



Implementing MPLS Traffic Engineering

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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 auto-tunnel 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 adjust 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 35](#).

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.

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.

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 2](#)
- [Creating an MPLS-TE Tunnel, on page 4](#)

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
```

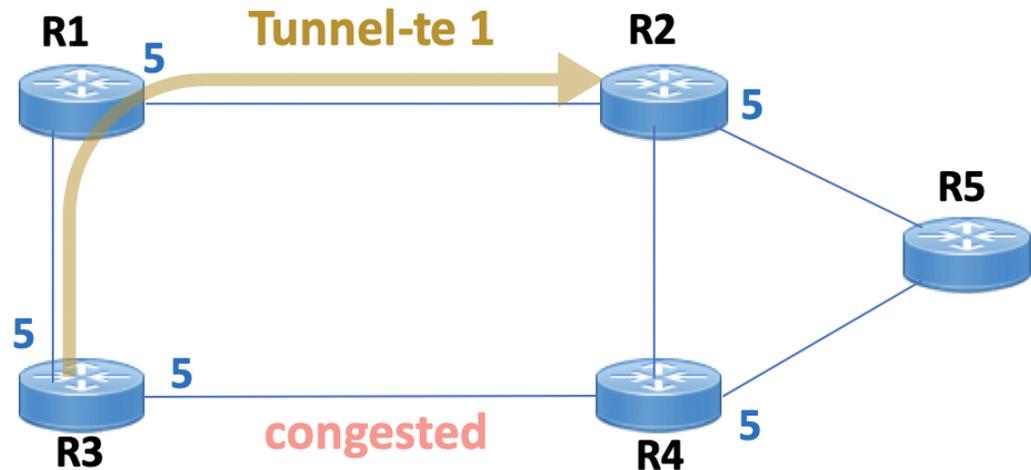
```
tunnel-te1          192.168.92.125          up      up
```

```
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 2](#)
- [Building MPLS-TE Topology, on page 3](#)

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 35](#)

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 1 explicit name backup-path protected by 10
RP/0/RP0/CPU0:router(config-if)# path-option 10 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 3](#)
- [Configuring Auto-Tunnel Backup, on page 8](#)

- [Configuring Next Hop Backup Tunnel, on page 9](#)
- [MPLS-TE Features - Details, on page 35](#)

Configuring Auto-Tunnel Backup

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 7](#)
- [Configuring Next Hop Backup Tunnel, on page 9](#)
- [MPLS-TE Features - Details, on page 35](#)

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 8](#)
- [Configuring Fast Reroute , on page 7](#)
- [MPLS-TE Features - Details, on page 35](#)

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-noddep
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 7
- [MPLS-TE Features - Details](#), on page 35

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 11

- [Configuring an IETF DS-TE Tunnel Using MAM, on page 11](#)
- [MPLS-TE Features - Details, on page 35](#)

Configuring an IETF DS-TE Tunnel Using RDM

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. 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 10](#)
- [Configuring an IETF DS-TE Tunnel Using MAM, on page 11](#)
- [MPLS-TE Features - Details, on page 35](#)

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 11](#)
- [Configuring Pre-Standard DS-TE, on page 10](#)
- [MPLS-TE Features - Details, on page 35](#)

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

Related Topics

- [MPLS-TE Features - Details, on page 35](#)

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 interareal
Router(config-expl-path)# index 1 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-tel
Router(config-if)# ipv4 unnumbered Loopback0
Router(config-if)# destination 172.16.255.2
Router(config-if)# path-option 10 explicit name interareal
Router(config)# commit

```

Configure Policy-Based Tunnel Selection

Configuring PBTS is a process of directing incoming traffic into specific TE tunnels based on a classification criteria (DSCP). The traffic forwarding decisions are made based on the categorized traffic classes and the destination network addresses. The following section lists the steps to configure PBTS on a MPLS-TE Tunnel network:

1. Define a class-map based on a classification criteria.
2. Define a policy-map by creating rules for the classified traffic.
3. Associate a forward-class to each type of ingress traffic.
4. Enable PBTS on the ingress interface, by applying this service-policy.
5. Create one or more egress MPLS-TE Tunnels (to carry packets based on priority) to the destination.
6. Associate the egress MPLS-TE Tunnel to a forward-class.

For more information on PBTS, see [Policy-Based Tunnel Selection](#), on page 39 in the *Implementing MPLS Traffic Engineering* chapter.

Configuration Example

The following section illustrates PBTS implementation:

```
RP/0/RP0/CPU0:router#configure
/* Class-map; classification using DSCP */
RP/0/RP0/CPU0:router(config)# class-map match-any AF41-Class
RP/0/RP0/CPU0:router(config-cmap)# match dscp AF41
RP/0/RP0/CPU0:router(config-cmap)# exit

/* Policy-map */
RP/0/RP0/CPU0:router(config)# policy-map INGRESS-POLICY
RP/0/RP0/CPU0:router(config-pmap)# class AF41-Class
/* Associating forward class */
RP/0/RP0/CPU0:router(config-pmap-c)# set forward-class 1
RP/0/RP0/CPU0:router(config-pmap-c)# exit
RP/0/RP0/CPU0:router(config-pmap)# exit

