Implementing MPLS Traffic Engineering

Implementing MPLS Traffic Engineering

Traditional IP routing emphasizes on forwarding traffic to the destination as fast as possible. As a result, the routing protocols find out the least-cost route according to its metric to each destination in the network and every router forwards the packet based on the destination IP address and packets are forwarded hop-by-hop. Thus, traditional IP routing does not consider the available bandwidth of the link. This can cause some links to be over-utilized compared to others and bandwidth is not efficiently utilized. Traffic Engineering (TE) is used when the problems result from inefficient mapping of traffic streams onto the network resources. Traffic engineering allows you to control the path that data packets follow and moves traffic flows from congested links to non-congested links that would not be possible by the automatically computed destination-based shortest path.

Multiprotocol Label Switching (MPLS) with its label switching capabilities, eliminates the need for an IP route look-up and creates a virtual circuit (VC) switching function, allowing enterprises the same performance on their IP-based network services as with those delivered over traditional networks such as Frame Relay or Asynchronous Transfer Mode (ATM). MPLS traffic engineering (MPLS-TE) relies on the MPLS backbone to replicate and expand upon the TE capabilities of Layer 2 ATM and Frame Relay networks.

MPLS-TE learns the topology and resources available in a network and then maps traffic flows to particular paths based on resource requirements and network resources such as bandwidth. MPLS-TE builds a unidirectional tunnel from a source to a destination in the form of a label switched path (LSP), which is then used to forward traffic. The point where the tunnel begins is called the tunnel headend or tunnel source, and the node where the tunnel ends is called the tunnel tailend or tunnel destination. A router through which the tunnel passes is called the mid-point of the tunnel.

MPLS uses extensions to a link-state based Interior Gateway Protocol (IGP), such as Intermediate System-to-Intermediate System (IS-IS) or Open Shortest Path First (OSPF). MPLS calculates TE tunnels at the LSP head based on required and available resources (constraint-based routing). If configured, the IGP automatically routes the traffic onto these LSPs. Typically, a packet that crosses the MPLS-TE backbone travels on a single LSP that connects the ingress point to the egress point. MPLS TE automatically establishes and maintains the LSPs across the MPLS network by using the Resource Reservation Protocol (RSVP).

Note Combination of unlabelled paths protected by labelled paths is not supported.

Overview of MPLS-TE Features

In MPLS traffic engineering, IGP extensions flood the TE information across the network. Once the IGP distributes the link attributes and bandwidth information, the headend router calculates the best path from head to tail for the MPLS-TE tunnel. This path can also be configured explicitly. Once the path is calculated, RSVP-TE is used to set up the TE LSP (Labeled Switch Path).

To forward the traffic, you can configure autoroute, forward adjacency, or static routing. The autoroute feature announces the routes assigned by the tailend router and its downstream routes to the routing table of the headend router and the tunnel is considered as a directly connected link to the tunnel.

If forward adjacency is enabled, MPLS-TE tunnel is advertised as a link in an IGP network with the link's cost associated with it. Routers outside of the TE domain can see the TE tunnel and use it to compute the shortest path for routing traffic throughout the network.

MPLS-TE provides protection mechanism known as fast reroute to minimize packet loss during a failure. For fast reroute, you need to create back up tunnels. The autotunnel backup feature enables a router to dynamically build backup tunnels when they are needed instead of pre-configuring each backup tunnel and then assign the backup tunnel to the protected interfaces.

DiffServ Aware Traffic Engineering (DS-TE) enables you to configure multiple bandwidth constraints on an MPLS-enabled interface to support various classes of service (CoS). These bandwidth constraints can be treated differently based on the requirement for the traffic class using that constraint.

The MPLS traffic engineering autotunnel mesh feature allows you to set up full mesh of TE tunnels automatically with a minimal set of MPLS traffic engineering configurations. The MPLS-TE auto bandwidth feature allows you to automatically adjusts bandwidth based on traffic patterns without traffic disruption.

The MPLS-TE interarea tunneling feature allows you to establish TE tunnels spanning multiple Interior Gateway Protocol (IGP) areas and levels, thus eliminating the requirement that headend and tailend routers should reside in a single area.

For detailed information about MPLS-TE features, see MPLS-TE Features - Details, on page 48.

Note

MPLS-TE Nonstop Routing (NSR) is enabled by default without any user configuration and cannot be disabled.

MPLS-TE NSR means the application is in hot-standby mode and standby MPLS-TE instance is ready to take over from the active instance quickly on RP failover.

Note that the MPLS-TE does not do routing. If there is standby card available then the MPLS-TE instance is in a hot-standby position.

The following output shows the status of MPLS-TE NSR:

```
Router#show mpls traffic-eng nsr status

TE Process Role         : V1 Active
Current Status        : Ready
    Ready since         : Tue Nov 01 10:42:34 UTC 2022 (1w3d ago)
   IDT started          : Tue Nov 01 03:28:48 UTC 2022 (1w3d ago)
    IDT ended           : Tue Nov 01 03:28:48 UTC 2022 (1w3d ago)
Previous Status         : Not ready
    Not ready reason    : Collaborator disconnected
    Not ready since     : Tue Nov 01 10:42:34 UTC 2022 (1w3d ago)
```

During any issues with the MPLS-TE, the NSR on the router gets affected which is displayed in the show redundancy output as follows:

```
Router#show mpls traffic-eng nsr status details
.
.
.

Current active rmf state: 4 (I_READY)
All standby not-ready bits clear - standby should be ready

Current active rmf state for NSR: Not ready
<jid> <node> <name> Reason for standby not NSR-ready
1082 0/RP0/CPU0 te_control TE NSR session not synchronized
Not ready set Wed Nov 19 17:28:14 2022: 5 hours, 23 minutes ago
1082 0/RP1/CPU0 te_control Standby not connected
Not ready set Wed Nov 19 17:29:11 2022: 5 hours, 22 minutes ago
```

Note

If you have disabled MPLS-TE NSR and configured only MPLS-TE nonstop forwarding (NSF), performing an RP failover results in a verification error causing unprotected LSPs to flap and triggering FRR on protected LSPs. To avoid the verification error, you must block the path verification using the **mpls traffic-eng topology block-verify-after-rpfo** command.

How MPLS-TE Works

MPLS-TE automatically establishes and maintains label switched paths (LSPs) across the backbone by using RSVP. The path that an LSP uses is determined by the LSP resource requirements and network resources, such as bandwidth. Available resources are flooded by extensions to a link state based Interior Gateway Protocol (IGP). MPLS-TE tunnels are calculated at the LSP headend router, based on a fit between the required and available resources (constraint-based routing). The IGP automatically routes the traffic to these LSPs. Typically, a packet crossing the MPLS-TE backbone travels on a single LSP that connects the ingress point to the egress point.

The following sections describe the components of MPLS-TE:

Tunnel Interfaces

From a Layer 2 standpoint, an MPLS tunnel interface represents the headend of an LSP. It is configured with a set of resource requirements, such as bandwidth and media requirements, and priority. From a Layer 3 standpoint, an LSP tunnel interface is the headend of a unidirectional virtual link to the tunnel destination.

MPLS-TE Path Calculation Module

This calculation module operates at the LSP headend. The module determines a path to use for an LSP. The path calculation uses a link-state database containing flooded topology and resource information.

RSVP with TE Extensions

RSVP operates at each LSP hop and is used to signal and maintain LSPs based on the calculated path.

MPLS-TE Link Management Module

This module operates at each LSP hop, performs link call admission on the RSVP signaling messages, and keep track on topology and resource information to be flooded.

Link-state IGP

Either Intermediate System-to-Intermediate System (IS-IS) or Open Shortest Path First (OSPF) can be used as IGPs. These IGPs are used to globally flood topology and resource information from the link management module.

Label Switching Forwarding

This forwarding mechanism provides routers with a Layer 2-like ability to direct traffic across multiple hops of the LSP established by RSVP signaling.

RSVP-TE Bandwidth Accounting

The total interface bandwidth utilization in the data plane, excluding RSVP-TE bandwidth, is called dark bandwidth. A network may have dark bandwidth due to IP, LDP, or segment routing traffic flowing in the network. Dark bandwidth effectively reduces the link bandwidth available to RSVP-TE LSPs.

When segment routing is enabled on the network, you should be aware of the segment routing traffic over the links so that RSVP-TE bandwidth reservations can avoid overbooking the links in the network. The RSVP-TE bandwidth accounting feature allows you to perform proper accounting of the traffic.

You can enable RSVP-TE bandwidth accounting, and start dark bandwidth advertisement based on accounting samples, for all MPLS-TE enabled links using the **bandwidth-accounting** command in MPLS-TE configuration mode.

Computing the Effective Maximum Reservable Bandwidth

The statistics collector process (statsD) is responsible for returning statistics counters for each feature. For each traffic engineering (TE)-enabled interface, the TE process collects new RSVP-TE bandwidth rate statistics (samples) from the statsD process, within a specified sampling interval. These samples are collected over a period of time called an application interval.

After each application interval, the average value of the collected rate samples is used to compute the dark bandwidth rate and the effective maximum reservable bandwidth (Max-Reservable-BW) rate.

The dark bandwidth rate is calculated as total rate - RSVP rate:

- The total rate includes IPv4 , IPv6, and MPLS rate (MPLS includes RSVP/LDP/BGP label packets)
- The RSVP rate includes IPv4/IPv6 encapsulation over tunnel, and MPLS label packet counters for RSVP-TE tunnels

The following example shows how the effective maximum reservable bandwidth (Effective-Max-Reservable-BW) is computed (assuming a link capacity of 10Gbps and a configured RSVP bandwidth of 90%):

- Link capacity = 10Gbps
- Max-reservable-bw = RSVP percentage of link capacity = 9Gbps
- Total rate (from statsD) = 5Gpbs
- RSVP rate (from statsD) = 3Gpbs
- Dark-bw = Total rate - RSVP rate = 2Gpbs
- Effective-Max-Reservable-BW = max-reservable-bw (9Gbps) - dark-bw (2Gbps) = 7Gbps

In this example, the bandwidth available for RSVP-TE LSP admission is 7Gbps. This value is flooded in the network if the flooding threshold is crossed.

Note When you change the RSVP bandwidth percentage configuration or when the bundle capacity changes due to bundle-member state change, TE accounts for the dark bandwidth when new bandwidth values are advertised.

Note The measured dark bandwidth can be increased or decreased based on a configurable adjustment factor.

When the computed dark bandwidth increases for a link, it will lower the max-reservable-bw of that link, which might trigger preemption of the RSVP-TE LSPs. Preemption consists of freeing the resources of an established LSP, and assigning them to a new LSP. The freeing of resources causes a traffic disruption to the LSP that is being preempted.

Note SR-TE LSPs at the head-end are treated with the highest priority and cannot be preempted.

You can apply measured rates immediately using the **bandwidth-accounting apply all** command. When you apply measured rates immediately, the RSVP-TE bandwidth-accounting might flood the updated bandwidth values immediately. Applying measured rates immediately does not affect the periodic application of the bandwidth.

Configuring MPLS-TE

MPLS-TE requires co-ordination among several global neighbor routers. RSVP, MPLS-TE and IGP are configured on all routers and interfaces in the MPLS traffic engineering network. Explicit path and TE tunnel interfaces are configured only on the head-end routers. MPLS-TE requires some basic configuration tasks explained in this section.

Restrictions for MPLS-TE

- Dark bandwidth is not supported.

Building MPLS-TE Topology

Building MPLS-TE topology, sets up the environment for creating MPLS-TE tunnels. This procedure includes the basic node and interface configuration for enabling MPLS-TE. To perform constraint-based routing, you need to enable OSPF or IS-IS as IGP extension.

Before You Begin

Before you start to build the MPLS-TE topology, the following pre-requisites are required:

- Stable router ID is required at either end of the link to ensure that the link is successful. If you do not assign a router ID, the system defaults to the global router ID. Default router IDs are subject to change, which can result in an unstable link.
- Enable RSVP on the port interface.

Example

This example enables MPLS-TE on a node and then specifies the interface that is part of the MPLS-TE. Here, OSPF is used as the IGP extension protocol for information distribution.

```
RP/0/RP0/CPU0:router# configure
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# interface hundredGigE0/0/0/3
RP/0/RP0/CPU0:router(config)# router ospf area 1
RP/0/RP0/CPU0:router(config-ospf)# area 0
RP/0/RP0/CPU0:router(config-ospf-ar)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-ospf-ar)# interface hundredGigE0/0/0/3
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit
RP/0/RP0/CPU0:router(config-ospf)# mpls traffic-eng router-id 192.168.70.1
RP/0/RP0/CPU0:router(config)# commit
```

Example

This example enables MPLS-TE on a node and then specifies the interface that is part of the MPLS-TE. Here, IS-IS is used as the IGP extension protocol for information distribution.

```
RP/0/RP0/CPU0:router# configure
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# interface hundredGigE0/0/0/3
RP/0/RP0/CPU0:router(config)# router isis 1
RP/0/RP0/CPU0:router(config-isis)# net 47.0001.0000.0000.0002.00
RP/0/RP0/CPU0:router(config-isis)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-isis-af)# metric-style wide
RP/0/RP0/CPU0:router(config-isis-af)# mpls traffic-eng level 1
RP/0/RP0/CPU0:router(config-isis-af)# exit
```

```
RP/0/RP0/CPU0:router(config-isis)# interface hundredGigE0/0/0/3
RP/0/RP0/CPU0:router(config-isis-if)# exit
RP/0/RP0/CPU0:router(config)# commit
```

Related Topics

- How MPLS-TE Works, on page 3
- Creating an MPLS-TE Tunnel, on page 7

Creating an MPLS-TE Tunnel

Creating an MPLS-TE tunnel is a process of customizing the traffic engineering to fit your network topology. The MPLS-TE tunnel is created at the headend router. You need to specify the destination and path of the TE LSP.

To steer traffic through the tunnel, you can use the following ways:

- Static Routing
- Autoroute Announce
- Forwarding Adjacency

From the 7.1.1 release, IS-IS autoroute announce function is enhanced to redirect traffic from a source IP address prefix to a matching IP address assigned to an MPLS-TE tunnel destination interface.

Before You Begin

The following prerequisites are required to create an MPLS-TE tunnel:

- You must have a router ID for the neighboring router.
- Stable router ID is required at either end of the link to ensure that the link is successful. If you do not assign a router ID to the routers, the system defaults to the global router ID. Default router IDs are subject to change, which can result in an unstable link.

Configuration Example

This example configures an MPLS-TE tunnel on the headend router with a destination IP address 192.168.92.125. The bandwidth for the tunnel, path-option, and forwarding parameters of the tunnel are also configured. You can use static routing, autoroute announce or forwarding adjacency to steer traffic through the tunnel.

```
RP/0/RP0/CPU0:router# configure
RP/0/RP0/CPU0:router(config)# interface tunnel-te 1
RP/0/RP0/CPU0:router(config-if)# destination 192.168.92.125
RP/0/RP0/CPU0:router(config-if)# ipv4 unnumbered Loopback0
RP/0/RP0/CPU0:router(config-if)# path-option 1 dynamic
RP/0/RP0/CPU0:router(config-if)# autoroute announce  or forwarding adjacency
RP/0/RP0/CPU0:router(config-if)# signalled-bandwidth 100
RP/0/RP0/CPU0:router(config)# commit
```

Verification

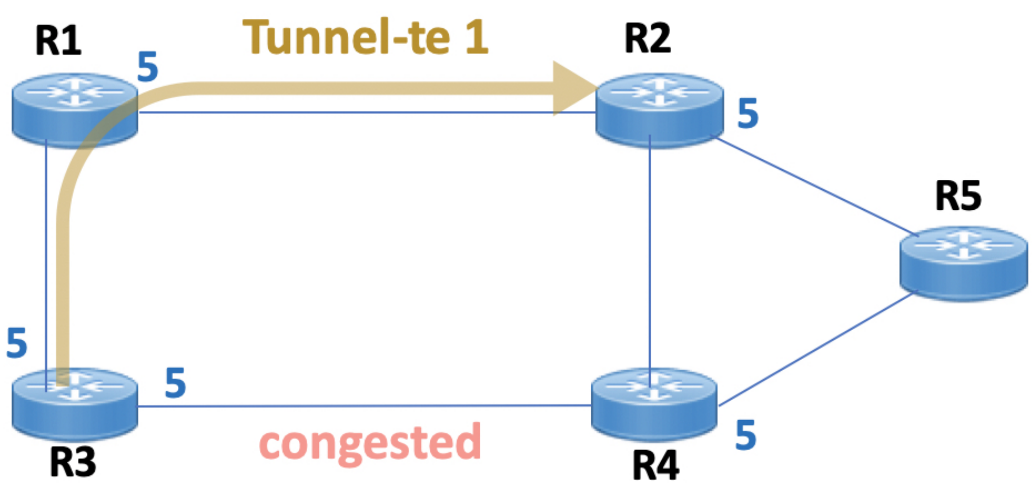
Verify the configuration of MPLS-TE tunnel using the following command.

```
RP/0/RP0/CPU0:router# show mpls traffic-engineering tunnels brief

            Signalling Summary:
                LSP Tunnels Process:  running
                       RSVP Process:  running
                         Forwarding:  enabled
            Periodic reoptimization:  every 3600 seconds, next in 2538 seconds
             Periodic FRR Promotion:  every 300 seconds, next in 38 seconds
            Auto-bw enabled tunnels:  0 (disabled)
                       TUNNEL NAME         DESTINATION      STATUS  STATE


                      tunnel-te1       192.168.92.125      up       up
            Displayed 1 up, 0 down, 0 recovering, 0 recovered heads
```

Automatic Modification Of An MPLS-TE Tunnel's Metric

If the IGP calculation on a router results in an equal cost multipath (ECMP) scenario where next-hop interfaces are a mix of MPLS-TE tunnels and physical interfaces, you may want to ensure that a TE tunnel is preferred. Consider this topology:

Figure 1: MPLS-TE Tunnel



1. All links in the network have a metric of 5.
2. To offload a congested link between R3 and R4, an MPLS-TE tunnel is created from R3 to R2.
3. If the metric of the tunnel is also 5, traffic from R3 to R5 is load-balanced between the tunnel and the physical R3-R4 link.

To ensure that the MPLS-TE tunnel is preferred in such scenarios, configure the **autoroute metric** command on the tunnel interface. The modified metric is applied in the routing information base (RIB), and the tunnel is preferred over the physical path of the same metric. Sample configuration:

```
Router# configure
Router(config)# interface tunnel-te 1
Router(config-if)# autoroute metric relative -1
```

The **autoroute metric** command syntax is **autoroute metric** {**absolute**|**relative**} *value*

- **absolute** enables the absolute metric mode, for a metric range between 1 and 2147483647.
- **relative** enables the relative metric mode, for a metric range between -10 and 10, including zero.

Note Since the **relative** metric is not saved in the IGP database, the advertised metric of the MPLS-TE tunnel remains 5, and doesn't affect SPF calculation outcomes on other nodes.

