol (TWAMP) Reflect Octets and Symmetrical Size Features*

RFC 8545, *Well-Known Port Assignments for the One-Way Active Measurement Protocol (OWAMP) and the Two-Way Active Measurement Protocol (TWAMP)* – TWAMP

RFC 8762, *Simple Two-Way Active Measurement Protocol* – unauthenticated

RFC 8972, *Simple Two-Way Active Measurement Protocol Optional Extensions* – unauthenticated

4.38 Virtual Private LAN Service (VPLS)

RFC 4761, *Virtual Private LAN Service (VPLS) Using BGP for Auto-Discovery and Signaling*

RFC 4762, *Virtual Private LAN Service (VPLS) Using Label Distribution Protocol (LDP) Signaling*

RFC 5501, *Requirements for Multicast Support in Virtual Private LAN Services*

RFC 6074, *Provisioning, Auto-Discovery, and Signaling in Layer 2 Virtual Private Networks (L2VPNs)*

RFC 7041, *Extensions to the Virtual Private LAN Service (VPLS) Provider Edge (PE) Model for Provider Backbone Bridging*

RFC 7117, *Multicast in Virtual Private LAN Service (VPLS)*

4.39 Voice and video

DVB BlueBook A86, *Transport of MPEG-2 TS Based DVB Services over IP Based Networks*

ETSI TS 101 329-5 Annex E, *QoS Measurement for VoIP - Method for determining an Equipment Impairment Factor using Passive Monitoring*

ITU-T G.1020 Appendix I, *Performance Parameter Definitions for Quality of Speech and other Voiceband Applications Utilizing IP Networks - Mean Absolute Packet Delay Variation & Markov Models*

ITU-T G.107, *The E Model - A computational model for use in planning*

ITU-T P.564, *Conformance testing for voice over IP transmission quality assessment models*

RFC 3550, *RTP: A Transport Protocol for Real-Time Applications* – Appendix A.8

RFC 4585, *Extended RTP Profile for Real-time Transport Control Protocol (RTCP)-Based Feedback (RTP/AVPF)*

RFC 4588, *RTP Retransmission Payload Format*

4.40 Yet Another Next Generation (YANG)

RFC 6991, *Common YANG Data Types*

RFC 7950, *The YANG 1.1 Data Modeling Language*

RFC 7951, *JSON Encoding of Data Modeled with YANG*

4.41 Yet Another Next Generation (YANG) OpenConfig Models

openconfig-aaa.yang version 0.4.0, *OpenConfig AAA Model*

openconfig-aaa-radius.yang version 0.3.0, *OpenConfig AAA RADIUS Model*

openconfig-aaa-tacacs.yang version 0.3.0, *OpenConfig AAA TACACS+ Model*

openconfig-acl.yang version 1.0.0, *OpenConfig ACL Model*

openconfig-alarms.yang version0.3.2, *OpenConfig System Alarms Model*

openconfig-bfd.yang version 0.2.2, *OpenConfig BFD Model*

openconfig-bgp.yang version 6.1.0, *OpenConfig BGP Model*

openconfig-bgp-common.yang version 6.0.0, *OpenConfig BGP Common Model*

openconfig-bgp-common-multiprotocol.yang version 6.0.0, *OpenConfig BGP Common Multiprotocol Model*

openconfig-bgp-common-structure.yang version 6.0.0, *OpenConfig BGP Common Structure Model*

openconfig-bgp-global.yang version 6.0.0, *OpenConfig BGP Global Model*

openconfig-bgp-neighbor.yang version 6.1.0, *OpenConfig BGP Neighbor Model*

openconfig-bgp-peer-group.yang version 6.1.0, *OpenConfig BGP Peer Group Model*

openconfig-bgp-policy.yang version 4.0.1, *OpenConfig BGP Policy Model*

openconfig-if-aggregate.yang version 2.4.3, *OpenConfig Interfaces Aggregated Model*

openconfig-if-ethernet.yang version 2.12.1, *OpenConfig Interfaces Ethernet Model*