RP/0/RP0/CPU0:router(config)# interface GigabitEthernet0/0/0/1
/* Applying service-policy to ingress interface */
RP/0/RP0/CPU0:router(config-if)# service-policy input INGRESS-POLICY
RP/0/RP0/CPU0:router(config-if)# ipv4 address 10.1.1.1 255.255.255.0
RP/0/RP0/CPU0:router(config-if)# exit

/* Creating TE-tunnels to carry traffic based on priority */
RP/0/RP0/CPU0:router(config)# interface tunnel-te61
RP/0/RP0/CPU0:router(config-if)# ipv4 unnumbered Loopback0
RP/0/RP0/CPU0:router(config-if)# signalled-bandwidth 1000
RP/0/RP0/CPU0:router(config-if)# autoroute announce
RP/0/RP0/CPU0:router(config-if)# destination 10.20.20.1
RP/0/RP0/CPU0:router(config-if)# record route

/* Associating egress TE tunnels to forward class */
RP/0/RP0/CPU0:router(config-if)# forward-class 1
RP/0/RP0/CPU0:router(config-if)# path-option 1 explicit identifier 61
RP/0/RP0/CPU0:router(config-if)# exit
```

Verification

Use **show mpls forwarding tunnels** command to verify the PBTS configuration:

```
RP/0/RP0/CPU0:ios# show mpls forwarding tunnels 10 detail
Tue May 16 01:18:19.681 UTC

Tunnel      Outgoing      Outgoing      Next Hop      Bytes
Name        Label         Interface     20.20.17.21   Switched
-----
tt10                Exp-Null-v4 Te0/0/0/16   20.20.17.21   0
Updated: May 11 19:31:54.716
Version: 483, Priority: 2
Label Stack (Top -> Bottom): { 0 }
NHID: 0x0, Encap-ID: N/A, Path idx: 0, Backup path idx: 0, Weight: 0
MAC/Encaps: 14/18, MTU: 1500
Packets Switched: 0

Interface:
Name: tunnel-te10 (ifhandle 0x0800005c)
Local Label: 64016, Forwarding Class: 1, Weight: 0

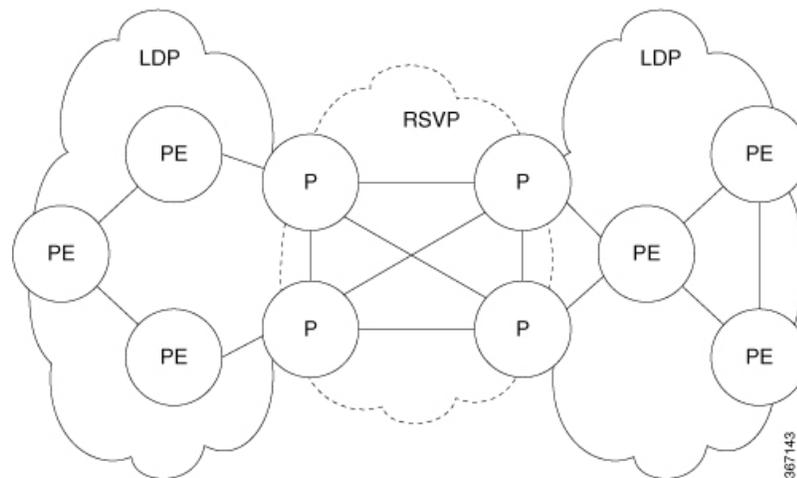
Packets/Bytes Switched: 0/0
```

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 reliable, 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 2: 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 enable 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

```

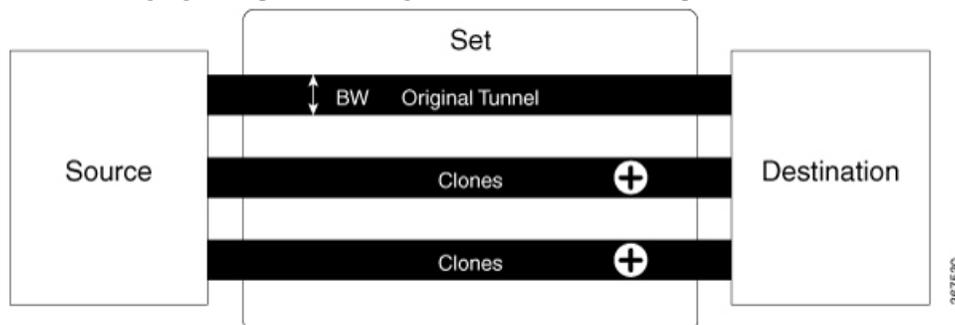
Configuring Autobandwidth Bundle TE++

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.