Related Topics

- How MPLS-TE Works, on page 3
- Building MPLS-TE Topology , on page 6

Teardown and Reestablishment of RSVP-TE Tunnels

Table 1: Feature History Table

Feature Name	Release Information	Feature Description
Teardown and Reestablishment of RSVP-TE Tunnels	Release 7.11.1	Introduced in this release on: NCS 5500 fixed port routers; NCS 5700 fixed port routers; NCS 5500 modular routers (NCS 5500 line cards; NCS 5700 line cards [Mode: Compatibility; Native]) You can now tear down and reestablish the existing tunnels of headend, midend, or tailend router tunnels of an MPLS network for optimized distribution of the traffic across MPLS and RSVP-TE to improve network performance and enhance resource utilization. Previously, you could reestablish tunnels only at the headend router using the mpls traffic-eng resetup command. The feature introduces these changes: **CLI**: mpls traffic-eng teardown **YANG Data Model**: Cisco-IOS-XR-mpls-te-act.yang (see GitHub, YANG Data Models Navigator)

In an MPLS-TE network which is configured with RSVP-TE, the headend, midend, and tailend router work together to establish and maintain tunnels or adjacencies for traffic engineering purposes. When the headend router boots up, it plays a critical role in MPLS-TE tunnel establishment using RSVP-TE signaling along the computed path with the tailend router.

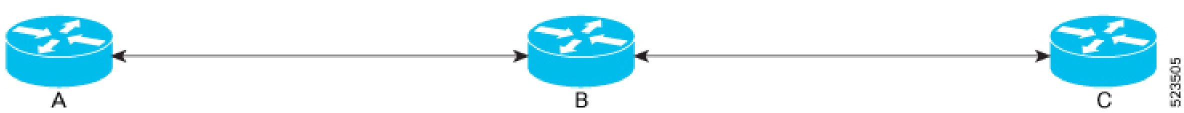
During a system reboot, if a tailend router comes up first, the Interior Gateway Protocol (IGP) adjacency establishes a path for the tailend with the adjacent network devices. However, if the headend router comes up and starts creating tunnels during this tailend path creation, it may result in a poor distribution of tunnels at the tailend. In such cases, it's necessary to tear down all the tunnels and recreate them to ensure optimal distribution and functioning of the RSVP-TE as per the network conditions.

From Release 7.11.1, you can tear down and reestablish tunnels across all headend, midend, and tailend routers using the **mpls traffic-eng teardown** command with **all, head, mid, tail** parameters.

Table 2: Network Routers and Description

Router Name	Router Function	Tunnel Tear-Down and Reestablish Command
Headend Router	The headend router is responsible for determining the tunnel's path. It initiates the signaling process, specifying the tunnel's parameters and requirements. It sets up and manages the MPLS-TE tunnels.	**mpls traffic-eng teardown head**
Midend Router	The midend router, or an intermediate router or network device, is located between the headend and the tailend along the tunnel's path. It's involved in the signaling process and ensures the proper forwarding of traffic along the established tunnel.	**mpls traffic-eng teardown mid**
Tailend Router	The tailend router is the terminating router or network device located at the other end of the tunnel. It receives and processes the traffic that traverses through the tunnel and ensures proper traffic delivery to the destination.	**mpls traffic-eng teardown tail**

Figure 2: RSVP-TE tunnel Teardown and Reestablishment Topology



When RSVP-TE tunnel teardown message is triggered and:

- Router B is configured as tailend and Router A is configured as headend: A **ResvTear upstream** message is sent to the headend router. This message informs the headend router to tear down the RSVP-TE tunnel and release the resources associated with the tunnel.
- Router B is configured as headend and Router C as tailend: A **PathTear downstream** message is sent to the tailend router. A headend router triggers the process of recomputing the tunnels. The headend router (Router B) initiates the process of recomputing the tunnels, which involves recalculating the path and parameters for establishing new tunnels.
- Router B is configured as midend where Router A and Router B as headend and tailend respectively: A **ResvTear upstream** message is sent to the headend router and a **PathTear downstream** message is sent to the tailend router. These messages inform the respective routers to tear down the RSVP-TE tunnel and release the associated resources.

You can tear down and set up all types of tunnels including P2P, P2MP, numbered, named, and auto tunnels.

Limitations

- A maximum 90 seconds are required for the tunnels to get reestablished once they are torn.
- Use the **mpls traffic-eng resetup** command to reestablish the tunnels only at the headend router.

Configure Tear down and Reestablishment of RSVP-TE Tunnels

Configuration Example

Use the **mpls traffic-eng teardown all** command to tear down and reestablish all the RSVP-TE tunnels in a network node. This command must be executed in XR EXEC mode.

```
Router# mpls traffic-eng teardown all
```

Use the **mpls traffic-eng teardown head** command to tear down and reestablish the RSVP-TE tunnels at the headend router. This command must be executed in XR EXEC mode.

```
Router# mpls traffic-eng teardown head
```

Note You can also use the **mpls traffic-eng resetup** command to reestablish tunnels only at the headend router in XR EXEC mode.

Use the **mpls traffic-eng teardown mid** command to tear down and reestablish the RSVP-TE tunnels at the midend router. This command must be executed in XR EXEC mode.

```
Router# mpls traffic-eng teardown mid
```

Use the **mpls traffic-eng teardown tail** command to tear down and reestablish the RSVP-TE tunnels at the tailend router. This command must be executed in XR EXEC mode.

```
Router# mpls traffic-eng teardown tail
```

Use the **show mpls traffic-eng tunnels summary** command to check RSVP-TE tunnel status after you run the teardown command.

```
Router# show mpls traffic-eng tunnels summary
Output received:
Thu Sep 14 10:48:45.007 UTC

        Path Selection Tiebreaker:  Min-fill (default)
              LSP Tunnels Process:  running
                     RSVP Process:  running
                       Forwarding:  enabled
          Periodic reoptimization:  every 3600 seconds, next in 2806 seconds
           Periodic FRR Promotion:  every 300 seconds, next in 9 seconds
      Periodic auto-bw collection:  5 minute(s) (disabled)

Signalling Summary:
    Head: 14006 interfaces, 14006 active signalling attempts, 14006 established
          14006 explicit, 0 dynamic
          14006 activations, 0 deactivations
          0 recovering, 0 recovered
    Mids: 2000
    Tails: 4003

Fast ReRoute Summary:
    Head:     14000 FRR tunnels, 14000 protected, 0 rerouted
    Mid:      2000 FRR tunnels, 2000 protected, 0 rerouted
    Summary:  16000 protected, 13500 link protected, 2500 node protected, 0 bw protected
```

```
    Backup:   6 tunnels, 4 assigned
    Interface: 10 protected, 0 rerouted

Bidirectional Tunnel Summary:
    Tunnel Head: 0 total, 0 connected, 0 associated, 0 co-routed
    Tunnel Tail: 0 total, 0 connected, 0 associated, 0 co-routed
    LSPs Head:   0 established, 0 proceeding, 0 associated, 0 standby
    LSPs Mid:    0 established, 0 proceeding, 0 associated, 0 standby
    LSPs Tail:   0 established, 0 proceeding, 0 associated, 0 standby
```

Configuring Fast Reroute

Fast reroute (FRR) provides link protection to LSPs enabling the traffic carried by LSPs that encounter a failed link to be rerouted around the failure. The reroute decision is controlled locally by the router connected to the failed link. The headend router on the tunnel is notified of the link failure through IGP or through RSVP. When it is notified of a link failure, the headend router attempts to establish a new LSP that bypasses the failure. This provides a path to reestablish links that fail, providing protection to data transfer. The path of the backup tunnel can be an IP explicit path, a dynamically calculated path, or a semi-dynamic path. For detailed conceptual information on fast reroute, see MPLS-TE Features - Details, on page 48

Before You Begin

The following prerequisites are required to create an MPLS-TE tunnel:

- You must have a router ID for the neighboring router.
- Stable router ID is required at either end of the link to ensure that the link is successful. If you do not assign a router ID to the routers, the system defaults to the global router ID. Default router IDs are subject to change, which can result in an unstable link.

Configuration Example

This example configures fast reroute on an MPLS-TE tunnel. Here, tunnel-te 2 is configured as the back-up tunnel. You can use the **protected-by** command to configure path protection for an explicit path that is protected by another path.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# interface tunnel-te 1
RP/0/RP0/CPU0:router(config-if)# fast-reroute
RP/0/RP0/CPU0:router(config-if)# exit
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# interface HundredGigabitEthernet0/0/0/3
RP/0/RP0/CPU0:router(config-mpls-te-if)# backup-path tunnel-te 2
RP/0/RP0/CPU0:router(config)# interface tunnel-te 2
RP/0/RP0/CPU0:router(config-if)# backup-bw global-pool 5000
RP/0/RP0/CPU0:router(config-if)# ipv4 unnumbered Loopback0
RP/0/RP0/CPU0:router(config-if)# destination 192.168.92.125
RP/0/RP0/CPU0:router(config-if)# path-option l explicit name backup-path protected by 10
RP/0/RP0/CPU0:router(config-if)# path-option l0 dynamic
RP/0/RP0/CPU0:router(config)# commit
```

Verification

Use the **show mpls traffic-eng fast-reroute database** command to verify the fast reroute configuration.

```
RP/0/RP0/CPU0:router# show mpls traffic-eng fast-reroute database

Tunnel head FRR information:
```

```
Tunnel       Out intf/label                    FRR intf/label      Status
----------   ----------------                  ----------------    -------
tt4000        HundredGigabitEthernet 0/0/0/3:34     tt1000:34        Ready
tt4001        HundredGigabitEthernet 0/0/0/3:35     tt1001:35        Ready
tt4002        HundredGigabitEthernet 0/0/0/3:36     tt1001:36        Ready
```

Related Topics

- Configuring MPLS-TE, on page 6
- Configuring Auto-Tunnel Backup, on page 13
- Configuring Next Hop Backup Tunnel, on page 16
- MPLS-TE Features - Details, on page 48

Configuring Auto-Tunnel Backup

Table 3: Feature History Table

Feature Name	Release Information	Feature Description
Bandwidth Protection Functions to Enhance auto-tunnel backup Capabilities	Release 7.5.1	This feature introduces bandwidth protection functions for auto-tunnel backups, such as signaled bandwidth, bandwidth protection, and soft-preemption. These functions provide better bandwidth usage and prevent traffic congestion and traffic loss. In earlier releases, auto-tunnel backups provided only link protection and node protection. Backup tunnels were signaled with zero bandwidth, causing traffic congestion when FRR went active. This feature introduces the following commands and keywords: • **bandwidth-protection maximum-aggregate** • **signalled-bandwidth** • **soft-preemption**

The MPLS Traffic Engineering Auto-Tunnel Backup feature enables a router to dynamically build backup tunnels on the interfaces that are configured with MPLS TE tunnels instead of building MPLS-TE tunnels statically.

The MPLS-TE Auto-Tunnel Backup feature has these benefits:

- Backup tunnels are built automatically, eliminating the need for users to pre-configure each backup tunnel and then assign the backup tunnel to the protected interface.
- Protection is expanded—FRR does not protect IP traffic that is not using the TE tunnel or Label Distribution Protocol (LDP) labels that are not using the TE tunnel.

The TE attribute-set template that specifies a set of TE tunnel attributes, is locally configured at the headend of auto-tunnels. The control plane triggers the automatic provisioning of a corresponding TE tunnel, whose characteristics are specified in the respective attribute-set.

Configuration Example

This example configures Auto-Tunnel backup on an interface and specifies the attribute-set template for the auto tunnels. In this example, unused backup tunnels are removed every 20 minutes using a timer and also the range of tunnel interface numbers are specified.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# interface HundredGigabitEthernet0/0/0/3
RP/0/RP0/CPU0:router(config-mpls-te-if)# auto-tunnel backup
RP/0/RP0/CPU0:router(config-mpls-te-if-auto-backup)# attribute-set ab
RP/0/RP0/CPU0:router(config-mpls-te)# auto-tunnel backup timers removal unused 20
RP/0/RP0/CPU0:router(config-mpls-te)# auto-tunnel backup tunnel-id min 6000 max 6500
RP/0/RP0/CPU0:router(config)# commit
```

Verification

This example shows a sample output for automatic backup tunnel configuration.

```
RP/0/RP0/CPU0:router# show mpls traffic-eng tunnels brief

            TUNNEL NAME         DESTINATION      STATUS  STATE
             tunnel-te0           200.0.0.3          up  up
             tunnel-te1           200.0.0.3          up  up
             tunnel-te2           200.0.0.3          up  up
             tunnel-te50          200.0.0.3          up  up
           *tunnel-te60         200.0.0.3         up  up
              *tunnel-te70        200.0.0.3          up  up
              *tunnel-te80        200.0.0.3          up  up
```

Related Topics

- Configuring Fast Reroute , on page 12
- Configuring Next Hop Backup Tunnel, on page 16
- MPLS-TE Features - Details, on page 48

Bandwidth Protection Functions to Enhance auto-tunnel backup Capabilities

Without bandwidth protection, auto-tunnel backups provide only link protection and node protection (per next-next-hop), and backup tunnels are signalled with zero bandwidth. This causes traffic congestion when FRR goes active, since the backup tunnels might be protecting huge amount of data, such as LSPs with large bandwidth or multiple LSPs.

To address the congestion issue, bandwidth protection capabilities are added for auto-tunnel backups. Bandwidth protection, signalled bandwidth, and soft-preemption settings are provided. Details:

- *Bandwidth protection* – A link or node protection backup might not provide bandwidth protection. But with this setting (**bandwidth-protection maximum-aggregate**), you can set the maximum bandwidth value that an auto-tunnel can protect.
- *Signalled bandwidth* – Without bandwidth protection, auto-tunnel backups are signaled with zero bandwidth too, with no guarantee that at least some bandwidth is backed up. So, the backup tunnels might be setup on links that are highly utilized, causing congestion drops when the backup tunnels start to transmit traffic after FRR is triggered.

  This setting (**signalled-bandwidth**) addresses the issue, since you can set the signalled bandwidth of the tunnel (and reserve minimal bandwidth for an auto-tunnel backup). When you set the signal bandwidth value for auto-backup tunnels, congestion over backup links reduces.
- *Soft-preemption* – Since bandwidth can be reserved for autobackup tunnels, a setting (**soft-preemption**) is provided for soft-preemption of the reserved bandwidth, if it is needed for a higher-priority tunnel.

Configurations

```
/*Enable Bandwidth Protection On a TE Auto-Tunnel Backup*/
```

```
Router # configure
Router(config)# mpls traffic-eng
Router(config-mpls-te)# interface GigabitEthernet 0/2/0/0 auto-tunnel backup
Router(config-te-if-auto-backup)# bandwidth-protection maximum-aggregate 100000
Router(config-te-if-auto-backup)# commit
```

```
/*Enable Signalled Bandwidth On a TE Auto-Tunnel Backup*/
```

```
Router # configure
Router(config)# mpls traffic-eng attribute-set auto-backup MyBackupConfig
Router(config-te-attribute-set)# signalled-bandwidth 700000
Router(config-te-attribute-set)# commit
```

After creating the auto backup attribute-set (**MyBackupConfig** in this case), associate with the auto-tunnel backup interface.

```
Router# configure
Router(config)# mpls traffic-eng
Router(config-mpls-te)# interface GigabitEthernet 0/2/0/0 auto-tunnel backup
Router(config-te-if-auto-backup)# attribute-set MyBackupConfig
Router(config-te-if-auto-backup)# auto-tunnel backup tunnel-id min 6000 max 6500
Router(config-mpls-te)# commit
```

```
/*Enable Soft-Preemption Bandwidth On a TE Auto-Tunnel Backup*/
```

```
Router# configure
Router(config)# mpls traffic-eng attribute-set auto-backup MyBackupConfig
Router(config-te-attribute-set)# soft-preemption
Router(config-te-attribute-set)# commit
```

Verification

```
/*Verify Auto-Tunnel Backup Configuration*/
```

In the output, bandwidth protection details are displayed, as denoted by *BW*.

```
Router# show mpls traffic-eng auto-tunnel backup
```

```
AutoTunnel Backup Configuration:
    Interfaces count: 1
    Unused removal timeout: 1h 0m 0s
    Configured tunnel number range: 6000-6500
```

```
AutoTunnel Backup Summary:
    AutoTunnel Backups:
             0 created, 0 up, 0 down, 0 unused
           0 NHOP, 0 NNHOP, 0 SRLG strict, 0 SRLG preferred, 0 SRLG weighted, 0 BW protected

  Protected LSPs:
             0 NHOP, 0 NHOP+SRLG, 0 NHOP+BW, 0 NHOP+BW+SRLG
             0 NNHOP, 0 NNHOP+SRLG, 0 NNHOP+BW, 0 NNHOP+BW+SRLG
    Protected S2L Sharing Families:
             0 NHOP, 0 NHOP+SRLG, 0 NNHOP+BW, 0 NNHOP+BW+SRLG
             0 NNHOP, 0 NNHOP+SRLG, 0 NNHOP+BW, 0 NNHOP+BW+SRLG
    Protected S2Ls:
             0 NHOP, 0 NHOP+SRLG, 0 NNHOP+BW, 0 NNHOP+BW+SRLG
             0 NNHOP, 0 NNHOP+SRLG, 0 NNHOP+BW, 0 NNHOP+BW+SRLG

 Cumulative Counters (last cleared 00:08:47 ago):
                         Total    NHOP  NNHOP
    Created:               0       0      0
    Connected:             0       0      0
    Removed (down):        0       0      0
    Removed (unused):      0       0      0
    Removed (in use):      0       0      0
    Range exceeded:        0       0      0
```

Configuring Next Hop Backup Tunnel

The backup tunnels that bypass only a single link of the LSP path are referred as Next Hop (NHOP) backup tunnels because they terminate at the LSP's next hop beyond the point of failure. They protect LSPs, if a link along their path fails, by rerouting the LSP traffic to the next hop, thus bypassing the failed link.