openconfig-if-ip.yang version 3.1.0, *OpenConfig Interfaces IP Model*

openconfig-if-ip-ext.yang version 2.3.1, *OpenConfig Interfaces IP Extensions Model*

openconfig-igmp.yang version 0.2.0, *OpenConfig IGMP Model*

openconfig-interfaces.yang version 3.0.0, *OpenConfig Interfaces Model*

openconfig-isis.yang version 1.1.0, *OpenConfig IS-IS Model*

openconfig-isis-policy.yang version 0.5.0, *OpenConfig IS-IS Policy Model*

openconfig-isis-routing.yang version 1.1.0, *OpenConfig IS-IS Routing Model*

openconfig-lacp.yang version 1.3.0, *OpenConfig LACP Model*

openconfig-lldp.yang version 0.1.0, *OpenConfig LLDP Model*

openconfig-local-routing.yang version 1.2.0, *OpenConfig Local Routing Model*

openconfig-mpls.yang version 2.3.0, *OpenConfig MPLS Model*

openconfig-mpls-ldp.yang version 3.0.2, *OpenConfig MPLS LDP Model*

openconfig-mpls-rsvp.yang version 2.3.0, *OpenConfig MPLS RSVP Model*

openconfig-mpls-te.yang version 2.3.0, *OpenConfig MPLS TE Model*

openconfig-network-instance.yang version 1.1.0, *OpenConfig Network Instance Model*

openconfig-network-instance-l3.yang version 0.11.1, *OpenConfig L3 Network Instance Model* – static routes

openconfig-ospfv2.yang version 0.4.0, *OpenConfig OSPFv2 Model*

openconfig-ospfv2-area.yang version 0.4.0, *OpenConfig OSPFv2 Area Model*

openconfig-ospfv2-area-interface.yang version 0.4.0, *OpenConfig OSPFv2 Area Interface Model*

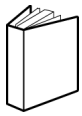
openconfig-ospfv2-common.yang version 0.4.0, *OpenConfig OSPFv2 Common Model*

openconfig-ospfv2-global.yang version 0.4.0, *OpenConfig OSPFv2 Global Model*

openconfig-packet-match.yang version 1.0.0, *OpenConfig Packet Match Model*

openconfig-pim.yang version 0.2.0, *OpenConfig PIM Model*
openconfig-platform.yang version 0.15.0, *OpenConfig Platform Model*
openconfig-platform-fan.yang version 0.1.1, *OpenConfig Platform Fan Model*
openconfig-platform-linecard.yang version 0.1.2, *OpenConfig Platform Linecard Model*
openconfig-platform-port.yang version 0.4.2, *OpenConfig Port Model*
openconfig-platform-transceiver.yang version 0.9.0, *OpenConfig Transceiver Model*
openconfig-procmon.yang version 0.4.0, *OpenConfig Process Monitoring Model*
openconfig-relay-agent.yang version 0.1.0, *OpenConfig Relay Agent Model*
openconfig-routing-policy.yang version 3.0.0, *OpenConfig Routing Policy Model*
openconfig-rsvp-sr-ext.yang version 0.1.0, *OpenConfig RSVP-TE and SR Extensions Model*
openconfig-system.yang version 0.10.1, *OpenConfig System Model*
openconfig-system-grpc.yang version 1.0.0, *OpenConfig System gRPC Model*
openconfig-system-logging.yang version 0.3.1, *OpenConfig System Logging Model*
openconfig-system-terminal.yang version 0.3.0, *OpenConfig System Terminal Model*
openconfig-telemetry.yang version 0.5.0, *OpenConfig Telemetry Model*
openconfig-terminal-device.yang version 1.9.0, *OpenConfig Terminal Optics Device Model*
openconfig-vlan.yang version 2.0.0, *OpenConfig VLAN Model*

Customer document and product support



Customer documentation

Customer documentation welcome page

Technical support

Product support portal

Documentation feedback

Customer documentation feedback