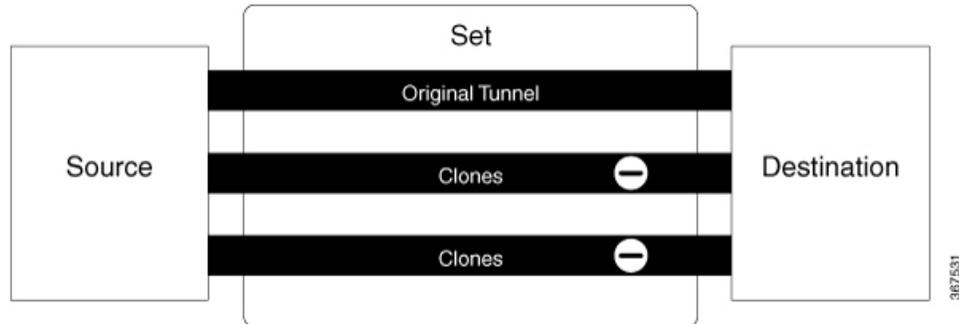
Splitting is the process of cloning a new tunnel when there is a demand for bandwidth increase. When the size of any of the tunnels in the set crosses a configured split bandwidth, then splitting is initiated and clone tunnels are created.

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 autobandwidth 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 5
RP/0/RP0/CPU0:router(config-te-tun-autocapacity)# split-bandwidth 200
RP/0/RP0/CPU0:router(config-te-tun-autocapacity)# merge-bandwidth 100

```

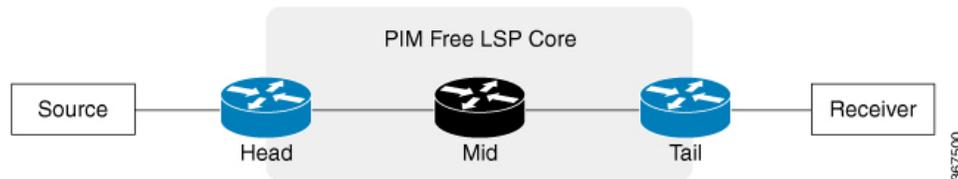
Configuring Point to Multipoint Traffic Engineering

To carry multicast traffic in service provider networks, a multicast protocol like PIM needs to be deployed to set up forwarding paths in the service provider core. However for an MPLS backbone network, service providers can use label encapsulation instead of IP tunneling. This approach helps to reduce the control traffic overhead on the service provider core and also leverages the MPLS traffic engineering and protection features.

The label encapsulation could be either point-to-multipoint (P2MP) label switched paths (LSPs) or multipoint-to-multipoint (MP2MP) LSPs. For creating multicast LSPs, RSVP-TE protocol extensions can be used. The RSVP-TE protocol is extended to signal P2MP LSPs across the MPLS networks. P2MP-TE feature enables transporting multicast traffic through a PIM free service provider core using P2MP-TE tunnels.

The following figure explains the topology that is used in this feature.

Figure 3: PIM Free LSP Core



In this figure, the following terminologies are used:

- Head—A router on which a TE tunnel is configured.
- Tail—The router on which the TE tunnel terminates.
- Mid—A router through which the TE tunnel passes.

A Multicast VPN (mVPN) profile is configured for the global context or per VRF. Different mVPN profiles can be applied depending on where the multicast streams need to be transported.

The following mVPN profiles are supported for the P2MP-TE feature:

- mVPN profile 8 for global context
- mVPN profile 10 for L3VPN context

Restrictions and Usage Guidelines

The following restrictions and guidelines apply for this feature:

- Only Source-Specific Multicast (SSM) traffic is supported.
- For profile 8, both IPv4 and IPv6 are supported.

- For profile 10, only IPv4 is supported.
- Fast Reroute (FRR) for P2MP-TE tunnel is not supported.
- BVI interface is not supported.

Configuration Example: P2MP-TE Profile 8

This example shows the P2MP-TE configuration for profile 8. You need to configure the head, mid, and tail routers in the P2MP tunnel.

The head router configuration is given as follows. This configuration includes IGP, MPLS-TE tunnel, and multicast configurations. You should also configure LDP and RSVP while configuring this feature.