Configuration Example

This example configures next hop backup tunnel on an interface and specifies the attribute-set template for the auto tunnels. In this example, unused backup tunnels are removed every 20 minutes using a timer and also the range of tunnel interface numbers are specified.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# interface HundredGigabitEthernet0/0/0/3
RP/0/RP0/CPU0:router(config-mpls-te-if)# auto-tunnel backup nhop-only
RP/0/RP0/CPU0:router(config-mpls-te-if-auto-backup)# attribute-set ab
RP/0/RP0/CPU0:router(config-mpls-te)# auto-tunnel backup timers removal unused 20
RP/0/RP0/CPU0:router(config-mpls-te)# auto-tunnel backup tunnel-id min 6000 max 6500
RP/0/RP0/CPU0:router(config)# commit
```

Related Topics

- Configuring Auto-Tunnel Backup, on page 13
- Configuring Fast Reroute , on page 12
- MPLS-TE Features - Details, on page 48

Configuring SRLG Node Protection

Shared Risk Link Groups (SRLG) in MPLS traffic engineering refer to situations in which links in a network share common resources. These links have a shared risk, and that is when one link fails, other links in the group might fail too.

OSPF and IS-IS flood the SRLG value information (including other TE link attributes such as bandwidth availability and affinity) using a sub-type length value (sub-TLV), so that all routers in the network have the SRLG information for each link.

MPLS-TE SRLG feature enhances backup tunnel path selection by avoiding using links that are in the same SRLG as the interfaces it is protecting while creating backup tunnels.

Configuration Example

This example creates a backup tunnel and excludes the protected node IP address from the explicit path.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# interface HundredGigabitEthernet0/0/0/3
RP/0/RP0/CPU0:router(config-mpls-te-if)# backup-path tunnl-te 2
RP/0/RP0/CPU0:router(config-mpls-te-if)# exit
RP/0/RP0/CPU0:router(config)# interface tunnel-te 2
RP/0/RP0/CPU0:router(config-if)# ipv4 unnumbered Loopback0
RP/0/RP0/CPU0:router(config-if)# path-option 1 explicit name backup-srlg
RP/0/RP0/CPU0:router(config-if)# destination 192.168.92.125
RP/0/RP0/CPU0:router(config-if)# exit
RP/0/RP0/CPU0:router(config)# explicit-path name backup-srlg-nodep
RP/0/RP0/CPU0:router(config-if)# index 1 exclude-address 192.168.91.1
RP/0/RP0/CPU0:router(config-if)# index 2 exclude-srlg 192.168.92.2
RP/0/RP0/CPU0:router(config)# commit
```

Related Topics

• Configuring Fast Reroute , on page 12

• MPLS-TE Features - Details, on page 48

Configuring Pre-Standard DS-TE

Regular traffic engineering does not provide bandwidth guarantees to different traffic classes. A single bandwidth constraint is used in regular TE that is shared by all traffic. MPLS DS-TE enables you to configure multiple bandwidth constraints on an MPLS-enabled interface. These bandwidth constraints can be treated differently based on the requirement for the traffic class using that constraint. Cisco IOS XR software supports two DS-TE modes: Pre-standard and IETF. Pre-standard DS-TE uses the Cisco proprietary mechanisms for RSVP signaling and IGP advertisements. This DS-TE mode does not interoperate with third-party vendor equipment. Pre-standard DS-TE is enabled only after configuring the sub-pool bandwidth values on MPLS-enabled interfaces.

Pre-standard Diff-Serve TE mode supports a single bandwidth constraint model a Russian Doll Model (RDM) with two bandwidth pools: global-pool and sub-pool.

Before You Begin

The following prerequisites are required to configure a Pre-standard DS-TE tunnel.

- You must have a router ID for the neighboring router.
- Stable router ID is required at either end of the link to ensure that the link is successful. If you do not assign a router ID to the routers, the system defaults to the global router ID. Default router IDs are subject to change, which can result in an unstable link.

Configuration Example

This example configures a pre-standard DS-TE tunnel.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# rsvp interface HundredGigabitEthernet 0/0/0/3
RP/0/RP0/CPU0:router(config-rsvp-if)# bandwidth 100 150 sub-pool 50
RP/0/RP0/CPU0:router(config-rsvp-if)# exit
RP/0/RP0/CPU0:router(config)# interface tunnel-te 2
RP/0/RP0/CPU0:router(config-if)# signalled bandwidth sub-pool 10
RP/0/RP0/CPU0:router(config)# commit
```

Verification

Use the **show mpls traffic-eng topology** command to verify the pre-standard DS-TE tunnel configuration.

Related Topics

- Configuring an IETF DS-TE Tunnel Using RDM, on page 18
- Configuring an IETF DS-TE Tunnel Using MAM, on page 19
- MPLS-TE Features - Details, on page 48

Configuring an IETF DS-TE Tunnel Using RDM

IETF DS-TE mode uses IETF-defined extensions for RSVP and IGP. This mode interoperate with third-party vendor equipment.

IETF mode supports multiple bandwidth constraint models, including Russian Doll Model (RDM) and Maximum Allocation Model (MAM), both with two bandwidth pools. In an IETF DS-TE network, identical bandwidth constraint models must be configured on all nodes.

Before you Begin

The following prerequisites are required to create a IETF mode DS-TE tunnel using RDM:

- You must have a router ID for the neighboring router.
- Stable router ID is required at either end of the link to ensure that the link is successful. If you do not assign a router ID to the routers, the system defaults to the global router ID. Default router IDs are subject to change, which can result in an unstable link.

Configuration Example

This example configures an IETF DS-TE tunnel using RDM.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# rsvp interface HundredGigabitEthernet 0/0/0/3
RP/0/RP0/CPU0:router(config-rsvp-if)# bandwidth rdm 100 150
RP/0/RP0/CPU0:router(config-rsvp-if)# exit
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# ds-te mode ietf
RP/0/RP0/CPU0:router(config-mpls-te)# exit
RP/0/RP0/CPU0:router(config)# interface tunnel-te 2
RP/0/RP0/CPU0:router(config-if)# signalled bandwidth sub-pool 10 class-type 1
```

```
RP/0/RP0/CPU0:router(config)# commit
```

Verification

Use the **show mpls traffic-eng topology** command to verify the IETF DS-TE tunnel using RDM configuration.

Related Topics

- Configuring Pre-Standard DS-TE, on page 17
- Configuring an IETF DS-TE Tunnel Using MAM, on page 19
- MPLS-TE Features - Details, on page 48

Configuring an IETF DS-TE Tunnel Using MAM

IETF DS-TE mode uses IETF-defined extensions for RSVP and IGP. This mode interoperates with third-party vendor equipment. IETF mode supports multiple bandwidth constraint models, including Russian Doll Model (RDM) and Maximum Allocation Model (MAM), both with two bandwidth pools.

Configuration Example

This example configures an IETF DS-TE tunnel using MAM.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# rsvp interface HundredGigabitEthernet 0/0/0/3
RP/0/RP0/CPU0:router(config-rsvp-if)# bandwidth mam max-reservable-bw 1000 bc0 600 bc1 400
RP/0/RP0/CPU0:router(config-rsvp-if)# exit
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# ds-te mode ietf
RP/0/RP0/CPU0:router(config-mpls-te)# ds-te bc-model mam
RP/0/RP0/CPU0:router(config-mpls-te)# exit
RP/0/RP0/CPU0:router(config)# interface tunnel-te 2
RP/0/RP0/CPU0:router(config-if)# signalled bandwidth sub-pool 10
RP/0/RP0/CPU0:router(config)# commit
```

Verification

Use the **show mpls traffic-eng topology** command to verify the IETF DS-TE tunnel using MAM configuration.

Related Topics

- Configuring an IETF DS-TE Tunnel Using RDM, on page 18
- Configuring Pre-Standard DS-TE, on page 17
- MPLS-TE Features - Details, on page 48

Configuring Flexible Name-Based Tunnel Constraints

MPLS-TE Flexible Name-based Tunnel Constraints provides a simplified and more flexible means of configuring link attributes and path affinities to compute paths for the MPLS-TE tunnels.

In traditional TE, links are configured with attribute-flags that are flooded with TE link-state parameters using Interior Gateway Protocols (IGPs), such as Open Shortest Path First (OSPF).

MPLS-TE Flexible Name-based Tunnel Constraints lets you assign, or map, up to 32 color names for affinity and attribute-flag attributes instead of 32-bit hexadecimal numbers. After mappings are defined, the attributes can be referred to by the corresponding color name.

Configuration Example

This example shows assigning a how to associate a tunnel with affinity constraints.

```
RP/0/RP0/CPU0:router# configure
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# affinity-map red 1
RP/0/RP0/CPU0:router(config-mpls-te)# interface HundredGigabitEthernet0/0/0/3
RP/0/RP0/CPU0:router(config-mpls-te-if)# attribute-names red
RP/0/RP0/CPU0:router(config)# interface tunnel-te 2
RP/0/RP0/CPU0:router(config-if)# affinity include red
RP/0/RP0/CPU0:router(config)# commit
```

Configuring Automatic Bandwidth

Automatic bandwidth allows you to dynamically adjust bandwidth reservation based on measured traffic. MPLS-TE automatic bandwidth monitors the traffic rate on a tunnel interface and resizes the bandwidth on the tunnel interface to align it closely with the traffic in the tunnel. MPLS-TE automatic bandwidth is configured on individual Label Switched Paths (LSPs) at every headend router.

The following table specifies the parameters that can be configured as part of automatic bandwidth configuration.

Table 4: Automatic Bandwidth Parameters

Bandwidth Parameters	Description
Application frequency	Configures how often the tunnel bandwidths changed for each tunnel. The default value is 24 hours.
Bandwidth limit	Configures the minimum and maximum automatic bandwidth to set on a tunnel.
Bandwidth collection frequency	Enables bandwidth collection without adjusting the automatic bandwidth. The default value is 5 minutes.
Overflow threshold	Configures tunnel overflow detection.
Adjustment threshold	Configures the tunnel-bandwidth change threshold to trigger an adjustment.

Configuration Example

This example enables automatic bandwidth on MPLS-TE tunnel interface and configure the following automatic bandwidth variables.

- Application frequency
- Bandwidth limit
- Adjustment threshold

- Overflow detection

```
RP/0/RP0/CPU0:router# configure
RP/0/RP0/CPU0:router(config)# interface tunnel-te 1
RP/0/RP0/CPU0:router(config-if)# auto-bw
RP/0/RP0/CPU0:router(config-if-tunte-autobw)# application 1000
RP/0/RP0/CPU0:router(config-if-tunte-autobw)# bw-limit min 30 max 1000
RP/0/RP0/CPU0:router(config-if-tunte-autobw)# adjustment-threshold 50 min 800
RP/0/RP0/CPU0:router(config-if-tunte-autobw)# overflow threshold 100 limit 1
RP/0/RP0/CPU0:router(config)# commit
```

Verification

Verify the automatic bandwidth configuration using the **show mpls traffic-eng tunnels auto-bw brief** command.

```
RP/0/RP0/CPU0:router# show mpls traffic-eng tunnels auto-bw brief

  Tunnel    LSP  Last appl  Requested  Signalled    Highest    Application
  Name       ID   BW(kbps)   BW(kbps)   BW(kbps)   BW(kbps)      Time Left
  -------------- ------ ---------- ---------- ---------- ---------- --------------
  tunnel-te1      5          500         300        420           1h 10m
```

Related Topics

- MPLS-TE Features - Details, on page 48

Enable per-application accounting for interfaces

The following configurations help enable per-application accounting for MPLS RSVP-TE IPv4 traffic and segment routing with MPLS IPv4 traffic on the interfaces respectively.

Example 1: Enable per-application accounting for MPLS RSVP-TE IPv4 traffic on the interfaces

```
RP/0/RP0/CPU0:router# config
RP/0/RP0/CPU0:router(config)# accounting
RP/0/RP0/CPU0:router(config-acct)# interfaces
RP/0/RP0/CPU0:router(config-acct-if)# mpls
RP/0/RP0/CPU0:router(config-acct-if-mpls)# ipv4 rspv-te
```

Example 2: Enable per-application accounting for segment routing MPLS IPv4 traffic on the interfaces

```
RP/0/RP0/CPU0:router# config
RP/0/RP0/CPU0:router(config)# accounting
RP/0/RP0/CPU0:router(config-acct)# interfaces
RP/0/RP0/CPU0:router (config-acct-if)# segment-routing mpls ipv4
```

Note The dark bandwidth accounting feature is not supported for segment routing with MPLS IPv6 traffic on the router.

Configure RSVP-TE dark bandwidth accounting

Perform these steps to enable RSVP-TE bandwidth accounting and dark bandwidth advertisement for all MPLS-TE enabled links:

Before you begin

Make sure that the traffic accounting feature is enabled on the router.

Procedure

Step 1 **configure**

Example:

```
RP/0/RP0/CPU0:router# configure
```

Enters global configuration mode.

Step 2 **mpls traffic-eng**

Example:

```
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
```

Enters MPLS TE configuration mode.

Step 3 **bandwidth-accounting**

Example:

```
RP/0/RP0/CPU0:router(config-mpls-te)# bandwidth-accounting
```

Enables RSVP-TE dark bandwidth accounting and enters bandwidth accounting configuration mode.

Step 4 **application interval** *seconds*

Example:

```
RP/0/RP0/CPU0:router(config-mpls-te-bw-account)# application interval 90
```

Configures the length of the application interval in seconds. At the end of application interval, dark bandwidth rates are computed and applied to all RSVP-TE enabled interfaces.

Note
Model-driven telemetry supports dark bandwidth. The telemetry polling interval is reduced to 10 seconds.

If the interval is reconfigured while the timer is running, the new value is compared to the time remaining for the running timer. The timer is adjusted so that the lower of these two values is used for this interval. The subsequent interval will use the newly configured value.

Note
TE stores sample history for the current and previous application intervals. If the application interval is lowered, TE may discard the sample history.

Range is from 90 to 1800. The default value is 180.

Step 5 **application enforced**

Example:

```
RP/0/RP0/CPU0:router(config-mpls-te-bw-account)# application enforced
```

Enables enforcement of the calculated effective maximum reservable bandwidth rate. This configuration is mandatory for the RSVP dark bandwidth accounting feature to work properly.

Step 6 **adjustment-factor** *percentage*

Example:

```
RP/0/RP0/CPU0:router(config-mpls-te-bw-account)# adjustment-factor 85
```

Configures TE to over-book (>100%) or under-book (<100%) the effective maximum reservable bandwidth. The measured dark-bandwidth will be scaled based on the adjustment factor. Range is from 0 to 200. The default value is 100.

Step 7 **sampling-interval** *seconds*

Example:

```
RP/0/RP0/CPU0:router(config-mpls-te-bw-account)# sampling-interval 30
```

Configures the length of the sampling interval in seconds. The bandwidth rate is collected from the statistics collector process (statsD) at the end of each sampling interval for each TE link.

If the interval is reconfigured while the timer is running, the new value is compared to the time remaining for the running timer. The timer is adjusted so that the lower of these two values is used for this interval. The subsequent interval will use the newly configured value.

Range is from 30 to 600. The default is 60.

Step 8 **flooding threshold** { **up** | **down** } *percentage*

Example:

```
RP/0/RP0/CPU0:router(config-mpls-te-bw-account)# flooding threshold up 30 down 30
```

Configures the reserved bandwidth thresholds. When bandwidth crosses one of these thresholds, flooding is triggered. Range is from 0 to 100. The default value is 10.

Step 9 **commit**

Step 10 **show mpls traffic-eng link-management summary**

Example:

```
RP/0/RP0/CPU0:router# show mpls traffic-eng link-management summary
```

(Optional)

Displays a summary of link management information, including bandwidth accounting information.

Step 11 **show mpls traffic-eng link-management advertisements**

Example:

```
RP/0/RP0/CPU0:router# show mpls traffic-eng link-management advertisements
```

(Optional)

Displays local link information that MPLS-TE link management is currently flooding into the global TE topology.

Step 12 **show mpls traffic-eng link-management interfaces** [*type interface-path-id*]

Example:

```
RP/0/RP0/CPU0:router# show mpls traffic-eng link-management interfaces gig0/1/1/1 detail
```

(Optional)

Displays bandwidth accounting and utilization details and link management information.

Autoroute Announce

The segment routing tunnel can be advertised into an Interior Gateway Protocol (IGP) as a next hop by configuring the autoroute announce statement on the source router. The IGP then installs routes in the Routing Information Base (RIB) for shortest paths that involve the tunnel destination. Autoroute announcement of IPv4 prefixes can be carried through either OSPF or IS-IS. Autoroute announcement of IPv6 prefixes can be carried only through IS-IS. IPv6 forwarding over tunnel needs additional parameter in tunnel configuration.

Restrictions

The Autoroute Announce feature is supported with the following restrictions:

- A maximum on 128 tunnels can be announced.
- Tunnels in ECMP may not be path diverse.

Note Configuring Segment Routing and Autoroute Destination together is not supported. If autoroute functionality is required in an Segment Routing network, we recommend you to configure Autoroute Announce.

Configuration

To specify that the Interior Gateway Protocol (IGP) should use the tunnel (if the tunnel is up) in its enhanced shortest path first (SPF) calculation, use the **autoroute announce** command in interface configuration mode.