```
RP/0/RP0/CPU0:router(config)# router ospf 1
RP/0/RP0/CPU0:router(config-router)# area 0
RP/0/RP0/CPU0:router(config-ospf-ar)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-ospf-ar-mpls-te)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# interface Loopback0
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-ospf-ar-if)# cost 1
RP/0/RP0/CPU0:router(config-ospf-ar-if)# network point-to-point
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# interface TenGigE0/0/0/2
RP/0/RP0/CPU0:router(config-ospf-ar-if)# cost 1
RP/0/RP0/CPU0:router(config-ospf-ar-if)# network point-to-point
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# exit
RP/0/RP0/CPU0:router(config-ospf)# mpls traffic-eng router-id loopback 0
RP/0/RP0/CPU0:router(config)# interface tunnel-mte 2
RP/0/RP0/CPU0:router(config-if)# ipv4 unnumbered Loopback0
RP/0/RP0/CPU0:router(config-if)# destination 10.2.2.2
RP/0/RP0/CPU0:router(config-if-p2mp-dest)# path-option 1 dynamic
RP/0/RP0/CPU0:router(config-if-p2mp-dest)# exit
RP/0/RP0/CPU0:router(config)# multicast-routing
RP/0/RP0/CPU0:router(config-mcast)# address-family ipv4
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# interface Loopback0
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# enable
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# exit
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# interface tunnel-mte 2
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# enable
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# exit
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# mdt source Loopback0
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# interface all enable
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# accounting per-prefix
RP/0/RP0/CPU0:router(config)# router igmp
RP/0/RP0/CPU0:router(config-igmp)# interface tunnel-mte 2
RP/0/RP0/CPU0:router(config-igmp-if)# static-group 232.0.0.2 10.0.0.100
RP/0/RP0/CPU0:router(config-igmp)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-igmp-if)# version 3
RP/0/RP0/CPU0:router(config)# router pim
RP/0/RP0/CPU0:router(config-pim)# address-family ipv4
RP/0/RP0/CPU0:router(config-pim-default-ipv4)# interface tunnel-mte 2
RP/0/RP0/CPU0:router(config-pim-default-ipv4-if)# enable
RP/0/RP0/CPU0:router(config-pim-default-ipv4-if)# exit
```

The running configuration for the head router is given as follows.

```
interface Loopback0
  ipv4 address 10.1.1.1 255.255.255.255
```

```

!
interface TenGigE0/0/0/0
ipv4 address 10.0.0.1 255.255.255.0
!
interface TenGigE0/0/0/2
ipv4 address 10.2.0.1 255.255.255.0
!
router ospf 1
area 0
 mpls traffic-eng
 !
 interface Loopback0
 interface TenGigE0/0/0/0
  cost 1
  network point-to-point
 interface TenGigE0/0/0/2
  cost 1
  network point-to-point
 !
 mpls traffic-eng router-id Loopback0
!
rsvp
 interface TenGigE0/0/0/2
  bandwidth percentage 100
!
!
mpls traffic-eng
 interface TenGigE0/0/0/2
!
mpls ldp
 discovery
  targeted-hello interval 10
!
 router-id 10.1.1.1
 address-family ipv4
  discovery targeted-hello accept
!
 interface TenGigE0/0/0/2
!
!
!
interface tunnel-mte2
 ipv4 unnumbered Loopback0
 destination 10.2.2.2
 path-option 1 dynamic
!
!
!
multicast-routing
 address-family ipv4
  interface Loopback0
   enable
 !
  interface tunnel-mte2
   enable
 !
 mdt source Loopback0
 interface all enable
 accounting per-prefix
!
!
router igmp
 interface tunnel-mte2

```

```

    static-group 232.0.0.2 10.0.0.100
    !
    interface TenGigE0/0/0/0
    version 3
    !
    !
    router pim
    address-family ipv4
    interface tunnel-mte2
    enable
    !
    !
    !

```

The mid router only requires MPLS-TE, RSVP and an IGP like OSPF configurations. The running configuration for the mid router is given as follows:

```

interface Loopback0
  ipv4 address 10.5.5.5 255.255.255.255
interface TenGigE0/0/0/2
  ipv4 address 10.10.0.5 255.255.255.0
interface TenGigE0/0/0/3
  ipv4 address 10.13.0.5 255.255.255.0
router ospf 1
  area 0
  mpls traffic-eng
  interface Loopback0
  interface TenGigE0/0/0/2
    cost 1
  network point-to-point
  interface TenGigE0/0/0/3
    cost 1
  network point-to-point
  mpls traffic-eng router-id Loopback0
  rsvp
  interface TenGigE0/0/0/2
    bandwidth percentage 100
  interface TenGigE0/0/0/3
    bandwidth percentage 100
  mpls traffic-eng
  interface TenGigE0/0/0/2
  interface TenGigE0/0/0/3
  mpls ldp
  discovery
  targeted-hello interval 10
  router-id 10.5.5.5
  address-family ipv4
  discovery targeted-hello accept
  interface TenGigE0/0/0/2
  interface TenGigE0/0/0/3
  !
  !

```

The tail router configuration is given as follows. This configuration includes IGP, MPLS-TE tunnel and multicast configurations. Similar to head router, you should also configure RSVP and LDP while configuring this feature.

```

RP/0/RP0/CPU0:router(config)# router ospf 1
RP/0/RP0/CPU0:router(config-router)# area 0
RP/0/RP0/CPU0:router(config-ospf-ar)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-ospf-ar-mpls-te)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# interface Loopback0
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit

```