```
RP/0/RP0/CPU0:router# configure
RP/0/RP0/CPU0:router(config)# interface tunnel-te 10
RP/0/RP0/CPU0:router(config-if)# autoroute announce [include-ipv6]
RP/0/RP0/CPU0:router(config-if)# commit
```

Verification

Verify the route using the following commands:

```
RP/0/RP0/CPU0:router# Show route
Mon Aug  8 00:31:29.406 UTC

Codes: C - connected, S - static, R - RIP, B - BGP, (>) - Diversion path
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - ISIS, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, su - IS-IS summary null, * - candidate default
       U - per-user static route, o - ODR, L - local, G  - DAGR, l - LISP
       A - access/subscriber, a - Application route
       M - mobile route, r - RPL, (!) - FRR Backup path

Gateway of last resort is not set

i L1 9.1.0.0/24 [115/30] via 9.9.9.9, 2d19h, tunnel-te3195
                [115/30] via 9.9.9.9, 2d19h, tunnel-te3196
                [115/30] via 9.9.9.9, 2d19h, tunnel-te3197
                [115/30] via 9.9.9.9, 2d19h, tunnel-te3198
                [115/30] via 9.9.9.9, 2d19h, tunnel-te3199
                [115/30] via 9.9.9.9, 2d19h, tunnel-te3200
                [115/30] via 9.9.9.9, 2d19h, tunnel-te3201
                [115/30] via 9.9.9.9, 2d19h, tunnel-te3202
i L1 9.9.9.9/32 [115/30] via 9.9.9.9, 2d22h, tunnel-te3195
                [115/30] via 9.9.9.9, 2d22h, tunnel-te3196
                [115/30] via 9.9.9.9, 2d22h, tunnel-te3197
                [115/30] via 9.9.9.9, 2d22h, tunnel-te3198
                [115/30] via 9.9.9.9, 2d22h, tunnel-te3199
                [115/30] via 9.9.9.9, 2d22h, tunnel-te3200
                [115/30] via 9.9.9.9, 2d22h, tunnel-te3201
                [115/30] via 9.9.9.9, 2d22h, tunnel-te3202

RP/0/RP0/CPU0:router# show route ipv6
Tue Apr 26 04:02:07.968 UTC

Codes: C - connected, S - static, R - RIP, B - BGP, (>) - Diversion path
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - ISIS, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, su - IS-IS summary null, * - candidate default
       U - per-user static route, o - ODR, L - local, G  - DAGR, l - LISP
       A - access/subscriber, a - Application route
       M - mobile route, r - RPL, (!) - FRR Backup path

Gateway of last resort is not set

L    ::ffff:127.0.0.0/104
      [0/0] via ::, 00:17:36
C    2002::/64 is directly connected,
      00:39:01, TenGigE0/0/0/2
L    2002::1/128 is directly connected,
      00:39:01, TenGigE0/0/0/2
i L1 2003::/64
      [115/20] via ::, 00:02:32, tunnel-te992
      [115/20] via ::, 00:02:32, tunnel-te993
      [115/20] via ::, 00:02:32, tunnel-te994
      [115/20] via ::, 00:02:32, tunnel-te995
      [115/20] via ::, 00:02:32, tunnel-te996
      [115/20] via ::, 00:02:32, tunnel-te997
      [115/20] via ::, 00:02:32, tunnel-te998
      [115/20] via ::, 00:02:32, tunnel-te999
C    2006::/64 is directly connected,
      00:39:01, TenGigE0/0/0/6
L    2006::1/128 is directly connected,
```

```
      00:39:01, TenGigE0/0/0/6
i L1 2007::/64
      [115/20] via ::, 00:02:32, tunnel-te992
      [115/20] via ::, 00:02:32, tunnel-te993
      [115/20] via ::, 00:02:32, tunnel-te994
      [115/20] via ::, 00:02:32, tunnel-te995
      [115/20] via ::, 00:02:32, tunnel-te996
      [115/20] via ::, 00:02:32, tunnel-te997
      [115/20] via ::, 00:02:32, tunnel-te998
      [115/20] via ::, 00:02:32, tunnel-te999

show cef ipv6 2007::5 hardware egress location 0/0/CPU0
Sun May  1 03:18:55.151 UTC 2007::/64, version 50, internal 0x1000001 0x0 (ptr 0x895e819c)
 [1], 0x0 (0x894d3678), 0x0 (0x0)  Updated May  1 03:13:49.066  Prefix Len 64, traffic index
 0, precedence n/a, priority 2
   via ::/128, tunnel-te1, 2 dependencies, weight 0, class 0 [flags 0x0]
    path-idx 0 NHID 0x0 [0x8b5ea420 0x0]
    next hop ::/128
    local adjacency
   via ::/128, tunnel-te2, 2 dependencies, weight 0, class 0 [flags 0x0]
    path-idx 1 NHID 0x0 [0x8b5ea5e0 0x0]
    next hop ::/128
    local adjacency


 LEAF - HAL pd context :
 sub-type : IPV6, ecd_marked:0, has_collapsed_ldi:0  collapse_bwalk_required:0, ecdv2_marked:0
 HW Walk:
LEAF:
    Handle: 0xaabbccdd type: 1 FEC handle: 0x8999fb18

    LWLDI:
        PI:0x894d3678 PD:0x894d36b8 rev:214 p-rev:212 ldi type:3
        FEC hdl: 0x8999fb18 fec index: 0x0(0) num paths:2, bkup: 0

        SHLDI:
            PI:0x893658e8 PD:0x89365968 rev:212 p-rev:0 flag:0x0
            FEC hdl: 0x8999fb18 fec index: 0x20000002(2) num paths: 2 bkup paths: 2
            Path:0 fec index: 0x20004000(16384) DSP:0x440 Dest fec index: 0x2000101c(4124)
            Path:1 fec index: 0x20004002(16386) DSP:0x440 Dest fec index: 0x2000101c(4124)
            Path:2 fec index: 0x20004001(16385) DSP:0x440 Dest fec index: 0x2000101c(4124)
            Path:3 fec index: 0x20004003(16387) DSP:0x440 Dest fec index: 0x2000101c(4124)

V6TE NH HAL PD context :
pdptr 0x8b5ea488, flags :1, index:0

              TE-NH:
              Flag: PHP HW Tun_O_Tun frr_active_chg te_protect_chg , PD(0x880d1640), Push:
 0, Swap: 0, Link: 0
            ifhandle:0x800001c llabel:24001 FEC hdl: 0x896d4eb8 fec index: 0x20001022(4130),
 SRTE fec hdl:(nil)

V6TE NH HAL PD context :
pdptr 0x8b5ea648, flags :1, index:0

              TE-NH:
              Flag: PHP HW , PD(0x880d12d0), Push: 0, Swap: 0, Link: 0x8b34d518
            ifhandle:0x8000024 llabel:24000 FEC hdl: 0x896d4238 fec index: 0x2000101c(4124),
 SRTE fec hdl:(nil)
```

Autoroute announce with IS-IS

Autoroute Announce (AA) with IS-IS is a feature that allows routers to install MPLS-TE tunnels to destinations based on the shortest path calculated by IS-IS, improving traffic engineering and path selection for anycast prefixes.

Table 5: Feature History Table

Feature Name	Release	Feature Description
MPLS-TE IPv6-only autoroute announce	Release 25.4.1	Introduced in this release on: NCS 5500 fixed port routers; NCS 5700 fixed port routers; NCS 5500 modular routers (NCS 5500 line cards; NCS 5700 line cards [Mode: Compatibility; Native]) This feature allows you to disable IPv4 autoroute announce without turning off autoroute announce entirely. To achieve IPv6-only announcements over MPLS-TE tunnels, use the new **exclude-ipv4** option along with the **include-ipv6** option in the autoroute announce configuration. This feature introduces these changes: CLI: A new keyword, **exclude-ipv4**, has been added to the **autoroute announce** command.

Feature Name	Release	Feature Description
Autoroute announce with IPv6 destination address for IS-IS	Release 25.2.1	Introduced in this release on: NCS 5500 fixed port routers; NCS 5700 fixed port routers; NCS 5500 modular routers (NCS 5500 line cards; NCS 5700 line cards [Mode: Compatibility; Native]) The autoroute announce feature now allows an MPLS-TE tunnel as the nexthop for IPv6 destinations thus ensuring a seamless IPv6 traffic engineering. IS-IS uses this IPv6 destination address when filtering prefixes. This feature introduces these changes: CLI: Two new keywords, **destination** and **ipv6**, were introduced in the **autoroute announce** command.

Feature Name	Release	Feature Description
Autoroute announce with IS-IS for anycast prefixes	Release 7.5.4	We have enabled seamless migration from autoroute announce (AA) tunnels with OSPF to AA tunnels with IS-IS. This is possible because you can now use AA tunnels with IS-IS to calculate the underlying native IGP metric for anycast prefixes to select the shortest path and then select a tunnel on that shortest path. Previously, autoroute announce tunnels with IS-IS behaved differently as compared to OSPF. IS-IS used the autoroute announce metric whereas, OSPF uses the underlying native IGP cost. With this feature the router uses the same method of cost calculation in autoroute announce in both OSPF and IS-IS. This feature introduces these: • CLI: **anycast-prefer-igp-cost** • YANG Data model: New Xpaths for Cisco-IOS-XR-um-router-isis-cfg.yang and Cisco-IOS-XR-clns-isis-cfg.yang (see GitHub and Yang Data Navigator)

When you configure Autoroute Announce (AA) tunnels, IGP installs the tunnel to the destination in the Routing Information Base (RIB) for the shortest paths. However, the behavior of AA for anycast destination is different from IS-IS compared to OSPF.

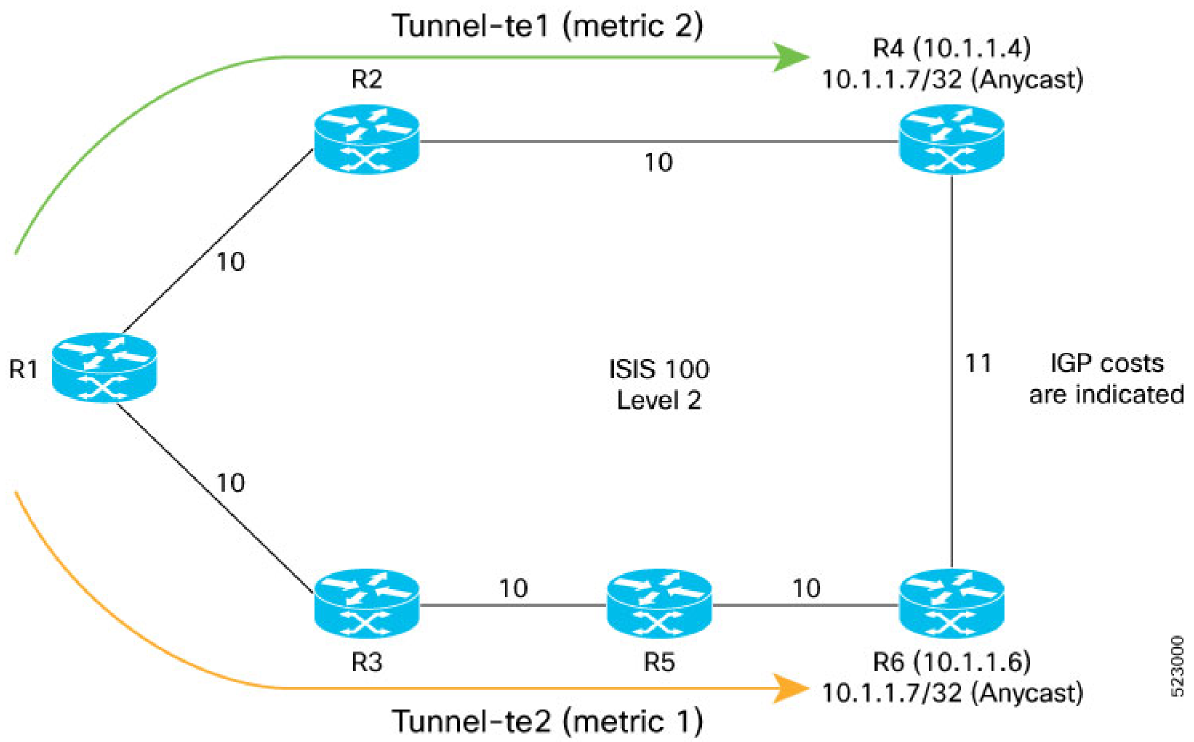
- IS-IS: AA tunnel with IS-IS considers the AA metric to calculate the prefix reachability for the shortest path.
- OSPF: AA with OSPF uses the lowest IGP cost to find the shortest path. And, then use the TE tunnel which is on that shortest path.

We now introduce the **anycast-prefer-igp-cost** command for AA tunnel with IS-IS anycast prefixes to allow the router to choose the shortest IGP path and select the tunnel on that shortest path, similar to OSPF behavior.

Starting from Cisco IOS XR Release 25.4.1, the autoroute announce feature restricts the usage of MPLS-TE tunnels by IGP to IPv6 prefixes. To enable the IPv6-only autoroute announce feature, configure the **autoroute announce exclude-ipv4** and **autoroute announce include-ipv6** commands.

Topology

Using this topology, let's see how the shortest path is chosen based on the IGP cost:



- In this topology, R1 is the headend and has MPLS RSVP-TE tunnels to R2 and R3.
- The tunnel destinations are loopback addresses of R4 and R6, which is 10.1.1.4 and 10.1.1.6.
- R1 uses AA to allow traffic to prefixes advertised by R2 and R3 to go over the MPLS-TE tunnel.
- Two AA tunnels are configured with different metrics and destinations. Tunnel-te1 has a metric value of 2 and tunnel-te2 has a metric value of 1.
- R1 can reach the anycast prefix (10.1.1.7/32) using two paths R1-R2-R4 and R1-R3-R5-R6.
- To reach the anycast prefix, the IGP cost is 20 for the R1-R2-R4 path and it is 30 for the R1-R3-R5-R6 path. Based on the IGP metric, the R1-R2-R4 path is the shortest path.
- With IS-IS, by default, the AA tunnel considers the tunnel metric to forward the traffic. In this topology, tunnel-te2 has a lower metric value when compared to tunnel-te1. As the AA metric is considered and the traffic is forwarded through te-2.
- When this feature is enabled, the IGP cost is first considered for the shortest path like AA with OSPF.

  In this topology, the R1-R2-R4 path is considered as the IGP cost is 20 that lower when compared to tunnel-te2, which is 30. Then the MPLS-TE tunnel on that path is considered, which is tunnel-te1.

Configure IPv6-only autoroute announce over MPLS-TE tunnels

Perform these steps to configure IPv6-only autoroute announce over MPLS-TE tunnels:

Procedure

Step 1 **configure**

Step 2 **interface tunnel-te** *tunnel-id*

Example:

```
RP/0/RP0/CPU0:router(config)# interface tunnel-te 1
```

Configures an MPLS-TE tunnel interface.

Step 3 **autoroute announce include-ipv6**

Example:

```
RP/0/RP0/CPU0:router(config-if)# autoroute announce include-ipv6
```

Enables IPv6 autoroute announce.

Step 4 **exclude-ipv4**

Example:

```
RP/0/RP0/CPU0:router(config-if-tunte-aa)# exclude-ipv4
```

Disables IPv4 autoroute announce.

Step 5 **commit**

Step 6 (Optional) **show mpls traffic-eng autoroute**

Example:

```
RP/0/RP0/CPU0:router#show mpls traffic-eng autoroute

  Destination 192.168.0.2 has 1 tunnels in IS-IS ring level 1
    T1 (traffic share 0, nexthop 192.168.0.3,  metric 0)
    (IS-IS ring level-1, IPV6 Unicast)
    Signalled-Name: T1
```

Verifies that the tunnel announces IPv6-only autoroute information.

Configure IGP path selection for anycast prefixes

This procedure provides the steps to configure MPLS RSVP-TE and enable **anycast-prefer-igp-cost** with IS-IS.

Procedure

Step 1 Configure MPLS RSVP-TE.

Example:

```
/* Configure MPLS RSVP-TE */
Router(config)#interface tunnel-te1
```

```
Router(config-if)#ipv4 unnumbered Loopback0
Router(config-if)#autoroute announce
Router(config-if-tunte-aa)#metric 2
Router(config-if-tunte-aa)#exit
Router(config-if)#destination 10.1.1.4
Router(config-if)#path-option 1 dynamic
Router(config-if)#commit

Router(config)#interface tunnel-te2
Router(config-if)#ipv4 unnumbered Loopback0
Router(config-if)#autoroute announce
Router(config-if-tunte-aa)#metric 1
Router(config-if-tunte-aa)#exit
Router(config-if)#destination 10.1.1.6
Router(config-if)#path-option 1 dynamic
Router(config-if)#exit
Router(config)#commit
```

Step 2 Enable **anycast-prefer-igp-cost** with IS-IS.

Example:

```
Router#configure
Router(config)#router isis 100
Router(config-isis)#is-type level-2-only
Router(config-isis)#net 47.2377.50ea.ffff.988a.2d13.00
Router(config-isis)#address-family ipv4 unicast
Router(config-isis-af)#metric-style wide
Router(config-isis-af)#mpls traffic-eng level-2-only
Router(config-isis-af)#mpls traffic-eng router-id Loopback0
Router(config-isis-af)#mpls traffic-eng tunnel anycast-prefer-igp-cost
Router(config-isis-af)#maximum-paths 64
Router(config-isis-af)#commit
```

Step 3 Use the **show running config** to view the running configuration details.

Example:

```
Router# show running-config
interface tunnel-te1
 ipv4 unnumbered Loopback0
 autoroute announce
  metric 2
 !
 destination 10.1.1.4
 path-option 1 dynamic
!
interface tunnel-te2
 ipv4 unnumbered Loopback0
 autoroute announce
  metric 1
 !
 destination 10.1.1.6
 path-option 1 dynamic
!
router isis 100
 is-type level-2-only
 net 47.2377.50ea.ffff.988a.2d13.00
 address-family ipv4 unicast
  metric-style wide
  mpls traffic-eng level-2-only
  mpls traffic-eng router-id Loopback0
  mpls traffic-eng tunnel anycast-prefer-igp-cost
  maximum-paths 64
```

```
 !
!
end
```

Step 4 Execute the **show route** command to verify the configuration.

- When you enable **anycast-prefer-igp-cost**, the traffic is forwarded through tunnel-te1:

```
Router#show route 10.1.1.7/32
Routing entry for 10.1.1.7/32
  Known via "isis 100", distance 115, metric 12, type level-2
  Installed Nov  3 09:48:39.520 for 00:00:05
  Routing Descriptor Blocks
    10.1.1.4, from 10.1.1.4, via tunnel-te1
      Route metric is 20
```

- When you disable **anycast-prefer-igp-cost**, the traffic is forwarded through tunnel-te2:

```
Router#show route 10.1.1.7/32
Routing entry for 10.1.1.7/32
  Known via "isis 100", distance 115, metric 11, type level-2
  Installed Nov  3 09:25:38.162 for 00:18:23
  Routing Descriptor Blocks
    10.1.1.6, from 10.1.1.6, via tunnel-te2
      Route metric is 11
```

Configuring Auto-Tunnel Mesh

The MPLS-TE auto-tunnel mesh (auto-mesh) feature allows you to set up full mesh of TE Point-to-Point (P2P) tunnels automatically with a minimal set of MPLS traffic engineering configurations. You can configure one or more mesh-groups and each mesh-group requires a destination-list (IPv4 prefix-list) listing destinations, which are used as destinations for creating tunnels for that mesh-group.

You can configure MPLS-TE auto-mesh type attribute-sets (templates) and associate them to mesh-groups. Label Switching Routers (LSRs) can create tunnels using the tunnel properties defined in this attribute-set.

Auto-Tunnel mesh configuration minimizes the initial configuration of the network. You can configure tunnel properties template and mesh-groups or destination-lists on TE LSRs that further creates full mesh of TE tunnels between those LSRs. It eliminates the need to reconfigure each existing TE LSR in order to establish a full mesh of TE tunnels whenever a new TE LSR is added in the network.

Configuration Example

This example configures an auto-tunnel mesh group and specifies the attributes for the tunnels in the mesh-group.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# auto-tunnel mesh
RP/0/RP0/CPU0:router(config-mpls-te-auto-mesh)# tunnel-id min 1000 max 2000
RP/0/RP0/CPU0:router(config-mpls-te-auto-mesh)# group 10
RP/0/RP0/CPU0:router(config-mpls-te-auto-mesh-group)# attribute-set 10
RP/0/RP0/CPU0:router(config-mpls-te-auto-mesh-group)# destination-list dl-65
RP/0/RP0/CPU0:router(config-mpls-te)# attribute-set auto-mesh 10
RP/0/RP0/CPU0:router(config-mpls-te-attribute-set)# autoroute announce
RP/0/RP0/CPU0:router(config-mpls-te-attribute-set)# auto-bw collect-bw-only
RP/0/RP0/CPU0:router(config)# commit
```

Verification

Verify the auto-tunnel mesh configuration using the **show mpls traffic-eng auto-tunnel mesh** command.

```
RP/0/RP0/CPU0:router# show mpls traffic-eng auto-tunnel mesh

Auto-tunnel Mesh Global Configuration:
  Unused removal timeout: 1h 0m 0s
  Configured tunnel number range: 1000-2000

Auto-tunnel Mesh Groups Summary:
  Mesh Groups count: 1
  Mesh Groups Destinations count: 3
  Mesh Groups Tunnels count:
    3 created, 3 up, 0 down, 0 FRR enabled

Mesh Group: 10 (3 Destinations)
  Status: Enabled
  Attribute-set: 10
  Destination-list: dl-65 (Not a prefix-list)
  Recreate timer: Not running
       Destination    Tunnel ID    State  Unused timer
  ----------------  -----------  -------  ------------
       192.168.0.2         1000     up   Not running
       192.168.0.3         1001     up   Not running
       192.168.0.4         1002     up   Not running
  Displayed 3 tunnels, 3 up, 0 down, 0 FRR enabled

Auto-mesh Cumulative Counters:
  Last cleared: Wed Oct  3 12:56:37 2015 (02:39:07 ago)
                      Total
  Created:                3
  Connected:              0
  Removed (unused):       0
  Removed (in use):       0
  Range exceeded:         0
```

Configuring an MPLS Traffic Engineering Interarea Tunneling

The MPLS TE Interarea Tunneling feature allows you to establish MPLS TE tunnels that span multiple Interior Gateway Protocol (IGP) areas and levels. This feature removes the restriction that required the tunnel headend and tailend routers both to be in the same area. The IGP can be either Intermediate System-to-Intermediate System (IS-IS) or Open Shortest Path First (OSPF).To configure an inter-area tunnel, you specify on the headend router a loosely routed explicit path for the tunnel label switched path (LSP) that identifies each area border router (ABR) the LSP should traverse using the next-address loose command. The headend router and the ABRs along the specified explicit path expand the loose hops, each computing the path segment to the next ABR or tunnel destination.

Configuration Example

This example configures an IPv4 explicit path with ABR configured as loose address on the headend router.

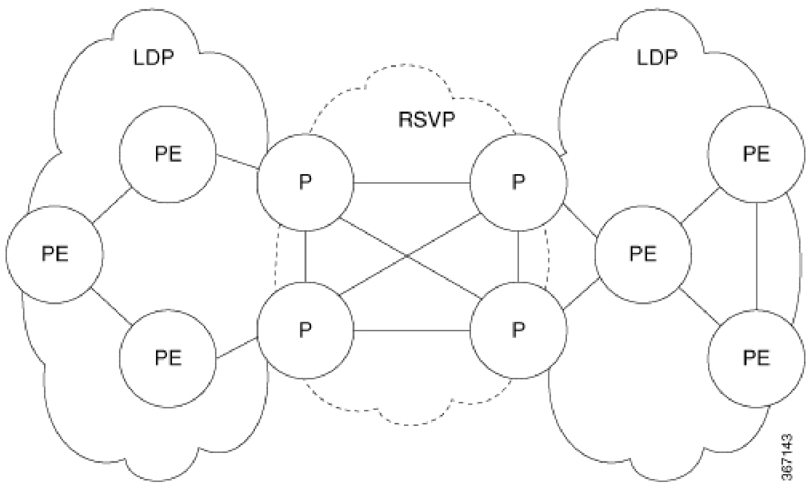
```
Router# configure
Router(config)# explicit-path name interarea1
Router(config-expl-path)# index1 next-address loose ipv4 unicast 172.16.255.129
Router(config-expl-path)# index 2 next-address loose ipv4 unicast 172.16.255.131
Router(config)# interface tunnel-te1
Router(config-if)# ipv4 unnumbered Loopback0
Router(config-if)# destination 172.16.255.2
Router(config-if)# path-option 10 explicit name interarea1
Router(config)# commit
```

Configuring LDP over MPLS-TE

LDP and RSVP-TE are signaling protocols used for establishing LSPs in MPLS networks. While LDP is easy to configure and reilable, it lacks the traffic engineering capabilities of RSVP that helps to avoid traffic congestions. LDP over MPLS-TE feature combines the benefits of both LDP and RSVP. In LDP over MPLS-TE, an LDP signalled label-switched path (LSP) runs through a TE tunnel established using RSVP-TE.

The following diagram explains a use case for LDP over MPLS-TE. In this diagram, LDP is used as the signalling protocol between provider edge (PE) router and provider (P) router. RSVP-TE is used as the signalling protocol between the P routers to establish an LSP. LDP is tunneled over the RSVP-TE LSP.

Figure 3: LDP over MPLS-TE



Restrictions and Guidelines for LDP over MPLS-TE

The following restrictions and guidelines apply for this feature in Cisco IOS-XR release 6.3.2:

- MPLS services over LDP over MPLS-TE are supported when BGP neighbours are on the head or tail node of the TE tunnel.
- MPLS services over LDP over MPLS-TE are supported when the TE headend router is acting as transit point for that service.
- If MPLS services are originating from the TE headend, but the TE tunnel is ending before the BGP peer, LDP over MPLS-TE feature is not supported.
- If LDP optimization is enabled using the **hw-module fib mpls ldp lsr-optimized** command, the following restrictions apply:
  - EVPN is not supported.
  - For any prefix or label all outgoing paths has to be LDP enabled.
- Do not use the **hw-module fib mpls ldp lsr-optimized** command on a Provider Edge (PE) router because already configured features such as EVPN, MPLS-VPN, and L2VPN might not work properly.

Configuration Example:

This example shows how to configure an MPLS-TE tunnel from provider router P1 to P2 and then enbale LDP over MPLS-TE. In this example, the destination of the tunnel from P1 is configured as the loop back for P2.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# interface tunnel-te 1
RP/0/RP0/CPU0:router(config-if)# ipv4 unnumbered Loopback0
RP/0/RP0/CPU0:router(config-if)# autoroute announce
RP/0/RP0/CPU0:router(config-if)# destination 4.4.4.4
RP/0/RP0/CPU0:router(config-if)# path-option 1 dynamic
RP/0/RP0/CPU0:router(config-if)# exit
RP/0/RP0/CPU0:Router(config)#  mpls ldp
RP/0/RP0/CPU0:Router(config-ldp)#  router-id 192.168.1.1
RP/0/RP0/CPU0:Router(config-ldp)#  interface TenGigE 0/0/0/0
RP/0/RP0/CPU0:Router(config-ldp-if)# interface tunnel-te 1
RP/0/RP0/CPU0:Router(config-ldp-if)# exit
```

Configuring MPLS-TE Path Protection

Path protection provides an end-to-end failure recovery mechanism for MPLS-TE tunnels. A secondary Label Switched Path (LSP) is established, in advance, to provide failure protection for the protected LSP that is carrying a tunnel's TE traffic. When there is a failure on the protected LSP, the source router immediately enables the secondary LSP to temporarily carry the tunnel's traffic. Failover is triggered by a RSVP error message sent to the LSP head end. Once the head end received this error message, it switches over to the secondary tunnel. If there is a failure on the secondary LSP, the tunnel no longer has path protection until the failure along the secondary path is cleared. Path protection can be used within a single area (OSPF or IS-IS), external BGP [eBGP], and static routes. Both the explicit and dynamic path-options are supported for the MPLS-TE path protection feature. You should make sure that the same attributes or bandwidth requirements are configured on the protected option.

Before You Begin

The following prerequisites are required for enabling path protection.

- You should ensure that your network supports MPLS-TE, Cisco Express Forwarding, and Intermediate System-to-Intermediate System (IS-IS) or Open Shortest Path First (OSPF).
- You should configure MPLS-TE on the routers.

Configuration Example

This example configures how to configure path protection for a mpls-te tunnel. The primary path-option should be present to configure path protection. In this configuration, R1 is the headend router and R3 is the tailend router for the tunnel while R2 and R4 are mid-point routers. In this example, 6 explicit paths and 1 dynamic path is created for path protection. You can have upto 8 path protection options for a primary path.

```
RP/0/RP0/CPU0:router # configure
RP/0/RP0/CPU0:router(config)# interface tunnel-te 0
RP/0/RP0/CPU0:router(config-if)# destination 192.168.3.3
RP/0/RP0/CPU0:router(config-if)# ipv4 unnumbered Loopback0
RP/0/RP0/CPU0:router(config-if)# autoroute announce
RP/0/RP0/CPU0:router(config-if)# path-protection
RP/0/RP0/CPU0:router(config-if)# path-option 1 explicit name r1-r2-r3-00 protected-by 2
RP/0/RP0/CPU0:router(config-if)# path-option 2 explicit name r1-r2-r3-01 protected-by 3
RP/0/RP0/CPU0:router(config-if)# path-option 3 explicit name r1-r4-r3-01 protected-by 4
RP/0/RP0/CPU0:router(config-if)# path-option 4 explicit name r1-r3-00 protected-by 5
```

```
RP/0/RP0/CPU0:router(config-if)# path-option 5 explicit name r1-r2-r4-r3-00 protected-by 6
RP/0/RP0/CPU0:router(config-if)# path-option 6 explicit name r1-r4-r2-r3-00 protected-by 7
RP/0/RP0/CPU0:router(config-if)# path-option 7 dynamic
RP/0/RP0/CPU0:router(config-if)# exit
RP/0/RP0/CPU0:router(config)# commit
```

Verification

Use the **show mpls traffic-eng tunnels** command to verify the MPLS-TE path protection configuration.

```
RP/0/RP0/CPU0:router# show mpls traffic-eng tunnels 0
Fri Oct 13 16:24:39.379 UTC
Name: tunnel-te0  Destination: 192.168.92.125  Ifhandle:0x8007d34
  Signalled-Name: router
  Status:
    Admin:    up Oper:   up   Path:  valid   Signalling: connected
    path option 1,  type explicit r1-r2-r3-00 (Basis for Setup, path weight 2)
      Protected-by PO index: 2
    path option 2,  type explicit r1-r2-r3-01 (Basis for Standby, path weight 2)
      Protected-by PO index: 3
    path option 3,  type explicit r1-r4-r3-01
      Protected-by PO index: 4
    path option 4,  type explicit r1-r3-00
      Protected-by PO index: 5
    path option 5,  type explicit r1-r2-r4-r3-00
      Protected-by PO index: 6
    path option 6,  type explicit r1-r4-r2-r3-00
      Protected-by PO index: 7
    path option 7,  type dynamic
    G-PID: 0x0800 (derived from egress interface properties)
    Bandwidth Requested: 0 kbps  CT0
    Creation Time: Fri Oct 13 15:05:28 2017 (01:19:11 ago)
  Config Parameters:
    Bandwidth:        0 kbps (CT0) Priority:  7  7 Affinity: 0x0/0xffff
    Metric Type: TE (global)
    Path Selection:
      Tiebreaker: Min-fill (default)
    Hop-limit: disabled
    Cost-limit: disabled
    Delay-limit: disabled
    Path-invalidation timeout: 10000 msec (default), Action: Tear (default)
    AutoRoute:  enabled  LockDown: disabled   Policy class: not set
    Forward class: 0 (not enabled)
    Forwarding-Adjacency: disabled
    Autoroute Destinations: 0
    Loadshare:          0 equal loadshares
    Auto-bw: disabled
    Fast Reroute: Disabled, Protection Desired: None
    Path Protection: Enabled
    BFD Fast Detection: Disabled
    Reoptimization after affinity failure: Enabled
    Soft Preemption: Disabled
  History:
    Tunnel has been up for: 01:14:13 (since Fri Oct 13 15:10:26 UTC 2017)
    Current LSP:
      Uptime: 01:14:13 (since Fri Oct 13 15:10:26 UTC 2017)
    Reopt. LSP:
      Last Failure:
        LSP not signalled, identical to the [CURRENT] LSP
        Date/Time: Fri Oct 13 15:08:41 UTC 2017 [01:15:58 ago]
    Standby Reopt LSP:
      Last Failure:
        LSP not signalled, identical to the [STANDBY] LSP
        Date/Time: Fri Oct 13 15:08:41 UTC 2017 [01:15:58 ago]
```

```
          First Destination Failed: 192.3.3.3
      Prior LSP:
        ID: 8 Path Option: 1
        Removal Trigger: path protection switchover
      Standby LSP:
        Uptime: 01:13:56 (since Fri Oct 13 15:10:43 UTC 2017)
    Path info (OSPF 1 area 0):
    Node hop count: 2
    Hop0: 192.168.1.2
    Hop1: 192.168.3.1
    Hop2: 192.168.3.2
    Hop3: 192.168.3.3
    Standby LSP Path info (OSPF 1 area 0), Oper State: Up :
    Node hop count: 2
    Hop0: 192.168.2.2
    Hop1: 192.168.3.1
    Hop2: 192.168.3.2
    Hop3: 192.168.3.3
  Displayed 1 (of 4001) heads, 0 (of 0) midpoints, 0 (of 0) tails
  Displayed 1 up, 0 down, 0 recovering, 0 recovered heads
```

Configuring Auto-bandwidth Bundle TE++

Table 6: Feature History Table

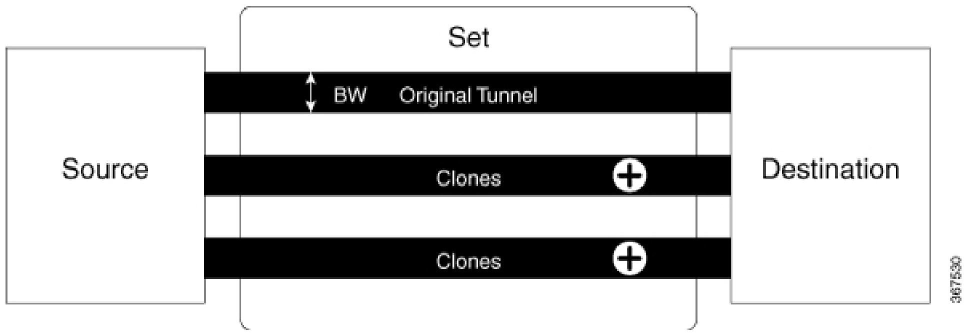
Feature Name	Release Information	Feature Description
Automatic Bandwidth Bundle TE++ for Numbered Tunnels	Release 7.10.1	Introduced in this release on: NCS 5700 fixed port routers; NCS 5500 modular routers (NCS 5700 line cards [Mode: Compatibility; Native]) We have optimized network performance and enabled efficient utilization of resources for numbered tunnels based on real-time traffic by automatically adding or removing tunnels between two endpoints. This is made possible because this release introduces support for auto-bandwidth TE++ for numbered tunnels, expanding upon the previous support for only named tunnels, letting you define explicit paths and allocate the bandwidth to each tunnel. The feature introduces these changes: • **CLI:** The **auto-capacity** keyword is added to the **interface tunnel-te** command. • **YANG Data Model:** New XPaths for `Cisco-IOS-XR-mpls-te-cfg.yang` (see GitHub, YANG Data Models Navigator)

MPLS-TE tunnels are used to set up labeled connectivity and to provide dynamic bandwidth capacity between endpoints. The auto-bandwidth feature addresses the dynamic bandwidth capacity demands by dynamically resizing the MPLS-TE tunnels based on the measured traffic loads. However, many customers require multiple auto-bandwidth tunnels between endpoints for load balancing and redundancy. When the aggregate bandwidth demand increases between two endpoints, you can either configure auto-bandwidth feature to resize the tunnels or create new tunnels and load balance the overall demand over all the tunnels between two endpoints. Similarly, when the aggregate bandwidth demand decreases between two endpoints you can either configure the auto-bandwidth feature to decrease the sizes of the tunnel or delete the new tunnels and load balance the traffic over the remaining tunnels between the endpoints. The autobandwidth bundle TE++ feature is an extension of the auto-bandwidth feature and allows you to automatically increase or decrease the number of MPLS-TE tunnels to a destination based on real time traffic needs.

Tunnels that are automatically created as a response to the increasing bandwidth demands are called clones. The cloned tunnels inherit properties of the main configured tunnel. However, user configured load interval cannot be inherited. The original tunnel and its clones are collectively called a set. You can specify an upper limit and lower limit on the number of clones that can be created for the original tunnel.

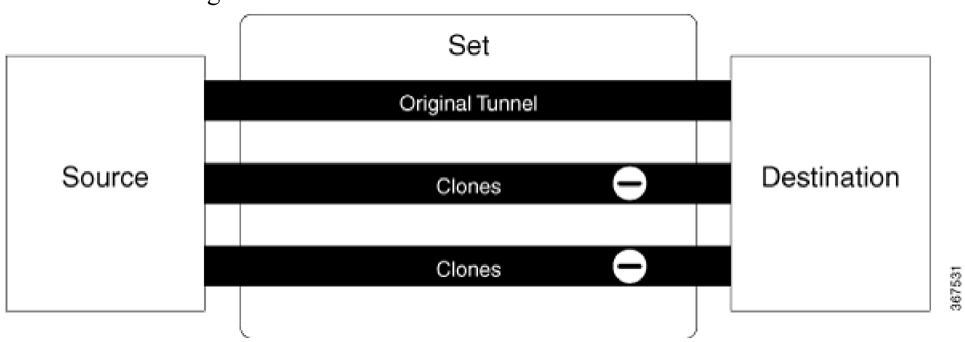
Splitting is the process of cloning a new tunnel when there is a demand for bandwidth increase. When the size of any of the tunnels in the set crosses a configured split bandwidth, then splitting is initiated and clone tunnels are created.

The following figure explains creating clone tunnels when the split bandwidth is exceeded.



Merging is the process of removing a clone tunnel when the bandwidth demand decreases. If the bandwidth goes below the configured merge bandwidth in any one of the tunnels in the set, clone tunnels are removed.

The following figure explains removing clone tunnels to merge with the original tunnel when the bandwidth falls below the merge bandwidth.



There are multiple ways to equally load-share the aggregate bandwidth demand among the tunnels in the set. This means that an algorithm is needed to choose the pair which satisfies the aggregate bandwidth requirements. You can configure a nominal bandwidth to guide the algorithm to determine the average bandwidths of the tunnels. If nominal bandwidth is not configured, TE uses the average of split and merge bandwidth as nominal bandwidth.

Restrictions and Usage Guidelines

The following usage guidelines apply for the auto-bandwidth bundle TE++ feature.

- This feature is only supported for the named tunnels and not supported on tunnel-te interfaces.
- The range for the lower limit on the number of clones is 0 to 63 and the default value for the lower limit on the number of clones is 0.

- The range for the upper limit on the number of clones is 1 to 63 and the default value for the upper limit on the number of clones is 63.

Configuration Example

This example shows how to configure the autobandwidth bundle TE++ feature for a named MPLS-TE traffic tunnel. You should configure the following values for this feature to work:

- min-clones: Specifies the minimum number of clone tunnels that the original tunnel can create.
- max-clones: Specifies the maximum number of clone tunnels that the original tunnel can create.
- nominal-bandwidth: Specifies the average bandwidth for computing the number of tunnels to satisfy the overall demand.
- split-bandwidth: Specifies the bandwidth value for splitting the original tunnel. If the tunnel bandwidth exceeds the configured split bandwidth, clone tunnels are created.
- merge-bandwidth: Specifies the bandwidth for merging clones with the original tunnel. If the bandwidth goes below the configured merge bandwidth, clone tunnels are removed.

In this example, the lower limit on the number of clones is configured as two and the upper limit on the number of clones is configured as four. The bandwidth size for splitting and merging is configured as 200 and 100 kbps.