```

RP/0/RP0/CPU0:router(config-ospf-ar)# interface TenGigE0/0/0/3
RP/0/RP0/CPU0:router(config-ospf-ar-if)# cost 1
RP/0/RP0/CPU0:router(config-ospf-ar-if)# network point-to-point
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# exit
RP/0/RP0/CPU0:router(config-ospf)# mpls traffic-eng router-id loopback 0
RP/0/RP0/CPU0:router(config)# interface tunnel-mte 2
RP/0/RP0/CPU0:router(config-if)# ipv4 unnumbered Loopback0
RP/0/RP0/CPU0:router(config-if)# destination 10.2.2.2
RP/0/RP0/CPU0:router(config-if-p2mp-dest)# path-option 1 dynamic
RP/0/RP0/CPU0:router(config-if-p2mp-dest)# exit
RP/0/RP0/CPU0:router(config)# multicast-routing
RP/0/RP0/CPU0:router(config-mcast)# address-family ipv4
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# interface Loopback0
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# enable
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# exit
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# mdt source Loopback0
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# core-tree-protocol rsvp-te
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# static-rpf 10.0.0.100 32 mpls 1.1.1.1
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# rate-per-route
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# interface all enable
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# accounting per-prefix
RP/0/RP0/CPU0:router(config)# router igmp
RP/0/RP0/CPU0:router(config-igmp)# interface TenGigE0/0/0/3
RP/0/RP0/CPU0:router(config-igmp-if)# version 3
RP/0/RP0/CPU0:router(config)# router pim
RP/0/RP0/CPU0:router(config-pim)# address-family ipv4
RP/0/RP0/CPU0:router(config-pim-default-ipv4)# interface TenGigE0/0/0/3
RP/0/RP0/CPU0:router(config-pim-default-ipv4-if)# enable
RP/0/RP0/CPU0:router(config-pim-default-ipv4-if)# exit

```

The running configuration for the tail router is given as follows:

```

!
interface Loopback0
  ipv4 address 10.2.2.2 255.255.255.255
!
interface TenGigE0/0/0/3
  ipv4 address 10.3.0.2 255.255.255.0
!
interface TenGigE0/0/0/6
  ipv4 address 10.6.0.2 255.255.255.0
!
router ospf 1
  area 0
    mpls traffic-eng
    interface Loopback0
    !
    interface TenGigE0/0/0/3
      cost 1
      network point-to-point
    !
  !
mpls traffic-eng router-id Loopback0
!
rsvp
  interface TenGigE0/0/0/3
    bandwidth percentage 100
  !
!
mpls traffic-eng
  interface TenGigE0/0/0/3
  !
mpls ldp

```

```

discovery
  targeted-hello interval 10
  !
router-id 10.2.2.2
address-family ipv4
  discovery targeted-hello accept
  !
interface TenGigE0/0/0/3
  !
!
multicast-routing
  address-family ipv4
interface Loopback0
  enable
  !
  mdt source Loopback0
  core-tree-protocol rsvp-te
  static-rpf 10.0.0.100 32 mpls 10.1.1.1
  rate-per-route
  interface all enable
  accounting per-prefix
  !
!
!
router igmp
  !
  interface TenGigE0/0/0/6
    version 3
  !
!
router pim
  !
  address-family ipv4
    interface TenGigE0/0/0/6
      enable
    !
  !
!
!

```

Configuration Example: P2MP-TE Profile 10

This example shows the P2MP-TE configuration for profile 10. You need to configure the head, mid, and tail routers.

The head router configuration is given as follows. This configuration includes IGP, L3VPN, and multicast configurations. You should also configure MPLS-TE, LDP, and RSVP while configuring this feature.

```

RP/0/RP0/CPU0:router(config)# router ospf 1
RP/0/RP0/CPU0:router(config-router)# area 0
RP/0/RP0/CPU0:router(config-ospf-ar)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-ospf-ar-mpls-te)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# interface Loopback0
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# interface TenGigE0/0/0/2
RP/0/RP0/CPU0:router(config-ospf-ar-if)# cost 1
RP/0/RP0/CPU0:router(config-ospf-ar-if)# network point-to-point
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# exit
RP/0/RP0/CPU0:router(config-ospf)# mpls traffic-eng router-id loopback 0
RP/0/RP0/CPU0:router(config-ospf)# exit
RP/0/RP0/CPU0:router(config)# vrf vpn_2
RP/0/RP0/CPU0:router(config-vrf)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-vrf-af)# import route-target 100:2

```