```
RP/0/RP0/CPU0:router(config)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-mpls-te)# named-tunnels
RP/0/RP0/CPU0:router(config-te-named-tunnels)# tunnel-te xyz
RP/0/RP0/CPU0:router(config-te-tun-name)# auto-bw
RP/0/RP0/CPU0:router(config-mpls-te-tun-autobw)# auto-capacity
RP/0/RP0/CPU0:router(config-te-tun-autocapacity)# min-clones 2
RP/0/RP0/CPU0:router(config-te-tun-autocapacity)# max-clones 4
RP/0/RP0/CPU0:router(config-te-tun-autocapacity)# nominal-bandwidth 150
RP/0/RP0/CPU0:router(config-te-tun-autocapacity)# split-bandwidth 200
RP/0/RP0/CPU0:router(config-te-tun-autocapacity)# merge-bandwidth 100
```

Configure Autoroute Tunnel as Designated Path

Table 7: Feature History Table

Feature Name	Release Information	Feature Description
Configure Autoroute Tunnel as Designated Path	Release 7.6.2	We now provide you the flexibility to simplify the path selection for a traffic class and split traffic among multiple TE tunnels. To split traffic, you can specify an autoroute tunnel to forward traffic to a particular tunnel destination address without considering the IS-IS metric for traffic path selection. IS-IS metric provides the shortest IGP path to a destination based only on link costs along the path. However, you may want to specify a tunnel interface to carry traffic regardless of IGP cost to meet your specific organizational requirements. Earlier, MPLS-TE considered either the Forwarding Adjacency (FA) or Autoroute (AA) tunnel for forwarding traffic based only on the IS-IS metric. The feature introduces the **mpls traffic-eng tunnel restricted** command.

MPLS-TE builds a unidirectional tunnel from a source to a destination using label switched path (LSP) to forward traffic.

To forward the traffic through MPLS tunneling, you can use autoroute, forwarding adjacency, or static routing:

- Autoroute (AA) functionality allows to insert the MPLS TE tunnel in the Shortest Path First (SPF) tree for the tunnel to transport all the traffic from the headend to all destinations behind the tail-end. AA is only known to the tunnel headend router.
- Forwarding Adjacency (FA) allows the MPLS-TE tunnel to be advertised as a link in an IGP network with the cost of the link associated with it. Routers outside of the TE domain can see the TE tunnel and use it to compute the shortest path for routing traffic throughout the network.
- Static routing allows you to inject static IP traffic into a tunnel as the output interface for the routing decision.

Prior to this release, by default, MPLS-TE considers FA or AA tunnels to forward traffic based on the IS-IS metric. The lower metric is always used to forward traffic. There was no mechanism to forward traffic to a specific tunnel interface.

For certain prefixes to achieve many benefits such as security and service-level agreements, there might be a need to forward traffic to a specific tunnel interface that has a matching destination address.

With this feature, you can exclusively use AA tunnels to forward traffic to their tunnel destination address irrespective of IS-IS metric. Traffic steering is performed based on the prefixes and not metrics. Traffic to other prefixes defaults to the forwarding-adjacency (FA) tunnels.

To enable this feature, use the **mpls traffic-eng tunnel restricted** command.

Also, you may require more than one AA tunnel to a particular remote PE and use ECMP to forward traffic across AA tunnels. You can configure a loopback interface with one primary address and multiple secondary addresses on the remote PE, using one IP for the FA tunnel destination, and others for the AA tunnels destinations. Multiple IP addresses are advertised in the MPLS TE domain using the typed length value (TLV) 132 in IS-IS. A TLV-encoded data stream contains code related to the record type, the record length of the value, and value. TLV 132 represents the IP addresses of the transmitting interface.

Feature Behavior

When MPLS-TE tunnel restricted is configured, the following is the behavior:

- A complete set of candidate paths is available for selection on a per-prefix basis during RIB update as the first hop computation includes all the AA tunnels terminating on a node up to a limit of 64 and the lowest cost forwarding-adjacency or native paths terminating on the node or inherited from the parent nodes in the first hops set for the node.
- During per-prefix computation, AA tunnel first hops are used for traffic sent to their tunnel destination address even if FA tunnel or native first hops have a better metric. AA tunnel first-hops are not used for any other prefixes.
- ECMP is used when multiple AA tunnel first hops have the same destination address and metric.
- During per-prefix computation, AA tunnel first hops are used for traffic sent to their tunnel destination address, and for all other destinations on the tunnel tail node or behind it, even if a native path has a better metric.

  Adding **mpls traffic-eng tunnel preferred** configuration has no effect when the tunnel restricted is already configured.
- If there’s no AA tunnel or if the tunnel is down, then native paths are used for all other destinations on the tunnel tail node or behind it.

  The route metric for a prefix reflects the chosen first-hop, not necessarily the lowest cost SPF distance to the node.

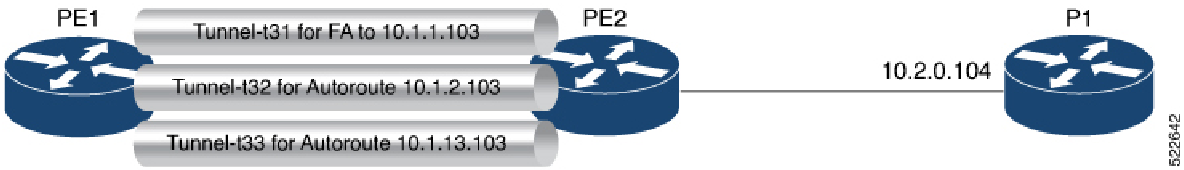
Restrictions for Configure Autoroute Tunnel as Designated Path

- The total number of interface addresses to the number that can be contained in 255 bytes is 63 for IPv4 and 15 for IPv6.
- When this feature is enabled, a maximum of 64 tunnels can terminate on the tail node.

Configure Autoroute Tunnel as Designated Path

Let's understand how to configure the feature using the following topology:

Figure 4: Topology



Consider the topology where PE1 has three MPLS tunnels connecting to PE2.

- Tunnel-t31: Forwarding adjacency (FA) is configured to the primary address of Loopback 0 on PE2 (10.1.1.103).
- Tunnel- t32: Autoroute announce (AA) is configured to a secondary address of Loopback 0 on PE2 (10.1.2.103).
- Tunnel-t33: Autoroute announce (AA) is configured to a secondary address of Loopback 0 on PE2 (10.1.3.103).

This feature is not enabled by default. When this feature is not enabled, traffic is load balanced over all AA tunnels towards the same remote PE provided the tunnel metric is the same:

```
Router# show routes
i L2 10.1.1.103/32 [115/40] via 10.1.2.103, 00:00:30, tunnel-t32
                   [115/40] via 10.1.3.103, 00:00:30, tunnel-t33
i L2 10.1.2.103/32 [115/40] via 10.1.2.103, 00:00:30, tunnel-t32
                   [115/40] via 10.1.3.103, 00:00:30, tunnel-t33
i L2 10.1.3.103/32 [115/40] via 10.1.2.103, 00:00:30, tunnel-t32
                   [115/40] via 10.1.3.103, 00:00:30, tunnel-t33
i L2 10.2.0.103/32 [115/40] via 10.1.2.103, 00:00:30, tunnel-t32
                   [115/40] via 10.1.3.103, 00:00:30, tunnel-t33
 10.2.0.104/32 [115/50] via 10.1.2.103, 00:00:30, tunnel-t32
                   [115/50] via 10.1.3.103, 00:00:30, tunnel-t33
```

Configuration Example

You can configure the feature using the **mpls traffic-eng tunnel restricted** command.

```
RP/0/RSP0/CPU0:ios# configure
RP/0/RSP0/CPU0:ios(config)# router isis 1
RP/0/RSP0/CPU0:ios(config-isis)# address-family ipv4 unicast
RP/0/RSP0/CPU0:ios(config-isis-af# mpls traffic-eng tunnel restricted
```

Running Configuration

The following example shows the AA tunnel metric running configuration:

```
router isis 1
 address-family ipv4 unicast
  mpls traffic-eng tunnel restricted
 !
!
end
```

Verification

When you enable the feature, traffic towards a particular prefix is sent only over the tunnel that has that IP address as destination.

```
Router# show route
i L2 10.1.1.103/32 [115/40] via 10.1.1.103, 00:00:04, tunnel-t31
i L2 10.1.2.103/32 [115/40] via 10.1.2.103, 00:00:04, tunnel-t32
i L2 10.1.3.103/32 [115/40] via 10.1.3.103, 00:00:04, tunnel-t33
i L2 10.2.0.103/32 [115/40] via 10.1.1.103, 00:00:04, tunnel-t31
i L2 10.2.0.104/32 [115/50] via 10.1.1.103, 00:00:04, tunnel-t31
```

When multiple restricted AA tunnels are created towards the same destination IP address, router load balances traffic across all those tunnels:

```
Router# show route
i L2 10.1.1.103/32 [115/40] via 10.1.1.101, 00:00:08, GigabitEthernet0/0/0/2
                   [115/40] via 10.1.3.101, 00:00:08, GigabitEthernet0/0/0/3
i L2 10.1.2.103/32 [115/40] via 10.1.2.103, 00:00:08, tunnel-t32
                   [115/40] via 10.1.2.103, 00:00:30, tunnel-t34
i L2 10.1.3.103/32 [115/40] via 10.1.3.103, 00:00:08, tunnel-t33
i L2 10.2.0.103/32 [115/40] via 10.1.1.101, 00:00:08, GigabitEthernet0/0/0/2
                   [115/40] via 10.1.3.101, 00:00:08, GigabitEthernet0/0/0/3
i L2 10.2.0.104/32 [115/50] via 10.1.1.101, 00:00:08, GigabitEthernet0/0/0/2
                   [115/50] via 10.1.3.101, 00:00:08, GigabitEthernet0/0/0/3
```

Configure IPv6 routing over IPv4 MPLS-TE tunnels

Perform these steps to configure IPv6 routing over IPv4 MPLS-TE tunnels:

Procedure

Step 1 **configure**

Step 2 **interface tunnel-te** *tunnel-id*

Example:

```
RP/0/RP0/CPU0:router# interface tunnel-te 1
```

Configures an MPLS-TE tunnel interface.

Step 3 **ipv4 unnumbered** *type interface-path-id*

Example:

```
RP/0/RP0/CPU0:router(config-if)#ipv4 unnumbered Loopback 0
```

Assigns a source address so that forwarding can be performed on the new tunnel. Loopback is the commonly-used interface type.

Step 4 **ipv6 enable**

Example:

```
RP/0/RP0/CPU0:router(config-if)#ipv6 enable
```

Enables IPv6 on interface.

Step 5 **signalled-bandwidth** *bandwidth*

Example:

```
RP/0/RP0/CPU0:router(config-if)# signalled-bandwidth 10
```

Sets the tunnel bandwidth requirement to be signalled in Kbps.

Step 6 **destination** *ip-address*

Example:

```
RP/0/RP0/CPU0:router(config-if)#destination 192.168.0.1
```

Specifies the IPv4 destination address.

Step 7 Use one of these options:

- **autoroute announce include-ipv6**
- **forwarding-adjacency include-ipv6**

Example:

```
RP/0/RP0/CPU0:router(config-if)#autoroute announce include-ipv6
```

Or

```
RP/0/RP0/CPU0:router(config-if)#forwarding-adjacency include-ipv6
```

Announces the tunnel as an IPv6 autoroute, or as an IPv6 forwarding adjacency.

Step 8 **path-option** *preference-priority* **dynamic**

Example:

```
RP/0/RP0/CPU0:router(config-if)#path-option 1 dynamic
```

Sets the path option to dynamic and assigns the path ID.

Step 9 **commit**

Step 10 (Optional) **show mpls traffic-eng autoroute**

Example:

```
RP/0/RP0/CPU0:router#show mpls traffic-eng autoroute

  Destination 192.168.0.2 has 1 tunnels in IS-IS ring level 1
    tunnel-te1 (traffic share 0, nexthop 192.168.0.2)
               (IPv4 unicast)
               (IPv6 unicast)
```

Verifies that the tunnel announces IPv6 autoroute information.

Step 11 (Optional) **show mpls traffic-eng forwarding-adjacency**

Example:

```
RP/0/RP0/CPU0:router#show mpls traffic-eng forwarding-adjacency

 destination 192.168.0.1 has 1 tunnels

              tunnel-te10    (traffic share 0, next-hop 192.168.0.1)
                             (Adjacency Announced: yes, holdtime 0)
                             (IS-IS 100, IPv4 unicast)
                             (IS-IS 100, IPv6 unicast)
```

Verifies that the tunnel announces IPv6 forwarding adjacency information.

Configure IPv6 routing over IPv6 MPLS-TE tunnels

Perform these steps to configure IPv6 routing over IPv6 MPLS-TE tunnels:

Procedure

Step 1 **configure**

Step 2 **interface tunnel-te** *tunnel-id*

Example:

```
RP/0/RP0/CPU0:router# interface tunnel-te 1
```

Configures an MPLS-TE tunnel interface.

Step 3 **ipv4 unnumbered** *type interface-path-id*

Example:

```
RP/0/RP0/CPU0:router(config-if)#ipv4 unnumbered Loopback 0
```

Assigns a source address so that forwarding can be performed on the new tunnel. Loopback is the commonly-used interface type.

Step 4 **ipv6 enable**

Example:

```
RP/0/RP0/CPU0:router(config-if)#ipv6 enable
```

Enables IPv6 on interface.

Step 5 **signalled-bandwidth** *bandwidth*

Example:

```
RP/0/RP0/CPU0:router(config-if)# signalled-bandwidth 10
```

Sets the tunnel bandwidth requirement to be signalled in Kbps.

Step 6 Use one of these options:

- **autoroute announce include-ipv6**
- **forwarding-adjacency include-ipv6**

Example:

```
RP/0/RP0/CPU0:router(config-if)#autoroute announce include-ipv6
```

Or

```
RP/0/RP0/CPU0:router(config-if)#forwarding-adjacency include-ipv6
```

Announces the tunnel as an IPv6 autoroute, or as an IPv6 forwarding adjacency.

Step 7 **destination ipv6** *ip-address*

Example:

```
RP/0/RP0/CPU0:router(config-if)#destination ipv6 2000::1
```

Specifies the IPv6 destination address.

Step 8 **path-option** *preference-priority* **dynamic**

Example:

```
RP/0/RP0/CPU0:router(config-if)#path-option 1 dynamic
```

Sets the path option to dynamic and assigns the path ID.

Step 9 **commit**

Step 10 (Optional) **show mpls traffic-eng autoroute**

Example:

```
RP/0/RP0/CPU0:router#show mpls traffic-eng autoroute

  Destination 192.168.0.2 has 1 tunnels in IS-IS ring level 1
    tunnel-te1 (traffic share 0, nexthop 192.168.0.2)
               (IPv4 unicast)
               (IPv6 unicast)
```

Verifies that the tunnel announces IPv6 autoroute information.

Step 11 (Optional) **show mpls traffic-eng forwarding-adjacency**

Example:

```
RP/0/RP0/CPU0:router#show mpls traffic-eng forwarding-adjacency

 destination 192.168.0.1 has 1 tunnels

              tunnel-te10    (traffic share 0, next-hop 192.168.0.1)
                             (Adjacency Announced: yes, holdtime 0)
                             (IS-IS 100, IPv4 unicast)
                             (IS-IS 100, IPv6 unicast)
```

Verifies that the tunnel announces IPv6 forwarding adjacency information.

MPLS-TE Features - Details

MPLS TE Fast Reroute Link and Node Protection

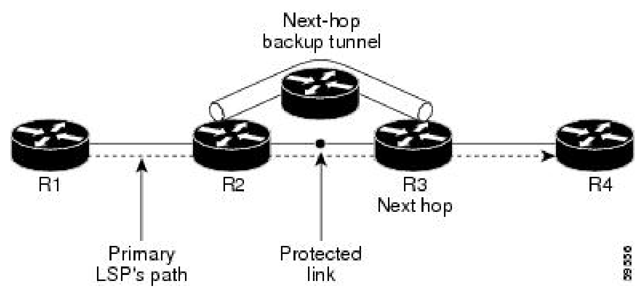
Fast Reroute (FRR) is a mechanism for protecting MPLS TE LSPs from link and node failures by locally repairing the LSPs at the point of failure, allowing data to continue to flow on them while their headend routers try to establish new end-to-end LSPs to replace them. FRR locally repairs the protected LSPs by rerouting them over backup tunnels that bypass failed links or node.

Note If FRR is greater than 50ms, it might lead to a loss of traffic.

Backup tunnels that bypass only a single link of the LSP’s path provide link protection. They protect LSPs if a link along their path fails by rerouting the LSP’s traffic to the next hop (bypassing the failed link). These tunnels are referred to as next-hop (NHOP) backup tunnels because they terminate at the LSP’s next hop beyond the point of failure.

The following figure illustrates link protection.

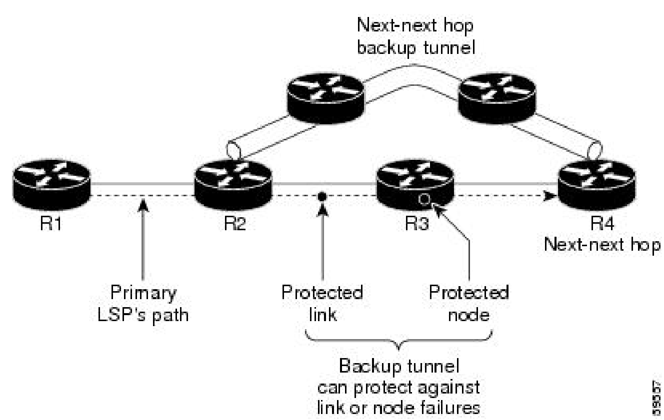
Figure 5: Link Protection



FRR provides node protection for LSPs. Backup tunnels that bypass next-hop nodes along LSP paths are called next-next-hop (NNHOP) backup tunnels because they terminate at the node following the next-hop node of the LSP paths, bypassing the next-hop node. They protect LSPs if a node along their path fails by enabling the node upstream of the failure to reroute the LSPs and their traffic around the failed node to the next-next hop. NNHOP backup tunnels also provide protection from link failures, because they bypass the failed link and the node.

The following figure illustrates node protection.

Figure 6: Node Protection



Differentiated Services Traffic Engineering

MPLS Differentiated Services Aware Traffic Engineering (DS-TE) is an extension of the regular MPLS-TE feature. Regular traffic engineering does not provide bandwidth guarantees to different traffic classes. A single bandwidth constraint is used in regular TE that is shared by all traffic. To support various classes of service (CoS), you can configure multiple bandwidth constraints. These bandwidth constraints can be treated differently based on the requirement for the traffic class using that constraint.

Cisco IOS XR software supports two DS-TE modes: pre-standard and IETF. The pre-standard DS-TE mode uses the Cisco proprietary mechanisms for RSVP signaling and IGP advertisements. This DS-TE mode does not interoperate with third-party vendor equipment. Pre-standard DS-TE is enabled only after configuring the sub-pool bandwidth values on MPLS-enabled interfaces. Pre-standard DS-TE mode supports a single bandwidth constraint model a Russian Doll Model (RDM) with two bandwidth pools: global-pool and sub-pool. TE class map is not used with Pre-standard DS-TE mode.

IETF DS-TE mode uses IETF-defined extensions for RSVP and IGP. This mode inter-operates with third-party vendor equipment. IETF mode supports multiple bandwidth constraint models, including RDM and Maximum Allocation Bandwidth Constraint Model (MAM), both with two bandwidth pools. In an IETF DS-TE network, identical bandwidth constraint models must be configured on all nodes. TE class map is used with IETF DS-TE mode and must be configured the same way on all nodes in the network.

The MAM constraint model has the following characteristics:

- Easy to use and intuitive.
- Isolation across class types.
- Simultaneously achieves isolation, bandwidth efficiency, and protection against QoS degradation.

The RDM constraint model has these characteristics:

- Allows greater sharing of bandwidth among different class types.
- Ensures bandwidth efficiency simultaneously and protection against QoS degradation of all class types.
- Specifies that it is used with preemption to simultaneously achieve isolation across class-types such that each class-type is guaranteed its share of bandwidth, bandwidth efficiency, and protection against QoS degradation of all class types.

MPLS-TE Forwarding Adjacency

MPLS TE forwarding adjacency allows you to handle a TE label-switched path (LSP) tunnel as a link in an Interior Gateway Protocol (IGP) network that is based on the Shortest Path First (SPF) algorithm. Both Intermediate System-to-Intermediate System (IS-IS) and Open Shortest Path First (OSPF) are supported as the IGP. A forwarding adjacency can be created between routers regardless of their location in the network. The routers can be located multiple hops from each other.

As a result, a TE tunnel is advertised as a link in an IGP network with the tunnel's cost associated with it. Routers outside of the TE domain see the TE tunnel and use it to compute the shortest path for routing traffic throughout the network. TE tunnel interfaces are advertised in the IGP network just like any other links. Routers can then use these advertisements in their IGPs to compute the SPF even if they are not the headend of any TE tunnels.

Automatic Bandwidth

Automatic bandwidth allows you to dynamically adjust bandwidth reservation based on measured traffic. MPLS-TE automatic bandwidth is configured on individual Label Switched Paths (LSPs) at every headend router. MPLS-TE automatic bandwidth monitors the traffic rate on a tunnel interface and resizes the bandwidth on the tunnel interface to align it closely with the traffic in the tunnel.

MPLS-TE automatic bandwidth can perform these functions:

- Monitors periodic polling of the tunnel output rate
- Resizes the tunnel bandwidth by adjusting the highest rate observed during a given period.

For every traffic-engineered tunnel that is configured for an automatic bandwidth, the average output rate is sampled, based on various configurable parameters. Then, the tunnel bandwidth is readjusted automatically based on either the largest average output rate that was noticed during a certain interval, or a configured maximum bandwidth value.

While re-optimizing the LSP with the new bandwidth, a new path request is generated. If the new bandwidth is not available, the last good LSP remains used. This way, the network experiences no traffic interruptions. If minimum or maximum bandwidth values are configured for a tunnel, the bandwidth, which the automatic bandwidth signals, stays within these values.

The output rate on a tunnel is collected at regular intervals that are configured by using the **application** command in MPLS-TE auto bandwidth interface configuration mode. When the application period timer expires, and when the difference between the measured and the current bandwidth exceeds the adjustment threshold, the tunnel is re-optimized. Then, the bandwidth samples are cleared to record the new largest output rate at the next interval. If a tunnel is shut down, and is later brought again, the adjusted bandwidth is lost, and the tunnel is brought back with the initially configured bandwidth. When the tunnel is brought back, the application period is reset.

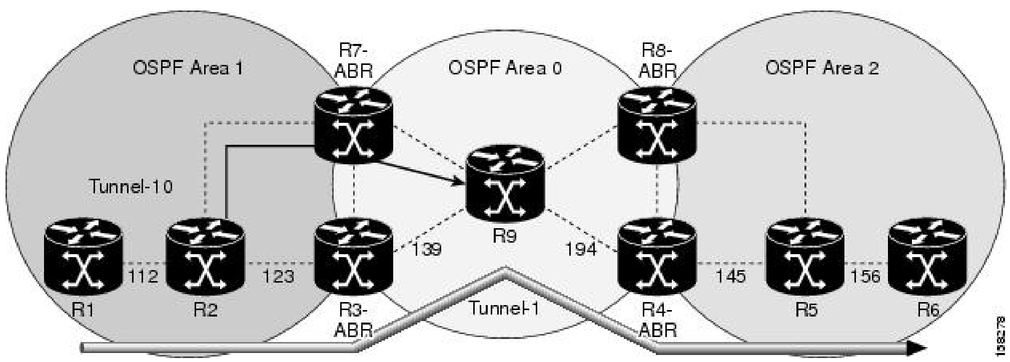
MPLS Traffic Engineering Interarea Tunneling

The MPLS-TE interarea tunneling feature allows you to establish TE tunnels spanning multiple Interior Gateway Protocol (IGP) areas and levels, thus eliminating the requirement that headend and tailend routers reside in a single area.

Interarea support allows the configuration of a TE LSP that spans multiple areas, where its headend and tailend label switched routers (LSRs) reside in different IGP areas. Customers running multiple IGP area backbones (primarily for scalability reasons) requires Multiarea and Interarea TE . This lets you limit the amount of flooded information, reduces the SPF duration, and lessens the impact of a link or node failure within an area, particularly with large WAN backbones split in multiple areas.

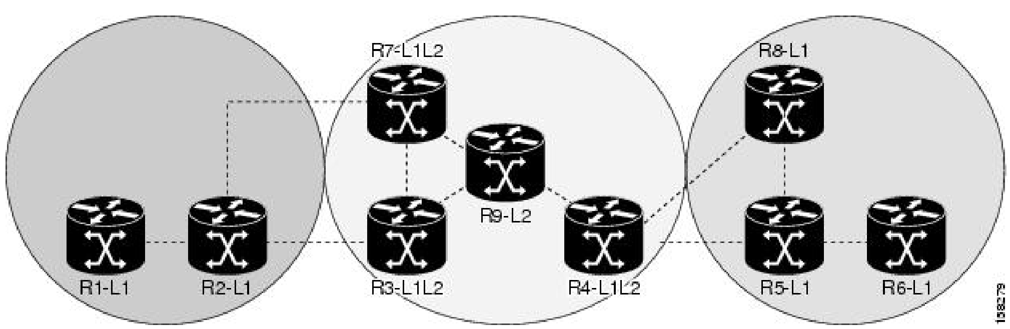
The following figure shows a typical interarea TE network using OSPF.

Figure 7: Interarea (OSPF) TE Network Diagram



The following figure shows a typical interlevel (IS-IS) TE Network.

Figure 8: Interlevel (IS-IS) TE Network Diagram



As shown in the Figure 8: Interlevel (IS-IS) TE Network Diagram, on page 51, R2, R3, R7, and R4 maintain two databases for routing and TE information. For example, R3 has TE topology information related to R2, flooded through Level-1 IS-IS LSPs plus the TE topology information related to R4, R9, and R7, flooded as Level 2 IS-IS Link State PDUs (LSPs) (plus, its own IS-IS LSP).

Loose hop optimization allows the re-optimization of tunnels spanning multiple areas and solves the problem which occurs when an MPLS-TE LSP traverses hops that are not in the LSP's headend's OSPF area and IS-IS level. Interarea MPLS-TE allows you to configure an interarea traffic engineering (TE) label switched path (LSP) by specifying a loose source route of ABRs along the path. Then it is the responsibility of the ABR (having a complete view of both areas) to find a path obeying the TE LSP constraints within the next area to reach the next hop ABR (as specified on the headend router). The same operation is performed by the last ABR connected to the tailend area to reach the tailend LSR.

You must be aware of these considerations when using loose hop optimization:

- You must specify the router ID of the ABR node (as opposed to a link address on the ABR).
- When multiarea is deployed in a network that contains subareas, you must enable MPLS-TE in the subarea for TE to find a path when loose hop is specified.
- You must specify the reachable explicit path for the interarea tunnel.

UCMP Over MPLS-TE

In Equal Cost Multi Path (ECMP), you can load-balance routed traffic over multiple paths of the same cost. With Unequal-Cost Multipath (UCMP), you can load-balance traffic over multiple paths of varying costs.

Consider three forwarding links, with two 10 Gigabit Ethernet links and a 100 Gigabit Ethernet link, as shown in the image.

In such a scenario, the incoming traffic load is not equally distributed using ECMP. On the other hand, UCMP applies a weight to a path, and adds more forwarding instances to a path that has a higher weight (larger bandwidth). This results in an equal load distribution over paths of varying bandwidths (and costs).

Configuration Example

UCMP Configuration:

```
R1# configure
R1(config)# mpls traffic-eng
R1(config-mpls-te)# load-share unequal
R1(config-mpls-te)# commit
```

Tunnels Configuration:

```
R1(config)# interface tunnel-te 1
R1(config-if)# ipv4 unnumbered loopback 1
R1(config-if)# load-share 5
R1(config-if)# autoroute announce
R1(config-if-tunte-aa)# commit
R1(config-if-tunte-aa)# exit
R1(config-if)# destination 172.16.0.1
R1(config-if)# path-option 1 dynamic

R1(config)# interface tunnel-te 2
R1(config-if)# ipv4 address 192.168.0.1 255.255.255.0
R1(config-if)# load-share 6
R1(config-if)# autoroute announce
R1(config-if-tunte-aa)# commit
R1(config-if-tunte-aa)# exit
R1(config-if)# destination 172.16.0.1
R1(config-if)# path-option 1 dynamic
```

Associated Commands

- load-share

- load-share unequal
- show cef

Verification

Verify UCMP Configuration:

```
R1# show cef 172.16.0.1 detail

172.16.0.1/32, version 16, internal 0x1000001 0x0 (ptr 0x97de1a58) [1], 0x0 (0x97fa3728), 
0xa20 (0x98fc00a8)
 Updated Jun 17 16:07:46.325
 Prefix Len 32, traffic index 0, precedence n/a, priority 3
  gateway array (0x97e0ba08) reference count 3, flags 0x68, source lsd (5), 1 backups
                [3 type 4 flags 0x8401 (0x9849f728) ext 0x0 (0x0)]
  LW-LDI[type=1, refc=1, ptr=0x97fa3728, sh-ldi=0x9849f728]
  gateway array update type-time 1 Jun 17 16:07:46.325
 LDI Update time Jun 17 16:07:46.350
 LW-LDI-TS Jun 17 16:07:46.350
   via 172.16.0.1/32, tunnel-te1, 5 dependencies, weight 100, class 0 [flags 0x0]
    path-idx 0 NHID 0x0 [0x98e19380 0x98e192f0]
    next hop 172.16.0.1/32
    local adjacency
     local label 24001      labels imposed {ImplNull}
   via 172.16.0.1/32, tunnel-te2, 7 dependencies, weight 10, class 0 [flags 0x0]
    path-idx 1 NHID 0x0 [0x98e194a0 0x98e19410]
    next hop 172.16.0.1/32
    local adjacency
     local label 24001      labels imposed {ImplNull}

    Weight distribution:

    slot 0, weight 100, normalized_weight 10, class 0
    slot 1, weight 10, normalized_weight 1, class 0
    Load distribution: 0 0 0 0 0 0 0 0 0 0 1 (refcount 3)

    Hash  OK  Interface                 Address
    0     Y   tunnel-te1                point2point
    1     Y   tunnel-te1                point2point
    2     Y   tunnel-te1                point2point
    3     Y   tunnel-te1                point2point
    4     Y   tunnel-te1                point2point
    5     Y   tunnel-te1                point2point
    6     Y   tunnel-te1                point2point
    7     Y   tunnel-te1                point2point
    8     Y   tunnel-te1                point2point
    9     Y   tunnel-te1                point2point
    10    Y   tunnel-te2                point2point
```

Some sample output:

```
Router# show run formal mpls traffic-eng

mpls traffic-eng
mpls traffic-eng interface Bundle-Ether2
mpls traffic-eng interface Bundle-Ether3
..
mpls traffic-eng load-share unequal
mpls traffic-eng reoptimize 180
mpls traffic-eng signalling advertise explicit-null
mpls traffic-eng reoptimize timers delay path-protection 60
```

```
Router# show run formal interface tunnel-te400

interface tunnel-te400
interface tunnel-te400 description TE-STI-GRTMIABR5-GRTBUEBA3-BW-0
interface tunnel-te400 ipv4 unnumbered Loopback0
interface tunnel-te400 load-interval 30
interface tunnel-te400 signalled-name TE-STI-GRTMIABR5-GRTBUEBA3-BW-0
interface tunnel-te400 load-share 80
interface tunnel-te400 autoroute destination 94.142.100.214
interface tunnel-te400 destination 94.142.100.214
interface tunnel-te400 path-protection
interface tunnel-te400 path-option 1 explicit name BR5-BA3-0 protected-by 2
interface tunnel-te400 path-option 2 explicit name BW-BR5-1-VAP3-BA3-0
interface tunnel-te400 path-option 3 explicit name BW-BR5-VAP3-BA3-0
```

```
Router# show run formal interface tunnel-te406

interface tunnel-te406
interface tunnel-te406 description TE-STI-GRTMIABR5-GRTBUEBA3-BW-20
interface tunnel-te406 ipv4 unnumbered Loopback0
interface tunnel-te406 load-interval 30
interface tunnel-te406 signalled-name TE-STI-GRTMIABR5-GRTBUEBA3-BW-20
interface tunnel-te406 load-share 10
interface tunnel-te406 autoroute destination 94.142.100.214
interface tunnel-te406 destination 94.142.100.214
interface tunnel-te406 path-protection
interface tunnel-te406 path-option 1 explicit name BR5-1-BA3-0 protected-by 2
interface tunnel-te406 path-option 2 explicit name BW-BR5-VAP4-BA3-0
```

```
Router# show cef 94.142.100.214/32 det

94.142.100.214/32, version 25708656, attached, internal 0x4004081 0x0 (ptr 0x764ff1b0) [3],
 0x0 (0x7267d848), 0x440 (0x7d93b2b8)
 Updated Nov 19 08:02:26.545
 Prefix Len 32, traffic index 0, precedence n/a, priority 3
  gateway array (0x72411528) reference count 3, flags 0xd0, source lsd (4), 1 backups
                [3 type 4 flags 0x10101 (0x7300d648) ext 0x0 (0x0)]
  LW-LDI[type=1, refc=1, ptr=0x7267d848, sh-ldi=0x7300d648]
   via tunnel-te400, 3 dependencies, weight 80, class 0 [flags 0x8]
    path-idx 0 NHID 0x0 [0x72082a40 0x72983b58]
    local adjacency
     local label 16440      labels imposed {ImplNull}
   via tunnel-te406, 3 dependencies, weight 10, class 0 [flags 0x8]
    path-idx 1 NHID 0x0 [0x7207b4ac 0x729886bc]
    local adjacency
     local label 16440      labels imposed {ImplNull}
   via tunnel-te410, 3 dependencies, weight 80, class 0 [flags 0x8]
    path-idx 2 NHID 0x0 [0x72085218 0x72985ee4]
    local adjacency
     local label 16440      labels imposed {ImplNull}
   via tunnel-te426, 3 dependencies, weight 10, class 0 [flags 0x8]
    path-idx 3 NHID 0x0 [0x7207d4b4 0x7297fecc]
    local adjacency
     local label 16440      labels imposed {ImplNull}
   via tunnel-te427, 3 dependencies, weight 25, class 0 [flags 0x8]
    path-idx 4 NHID 0x0 [0x720802cc 0x7298726c]
    local adjacency
     local label 16440      labels imposed {ImplNull}
   via tunnel-te1089, 3 dependencies, weight 40, class 0 [flags 0x8]
    path-idx 5 NHID 0x0 [0x72081848 0x7298037c]
    local adjacency
     local label 16440      labels imposed {ImplNull}
   via tunnel-te1090, 3 dependencies, weight 60, class 0 [flags 0x8]
    path-idx 6 NHID 0x0 [0x7207d770 0x72987780]
    local adjacency
```

```
     local label 16440      labels imposed {ImplNull}
   via tunnel-te1099, 3 dependencies, weight 60, class 0 [flags 0x8]
    path-idx 7 NHID 0x0 [0x7207ed50 0x72981c7c]
    local adjacency
     local label 16440      labels imposed {ImplNull}

    Weight distribution:
    slot 0, weight 80, normalized_weight 7, class 0
    slot 1, weight 10, normalized_weight 1, class 0
    slot 2, weight 80, normalized_weight 7, class 0
    slot 3, weight 10, normalized_weight 1, class 0
    slot 4, weight 25, normalized_weight 1, class 0
    slot 5, weight 40, normalized_weight 3, class 0
    slot 6, weight 60, normalized_weight 5, class 0
    slot 7, weight 60, normalized_weight 5, class 0

Router# show cef 94.142.100.213/32 det

94.142.100.213/32, version 25708617, attached, internal 0x4004081 0x0 (ptr 0x771925c8) [3],
 0x0 (0x7267a594), 0x440 (0x7d93d364)
 Updated Nov 19 08:02:01.029
 Prefix Len 32, traffic index 0, precedence n/a, priority 3
  gateway array (0x7240f638) reference count 3, flags 0xd0, source lsd (4), 1 backups
                [3 type 4 flags 0x10101 (0x73013360) ext 0x0 (0x0)]
  LW-LDI[type=1, refc=1, ptr=0x7267a594, sh-ldi=0x73013360]
   via tunnel-te220, 3 dependencies, weight 60, class 0 [flags 0x8]
    path-idx 0 NHID 0x0 [0x7207d838 0x72982af0]
    local adjacency
     local label 17561      labels imposed {ImplNull}
   via tunnel-te230, 3 dependencies, weight 60, class 0 [flags 0x8]
    path-idx 1 NHID 0x0 [0x7207d068 0x72986e20]
    local adjacency
     local label 17561      labels imposed {ImplNull}
   via tunnel-te236, 3 dependencies, weight 50, class 0 [flags 0x8]
    path-idx 2 NHID 0x0 [0x720830e4 0x7297f508]
    local adjacency
     local label 17561      labels imposed {ImplNull}
   via tunnel-te246, 3 dependencies, weight 100, class 0 [flags 0x8]
    path-idx 3 NHID 0x0 [0x7207a1ec 0x7298483c]
    local adjacency
     local label 17561      labels imposed {ImplNull}
   via tunnel-te221, 3 dependencies, weight 50, class 0 [flags 0x8]
    path-idx 4 NHID 0x0 [0x7207ea30 0x72982834]
    local adjacency
     local label 17561      labels imposed {ImplNull}
   via tunnel-te222, 3 dependencies, weight 25, class 0 [flags 0x8]
    path-idx 5 NHID 0x0 [0x72084a48 0x72989850]
    local adjacency
     local label 17561      labels imposed {ImplNull}
   via tunnel-te1091, 3 dependencies, weight 30, class 0 [flags 0x8]
    path-idx 6 NHID 0x0 [0x720851b4 0x729895f8]
    local adjacency
     local label 17561      labels imposed {ImplNull}
   via tunnel-te342, 3 dependencies, weight 100, class 0 [flags 0x8]
    path-idx 7 NHID 0x0 [0x72085344 0x7298b024]
    local adjacency
     local label 17561      labels imposed {ImplNull}