```

RP/0/RP0/CPU0:router(config-vrf-af)# export route-target 120:2
RP/0/RP0/CPU0:router(config)# interface TengigE0/0/0/0
RP/0/RP0/CPU0:router(config-if)# vrf vpn_2
RP/0/RP0/CPU0:router(config-if-vrf)# ipv4 address 10.0.0.1 255.255.255.0
RP/0/RP0/CPU0:router(config)# route-policy pass-all
RP/0/RP0/CPU0:router(config)# pass
RP/0/RP0/CPU0:router(config)#router bgp 1
RP/0/RP0/CPU0:router(config-bgp)# bgp router-id 10.1.1.1
RP/0/RP0/CPU0:router(config-bgp)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-bgp-af)# address-family vpnv4 unicast
RP/0/RP0/CPU0:router(config-bgp-af)# address-family ipv4 mvpn
RP/0/RP0/CPU0:router(config-bgp)# neighbor 10.2.2.2
RP/0/RP0/CPU0:router(config-bgp-nbr)# remote-as 1
RP/0/RP0/CPU0:router(config-bgp-nbr)# update-source Loopback0
RP/0/RP0/CPU0:router(config-bgp-nbr)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all in
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all out
RP/0/RP0/CPU0:router(config-bgp-nbr)# address-family vpnv4 unicast
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all in
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all out
RP/0/RP0/CPU0:router(config-bgp-nbr)# address-family ipv4 mvpn
RP/0/RP0/CPU0:router(config-bgp)# vrf vpn_2
RP/0/RP0/CPU0:router(config-bgp-vrf)#rd 100:2
RP/0/RP0/CPU0:router(config-bgp-vrf)#address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-bgp-vrf-af)#label mode per-prefix
RP/0/RP0/CPU0:router(config-bgp-vrf-af)#redistribute connected
RP/0/RP0/CPU0:router(config-bgp-vrf-af)#exit
RP/0/RP0/CPU0:router(config-bgp-vrf)# address-family ipv4 mvpn
RP/0/RP0/CPU0:router(config)# multicast-routing
RP/0/RP0/CPU0:router(config-mcast)# address-family ipv4
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# interface Loopback0
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# enable
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# exit
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# mdt source Loopback0
RP/0/RP0/CPU0:router(config-mcast)# vrf vpn_2
RP/0/RP0/CPU0:router(config-mcast-vpn_2)# address-family ipv4
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4)# mdt source loopback0
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4)# rate-per-route
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4)# interface all enable
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4)# bgp auto-discovery p2mp-te
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4-bgp-ad)# mdt static p2mp-te tunnel-mte2
RP/0/RP0/CPU0:router(config)# router igmp
RP/0/RP0/CPU0:router(config-igmp)# vrf vpn_2
RP/0/RP0/CPU0:router(config-igmp-vpn_2)# interface tunnel-mte2
RP/0/RP0/CPU0:router(config-igmp-vpn_2-if)# static-group 239.0.0.1 100.0.0.100
RP/0/RP0/CPU0:router(config-igmp-vpn_2-if)# exit
RP/0/RP0/CPU0:router(config-igmp-vpn_2)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-igmp-vpn_2-if)# version 3
RP/0/RP0/CPU0:router(config-igmp-vpn_2-if)# exit
RP/0/RP0/CPU0:router(config-igmp-vpn_2)#
RP/0/RP0/CPU0:router(config)# router pim
RP/0/RP0/CPU0:router(config-pim)# vrf vpn_2
RP/0/RP0/CPU0:router(config-pim-vpn_2)# address-family ipv4
RP/0/RP0/CPU0:router(config-pim-vpn_2-ipv4)# interface tunnel-mte2
RP/0/RP0/CPU0:router(config-pim-vpn_2-ipv4-if)# enable
RP/0/RP0/CPU0:router(config-pim-vpn_2-ipv4-if)# exit
RP/0/RP0/CPU0:router(config-pim-vpn_2-ipv4)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-pim-vpn_2-ipv4-if)# enable

```

The running configuration for the head router is given as follows.

```

!
interface Loopback0
  ipv4 address 10.1.1.1 255.255.255.255

```

```

!
interface TenGigE0/0/0/2
ipv4 address 10.2.0.1 255.255.255.0
!
router ospf 1
 area 0
  mpls traffic-eng
  !
  interface Loopback0
  !
  interface TenGigE0/0/0/2
    cost 1
    network point-to-point
  !
  mpls traffic-eng router-id Loopback0
!
rsvp
 interface TenGigE0/0/0/2
  bandwidth percentage 100
!
!
mpls traffic-eng
 interface TenGigE0/0/0/2
!
mpls ldp
 discovery
  targeted-hello interval 10
!
 router-id 10.1.1.1
 address-family ipv4
  discovery targeted-hello accept
!
 interface TenGigE0/0/0/2
!
!
vrf vpn_2
 address-family ipv4 unicast
  import route-target
  100:2
  export route-target
  100:2

interface TenGigE0/0/0/0
 vrf vpn_2
 ipv4 address 10.0.0.1 255.255.255.0

route-policy pass-all
 pass
end-policy

router bgp 1
 bgp router-id 10.1.1.1
 address-family ipv4 unicast
 address-family vpnv4 unicast
 address-family ipv4 mvpn
 neighbor 10.2.2.2
  remote-as 1
 update-source Loopback0
 address-family ipv4 unicast
  route-policy pass-all in
  route-policy pass-all out
 address-family vpnv4 unicast
  route-policy pass-all in
  route-policy pass-all out

```

```

    address-family ipv4 mvpn
vrf vpn_2
  rd 100:2
  address-family ipv4 unicast
    label mode per-prefix
    redistribute connected
  address-family ipv4 mvpn
hostname head
!
multicast-routing
address-family ipv4
interface Loopback0
  enable
!
mdt source Loopback0
!
vrf vpn_2
  address-family ipv4
    mdt source Loopback0
    rate-per-route
  interface all enable
  bgp auto-discovery p2mp-te
  !
  mdt static p2mp-te tunnel-mte2
  !
!
!
router igmp
vrf vpn_2
  interface tunnel-mte2
    static-group 239.0.0.1 100.0.0.100
  !
  interface TenGigE0/0/0/0
    version 3
  !
!
router pim
vrf vpn_2
  address-family ipv4
    interface tunnel-mte2
      enable
    !
    interface TenGigE0/0/0/0
      enable
    !
  !
!
!

```

The mid router only requires MPLS-TE, RSVP, and IGP configuration. The running configuration for the mid router is given as follows:

```

interface Loopback0
  ipv4 address 10.5.5.5 255.255.255.255

interface TenGigE0/0/0/2
  ipv4 address 10.0.0.5 255.255.255.0

interface TenGigE0/0/0/3
  ipv4 address 10.3.0.5 255.255.255.0

router ospf 1
  area 0
  mpls traffic-eng
  interface Loopback0

```

```

interface TenGigE0/0/0/2
  cost 1
  network point-to-point
interface TenGigE0/0/0/3
  cost 1
  network point-to-point
mpls traffic-eng router-id Loopback0

rsvp
interface TenGigE0/0/0/2
  bandwidth percentage 100
interface TenGigE0/0/0/3
  bandwidth percentage 100

mpls traffic-eng
interface TenGigE0/0/0/2
interface TenGigE0/0/0/3

mpls ldp
discovery
  targeted-hello interval 10
router-id 10.5.5.5
address-family ipv4
  discovery targeted-hello accept
interface TenGigE0/0/0/2
interface TenGigE0/0/0/3
!
!

```

The tail router configuration is given as follows. This configuration includes L3VPN, multicast, and IGP configurations. Similar to the head router, you should also configure MPLS-TE and RSVP before configuring this feature.

```

RP/0/RP0/CPU0:router# configure
RP/0/RP0/CPU0:router(config)# router ospf 1
RP/0/RP0/CPU0:router(config-router)# area 0
RP/0/RP0/CPU0:router(config-ospf-ar)# mpls traffic-eng
RP/0/RP0/CPU0:router(config-ospf-ar-mpls-te)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# interface Loopback0
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# interface TenGigE0/0/0/3
RP/0/RP0/CPU0:router(config-ospf-ar-if)# cost 1
RP/0/RP0/CPU0:router(config-ospf-ar-if)# network point-to-point
RP/0/RP0/CPU0:router(config-ospf-ar-if)# exit
RP/0/RP0/CPU0:router(config-ospf-ar)# exit
RP/0/RP0/CPU0:router(config-ospf)# mpls traffic-eng router-id loopback 0
RP/0/RP0/CPU0:router(config-ospf)# exit
RP/0/RP0/CPU0:router(config)# vrf vpn_2
RP/0/RP0/CPU0:router(config-vrf)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-vrf-af)# import route-target 100:2
RP/0/RP0/CPU0:router(config-vrf-af)# export route-target 120:2
RP/0/RP0/CPU0:router(config)# interface TengigE0/0/0/6
RP/0/RP0/CPU0:router(config-if)# vrf vpn_2
RP/0/RP0/CPU0:router(config-if-vrf)# ipv4 address 10.0.0.1 255.255.255.0
RP/0/RP0/CPU0:router(config)# route-policy pass-all
RP/0/RP0/CPU0:router(config)# pass
RP/0/RP0/CPU0:router(config)# end-policy
RP/0/RP0/CPU0:router(config)# router bgp 1
RP/0/RP0/CPU0:router(config-bgp)# bgp router-id 10.2.2.2
RP/0/RP0/CPU0:router(config-bgp)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-bgp-af)# address-family vpnv4 unicast
RP/0/RP0/CPU0:router(config-bgp-af)# address-family ipv4 mvpn
RP/0/RP0/CPU0:router(config-bgp)# neighbor 10.1.1.1

```