    Weight distribution:
    slot 0, weight 60, normalized_weight 2, class 0
    slot 1, weight 60, normalized_weight 2, class 0
    slot 2, weight 50, normalized_weight 2, class 0
    slot 3, weight 100, normalized_weight 4, class 0
    slot 4, weight 50, normalized_weight 2, class 0
    slot 5, weight 25, normalized_weight 1, class 0
```

```
slot 6, weight 30, normalized_weight 1, class 0
slot 7, weight 100, normalized_weight 4, class 0

Load distribution: 0 0 1 1 2 2 3 3 3 3 4 4 5 6 7 7 7 7 (refcount 3)

Hash  OK  Interface                 Address
0     Y   tunnel-te220              point2point
1     Y   tunnel-te220              point2point
2     Y   tunnel-te230              point2point
3     Y   tunnel-te230              point2point
4     Y   tunnel-te236              point2point
5     Y   tunnel-te236              point2point
6     Y   tunnel-te246              point2point
7     Y   tunnel-te246              point2point
8     Y   tunnel-te246              point2point
9     Y   tunnel-te246              point2point
10    Y   tunnel-te221              point2point
11    Y   tunnel-te221              point2point
12    Y   tunnel-te222              point2point
13    Y   tunnel-te1091             point2point
14    Y   tunnel-te342              point2point
15    Y   tunnel-te342              point2point
16    Y   tunnel-te342              point2point
17    Y   tunnel-te342              point2point
```

Event history for MPLS-TE tunnels

MPLS-TE tunnel event histories are network diagnostic records that

- chronologically document significant events and actions that occur within MPLS-TE headend tunnels
- enable detailed tracking and analysis of tunnel lifecycle changes, including RSVP signaling events, and
- facilitate monitoring, troubleshooting, and compliance by recording each event with timestamps and associated metadata.

Table 8: Feature History Table

Feature Name	Release	Feature Description
Event history for MPLS-TE headend tunnels	Release 25.4.1	Introduced in this release on: NCS 5500 fixed port routers; NCS 5700 fixed port routers; NCS 5500 modular routers (NCS 5500 line cards; NCS 5700 line cards [Mode: Compatibility; Native]) This feature introduces a granular and configurable event tracking mechanism for operational visibility into MPLS-TE tunnels. You can enable event history with the **mpls traffic-eng event-history tunnel** command and set the number of tracked events with the **mpls traffic-eng event-history tunnel event-count** command. This feature introduces these changes: CLI: • Three new keywords, **event-history, tunnel**,and **event-count**, are added to the **mpls traffic-eng** command. • Two new keywords, **event-history**, and **tunnels** are added to the **show mpls traffic-eng** command. • A new **clear mpls traffic-eng event-history tunnels** command has been added. • The **show mpls traffic-eng counters global** and **show mpls traffic-eng chunks** commands have been modified to include the event history information.

Cisco IOS XR Release 25.4.1 introduces the tunnel event history for MPLS-TE tunnels to track and analyse the timeline of events in the tunnel lifecycle, including RSVP signaling. This feature enables enhanced operational visibility for MPLS-TE tunnels by providing granular, configurable event tracking.

To enable the MPLS-TE tunnel event history feature, use the **mpls traffic-eng event-history tunnel** command. To set the event count for the tunnel event history, configure the use the **mpls traffic-eng event-history tunnel event-count** command.

Benefits of tunnel event history

You can use the event history feature for MPLS-TE headend tunnels to:

- maintain a familiar workflow with minimal changes,
- log events in dedicated, per-tunnel buffers for fair and isolated event recording,
- flexibly capture and report events with comprehensive argument handling,
- compress duplicate events to minimize log size and clutter, and
- enhance debugging with accessible historical records for troubleshooting.

Restrictions for tunnel event history

The tunnel event history feature is:

- Disabled by default.
- Supported only on MPLS-TE headend tunnels.

Configure tunnel event history and event count

This procedure helps you to configure the tunnel event history and the event count.

Procedure

Step 1 Enable the tunnel event history.

Example:

```
Router# configure
Router(config)# mpls traffic-eng event-history tunnel
Router(config-te-evt-hist)# commit
```

Step 2 Specify the event count.

Example:

```
Router# configure
Router(config)# mpls traffic-eng event-history tunnel event-count 45
Router(config-te-evt-hist)# commit
```

The default number of events is 25. You can set up to 1000 events per tunnel.

Step 3 Verify the tunnel event history configuration.

Example:

This output shows the event history for all tunnels.

```
Router# show mpls traffic-eng event-history tunnel all
Wed Dec 3 14:08:59.529 UTC
```

```
Name: tunnel-te1
Event history (oldest first):
ID                   Time               LSP  Event-Type  Rep  Event-Message
01764770758196406124 Dec 3 14:06:05.309   2  Path          0  BW:300 kbps ERO: 10.1.3.103 10.3.5.105
 10.5.6.106 20.1.0.106
01764770758196406128 Dec 3 14:06:05.346   2  Path Err      0  (24,0), Error: routing (24), Suberror:
 none (0), error-node: 10.1.3.103
01764770758196406129 Dec 3 14:06:05.346   2  Path Tear     0
01764770758196406131 Dec 3 14:06:08.349   3  Path          0   BW:300 kbps ERO: 10.1.3.103 10.3.5.105
 10.5.6.106 20.1.0.106
01764770758196406132 Dec 3 14:06:08.449   3  Resv          0   BW:300 kbps RRO:
01764770758196406134 Dec 3 14:06:08.449   3  Oper State    0   New tunnel state: UP

Name: T10
Event history (oldest first):
ID                   Time               LSP  Event-Type  Rep  Event-Message
01764770758196406125 Dec 3 14:06:05.309   2  Path          0  BW:300 kbps ERO: 10.1.2.102 10.2.4.104
 10.4.6.106 20.1.0.106
01764770758196406126 Dec 3 14:06:05.346   2  Path Err      0  (24,0), Error: routing (24), Suberror:
 none (0), error-node: 10.1.2.102
01764770758196406127 Dec 3 14:06:05.346   2  Path Tear     0
01764770758196406130 Dec 3 14:06:08.346   3  Path          0  BW:300 kbps ERO: 10.1.2.102 10.2.4.104
 10.4.6.106 20.1.0.106
01764770758196406133 Dec 3 14:06:08.449   3  Resv          0  BW:300 kbps RRO:
01764770758196406135 Dec 3 14:06:08.496   3  Oper State    0  New tunnel state: UP

Name: SELFPING-101
 Event history (oldest first):
 ID                     Time                  LSP  Event-Type  Rep  Event-Message
 01769076278173248001  Jan 22 05:30:13.487    2  Path         0  BW:0 kbps ERO: 10.10.10.2 17.17.17.2
 17.17.17.3 22.22.22.3 22.22.22.4 192.168.0.4
 01769076278173248002  Jan 22 05:30:13.546     2  Resv          0  BW:0 kbps RRO:
 01769076278173248003  Jan 22 05:30:23.551     2  Self-Ping     0  Timed-out (started at Jan 22
05:01:30.769)
 01769076278173248004  Jan 22 05:30:23.554     2  Oper State    0  New tunnel state: UP

Name: SELFPING-103
 Event history (oldest first):
 ID                     Time                  LSP  Event-Type  Rep  Event-Message
 01769076278173248011  Jan 22 05:31:54.518    2  Path         0  BW:0 kbps ERO: 10.10.10.2 17.17.17.2
 17.17.17.3 22.22.22.3 22.22.22.4 192.168.0.4
 01769076278173248012  Jan 22 05:31:54.581     2  Resv          0  BW:0 kbps RRO:
 01769076278173248013  Jan 22 05:32:02.917     2  Self-Ping     0  Aborted (started at Jan 22
05:01:30.769)
 01769076278173248014  Jan 22 05:32:02.925     2  Path Tear     0
 01769076278173248015  Jan 22 05:32:02.936    3  Path         0  BW:0 kbps ERO: 11.11.11.2 17.17.17.2
 17.17.17.3 22.22.22.3 22.22.22.4 192.168.0.4
 01769076278173248016  Jan 22 05:32:02.987     3  Resv          0  BW:0 kbps RRO:
 01769076278173248017  Jan 22 05:32:06.994     3  Self-Ping     0  Succeeded (started at Jan 22
05:01:30.769)
 01769076278173248018  Jan 22 05:32:06.995     3  Oper State    0  New tunnel state: UP
```

Example:

This output shows the event history for a specific tunnel.

```
Router# show mpls traffic-eng event-history tunnels tunnel-T10


Thu Dec 18 07:30:57.167 UTC
Name: tunnel-T10
 Event history (oldest first):
 ID                     Time                  LSP  Event-Type  Rep  Event-Message
 01765952238563713933  Jan 1 07:15:28.220     5  Path Tear     0
```

```
 01765952238563713934  Jan 1 07:15:32.660    8  Path        0  BW:300 kbps ERO: 10.1.2.102 10.2.4.104

 01765952238563713935  Jan 1 07:15:32.763     8  Resv         0  BW:300 kbps RRO:
 01765952238563713936  Jan 1 07:15:32.803     6  Path Tear    0
 01765952238563713937  Jan 1 07:15:37.387    9  Path        0  BW:300 kbps ERO: 10.1.2.102 10.2.4.104

 01765952238563713938  Jan 1 07:15:37.480     9  Resv         0  BW:300 kbps RRO:
 01765952238563713939  Jan 1 07:15:37.517     7  Path Tear    0
 01765952238563713940  Jan 1 07:15:47.193   10  Path        0  BW:300 kbps ERO: 10.1.2.102 10.2.4.104

 01765952238563713941  Jan 1 07:15:47.283    10  Resv         0  BW:300 kbps RRO:
 01765952238563713942  Jan 1 07:15:47.320     8  Path Tear    0
 01765952238563713943  Jan 1 07:16:07.420     9  Path Tear    0
 01765952238563713944  Jan 1 07:16:15.573   11  Path        0  BW:300 kbps ERO: 10.1.2.102 10.2.4.104

 01765952238563713945  Jan 1 07:16:15.670    11  Resv         0  BW:300 kbps RRO:
 01765952238563713946  Jan 1 12:23:05.711    10  Self-Ping    0  Succeeded (started at Jan  1
12:23:05.709)
 01765952238563713947  Jan 1 07:16:35.810    10  Path Tear    0
 01765952238563713948  Jan 1 07:22:49.863   12  Path        0  BW:300 kbps ERO: 10.1.2.102 10.2.4.104

 01765952238563713949  Jan 1 07:22:49.963    12  Resv         0  BW:300 kbps RRO:
 01765952238563713950  Jan 1 07:23:10.103    11  Path Tear    0
 01765952238563713951  Jan 1 07:23:49.240   13  Path        0  BW:300 kbps ERO: 10.1.2.102 10.2.4.104

 01765952238563713952  Jan 1 07:23:49.340    13  Resv         0  BW:300 kbps RRO:
 01765952238563713953  Jan 1 07:24:09.480    12  Path Tear    0
 01765952238563713954  Jan 1 12:45:45.473    11  Self-Ping    0  Succeeded (started at Jan  1
12:45:45.472)
```

Example:

This output shows the specified event count.

```
Router# show run mpls traffic-eng event-history
Thu Dec 4 06:56:44.650 UTC
mpls traffic-eng
event-history
tunnel
event-count 45
!
!
!
```

Example:

This example shows the event history size.

```
Router# show mpls traffic-eng counters global

Wed Dec 3 14:09:38.405 UTC

Global Statistics:
Number of VIF : 2
Number of LSP : 2
Number of S2L : 2

Checkpoint request queue high watermark : 3
Checkpoint response queue high watermark : 16
Checkpoint reschedules : 28
Checkpoint enqueues (request queue) : 86
Checkpoint dequeues (request queue) : 86
Checkpoint enqueues (response queue) : 86
Checkpoint dequeues (response queue) : 86
Checkpoint write (VIF) : 32
Checkpoint read (VIF) : 0
```

```
Checkpoint write (DST) : 0
Checkpoint read (DST) : 0
Checkpoint write (S2L) : 4
Checkpoint read (S2L) : 0
Checkpoint write (Autobackup) : 0
Checkpoint read (Autobackup) : 0
Checkpoint write (PI backup) : 0
Checkpoint read (PI backup) : 0
Number of RSVP connection : 1
Number of RSVP disconnection : 0
Number of RSVP restart time change : 0
Number of LSD connection : 1
Number of LSD disconnection : 0
Number of LSD replay : 1
Number of LMRIB connection : 1
Number of LMRIB disconnection : 0
Number of LMRIB restart time change : 1
Number of LMRIB restart failed : 0
Number of LMRIB restart passed : 1
Number of LMRIB recovery failed : 0
Number of LMRIB recovery passed : 1
Number of RSI connection : 1
Number of RSI disconnection : 0
Event-history size (bytes)
 Tunnels (excluding chunks) : 16444912
```

Example:

This example displays the memory information for the tunnel event history.

```
Router# show mpls traffic-eng chunks

  Tue Dec  9 06:30:40.055 UTC
Pool name            InUse     Free      Allocs    Deallocs  Sib creat Sib trimm
-------------------- --------- --------- --------- --------- --------- ---------
mpls wavl Chunks             0     32000         0         0         0         0
mpls wavl Chunks            28      7972        28         0         0         0
mpls wavl Chunks           101      3899       101         0         0         0
mpls wavl Chunks            59      1941        59         0         0         0
mpls wavl Chunks            27       973        27         0         0         0
mpls wavl Chunks             9       491         9         0         0         0
mpls wavl Chunks             0       240         0         0         0         0
mpls wavl Chunks             0       120         0         0         0         0
TE S2L chunk                 0       200         0         0         0         0
TE S2L stats chunk           0      1024         0         0         0         0
TE LSP chunk                 0       200         0         0         0         0
TE collab chunk             15        25        15         0         0         0
TE FSM Q chunk               0       128         0         0         0         0
TE NextHop Route Po          0       128         0         0         0         0
TE Binding Sid Cont          0       128         0         0         0         0
TE CHKPT Q Elements          0       600        10        10         0         0
RSVP CHKPT LIST Chu          0      8192         0         0         0         0
TE Tunnel Service R          0       128         0         0         0         0
TE Tunnel Service R          0       128         0         0         0         0
RSVP API CTX                 0       156         0         0         0         0
RSVP API CTX stats           0        48         0         0         0         0
RSVP API CTX event           0      1248         0         0         0         0
RSVP API CTX event           0      1248         0         0         0         0
RSVP API CTX Histor          0      1248         0         0         0         0
TE S2L RW chunk              0       124         0         0         0         0
TE S2L RW chunk              0       128         0         0         0         0
TE Event History             0       200         0         0         0         0
VIF Pulse Context c          0      1024       668       668         0         0
```

Step 4 (Optional) Clear the tunnel event history for all tunnels, if required.

Example:

```
Router# clear mpls traffic-eng event-history tunnels all
```

Configuring Performance Measurement

Network performance metrics such as packet loss, delay, delay variation, and bandwidth utilization is a critical measure for traffic engineering (TE) in service provider networks. These network performance metrics provide network operators information about the performance characteristics of their networks for performance evaluation and helps to ensure compliance with service level agreements. The service-level agreements (SLAs) of service providers depend on the ability to measure and monitor these network performance metrics. Network operators can use performance measurement (PM) feature to monitor the network metrics for links as well as end-to-end TE label switched paths (LSPs).

Path Calculation Metric Type

To configure the metric type to be used for path calculation for a given tunnel, use the **path-selection metric** command in either the MPLS-TE configuration mode or under the tunnel interface configuration mode.

The metric type specified per interface takes the highest priority, followed by the MPLS-TE global metric type.

Note If the delay metric is configured, CSPF finds a path with optimized*minimum* link delay metric. See the *Configuring Performance Measurement* chapter in the Segment Routing Configuration Guide for information on configuring interface performance delay measurement.

Configuration Example

The following example shows how to set the path-selection metric to use the IGP metric under a specific tunnel interface:

```
Router# configure
Router(config)# interface tunnel-te 1
Router(config-if)# path-selection metric igp
Router(config-if)# commit
```

The following example shows how to set the path-selection metric to use the delay metric under the MPLS-TE configuration mode:

```
Router# configure
Router(config)# mpls traffic-eng
Router(config-mpls-te)# path-selection metric delay
Router(config-mpls-te)# commit
```

Path-Selection Delay Limit

Apply the **path-selection delay-limit** configuration to set the upper limit on the path aggregate delay when computing paths for MPLS-TE LSPs. After you configure the **path-selection delay-limit** value, if the sum of minimum-delay metric from all links that are traversed by the path exceeds the specified delay-limit, CSPF will not return any path. The periodic path verification checks if the delay-limit is crossed.

The **path-selection delay-limit** value can be configured at the global MPLS-TE, per-interface tunnel, and per path-option attribute set. The path-selection delay-limit per path-option attribute set takes the highest priority, followed by per-interface, and then the MPLS-TE global path-selection delay-limit values.

The delay limit range is a value from 1 to 4294967295 microseconds.

Note See the *Configuring Performance Measurement* chapter in the Segment Routing Configuration Guide for information on configuring interface performance delay measurement.

Configuration Example

The following example shows how to set the path-selection delay limit under a specific tunnel interface:

```
Router# configure
Router(config)# interface tunnel-te2000
Router(config-if)# path-selection metric delay
Router(config-if)# path-selection delay-limit 200
Router(config-if)# commit
```

The following example shows how to set the path-selection delay limit under a path-option attribute set:

```
Router# configure
Router(config)# mpls traffic-eng
Router(config-mpls-te)# attribute-set path-option test
Router(config-te-attribute-set)# path-selection delay-limit 300
Router(config-te-attribute-set)# root
Router(config)# interface tunnel-te1000
Router(config-if)# path-option 10 dynamic attribute-set test
Router(config-if)# commit
```

The following example shows how to set the path-selection delay limit under the global MPLS-TE configuration mode:

```
Router# configure
Router(config)# mpls traffic-eng
Router(config-mpls-te)# path-selection metric delay
Router(config-mpls-te)# path-selection delay-limit 150
Router(config-mpls-te)# commit
```