```

RP/0/RP0/CPU0:router(config-bgp-nbr)# remote-as 1
RP/0/RP0/CPU0:router(config-bgp-nbr)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all in
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all out
RP/0/RP0/CPU0:router(config-bgp-nbr)# address-family vpnv4 unicast
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all in
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all out
RP/0/RP0/CPU0:router(config-bgp-nbr)# address-family ipv4 mvpn
RP/0/RP0/CPU0:router(config)# multicast-routing
RP/0/RP0/CPU0:router(config-mcast)# address-family ipv4
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# interface Loopback0
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# enable
RP/0/RP0/CPU0:router(config-mcast-default-ipv4-if)# exit
RP/0/RP0/CPU0:router(config-mcast-default-ipv4)# mdt source Loopback0
RP/0/RP0/CPU0:router(config-mcast)# vrf vpn_2
RP/0/RP0/CPU0:router(config-mcast-vpn_2)# address-family ipv4
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4)# mdt source loopback0
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4)# core-tree-protocol rsvp-te
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4)# rate-per-route
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4)# interface all enable
RP/0/RP0/CPU0:router(config-mcast-vpn_2-ipv4)# bgp auto-discovery p2mp-te
RP/0/RP0/CPU0:router(config)# router igmp
RP/0/RP0/CPU0:router(config-igmp)# vrf vpn_2
RP/0/RP0/CPU0:router(config-igmp-vpn_2)# interface TenGigE0/0/0/6
RP/0/RP0/CPU0:router(config-igmp-vpn_2-if)# version 3
RP/0/RP0/CPU0:router(config-igmp-vpn_2-if)# exit
RP/0/RP0/CPU0:router(config)# router pim
RP/0/RP0/CPU0:router(config-pim)# vrf vpn_2
RP/0/RP0/CPU0:router(config-pim-vpn_2)# address-family ipv4
RP/0/RP0/CPU0:router(config-pim-vpn_2-ipv4)# interface TenGigE0/0/0/6
RP/0/RP0/CPU0:router(config-pim-vpn_2-ipv4-if)# enable
RP/0/RP0/CPU0:router(config)#router bgp 1
RP/0/RP0/CPU0:router(config-bgp)# bgp router-id 192.168.1.2
RP/0/RP0/CPU0:router(config-bgp)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-bgp-af)# address-family vpnv4 unicast
RP/0/RP0/CPU0:router(config-bgp-af)# address-family ipv4 mvpn
RP/0/RP0/CPU0:router(config-bgp)# neighbor 192.168.1.1
RP/0/RP0/CPU0:router(config-bgp-nbr)# remote-as 2002
RP/0/RP0/CPU0:router(config-bgp-nbr)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all in
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all out
RP/0/RP0/CPU0:router(config-bgp-nbr)# address-family vpnv4 unicast
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all in
RP/0/RP0/CPU0:router(config-bgp-nbr-af)# route-policy pass-all out
RP/0/RP0/CPU0:router(config-bgp-nbr)# address-family ipv4 mvpn
RP/0/RP0/CPU0:router(config-bgp)# vrf vpn_2
RP/0/RP0/CPU0:router(config-bgp-vrf)#rd 100:2
RP/0/RP0/CPU0:router(config-bgp-vrf)#address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-bgp-vrf-af)#label mode per-prefix
RP/0/RP0/CPU0:router(config-bgp-vrf-af)#redistribute connected
RP/0/RP0/CPU0:router(config-bgp-vrf-af)#exit
RP/0/RP0/CPU0:router(config-bgp-vrf)# address-family ipv4 mvpn

```

Running configuration for the tail router is given as follows:

```

interface Loopback0
  ipv4 address 10.2.2.2 255.255.255.255
!
interface TenGigE0/0/0/3
  ipv4 address 10.3.0.2 255.255.255.0
!
router ospf 1
  area 0
  mpls traffic-eng

```

```
interface Loopback0
!
interface TenGigE0/0/0/3
  cost 1
  network point-to-point
!
!
mpls traffic-eng router-id Loopback0
!
rsvp
  interface TenGigE0/0/0/3
    bandwidth percentage 100
!
!
mpls traffic-eng
  interface TenGigE0/0/0/3
!
mpls ldp
  discovery
    targeted-hello interval 10
!
  router-id 10.2.2.2
  address-family ipv4
    discovery targeted-hello accept
!
  interface TenGigE0/0/0/3
!
! vrf vpn_2
  address-family ipv4 unicast
    import route-target
      100:2
    export route-target
      100:2

interface TenGigE0/0/0/6
  vrf vpn_2
  ipv4 address 10.6.0.2 255.255.255.0

route-policy pass-all
  pass
end-policy

router bgp 1
  bgp router-id 10.2.2.2
  address-family ipv4 unicast
  address-family vpnv4 unicast
  address-family ipv4 mvpn
  neighbor 10.1.1.1
  remote-as 1
  update-source Loopback0
  address-family ipv4 unicast
    route-policy pass-all in
    route-policy pass-all out
  address-family vpnv4 unicast
    route-policy pass-all in
    route-policy pass-all out
  address-family ipv4 mvpn
  vrf vpn_2
  rd 100:2
  address-family ipv4 unicast
    label mode per-prefix
    redistribute connected
  address-family ipv4 mvpn
!
```

```

multicast-routing
 address-family ipv4
   interface Loopback0
     enable
     !
     mdt source Loopback0
     !
 vrf vpn_2
   address-family ipv4
     mdt source Loopback0
     core-tree-protocol rsvp-te
     rate-per-route
     interface all enable
     bgp auto-discovery p2mp-te
     !
 !
router igmp
 vrf vpn_2
   interface TenGigE0/0/0/6
     version 3
     !
 !
router pim
 vrf vpn_2
   address-family ipv4
     interface TenGigE0/0/0/6
       enable
     !
 !
 !

```

Verification: P2MP-TE

This example shows how to verify if the multicast control state is correct on the head router using the **show mrib vrf vpn_2 route** command.

```

RP/0/RP0/CPU0:router# show mrib vrf vpn_2 route

(10.0.0.100,232.0.0.1) RPF nbr: 10.0.0.100 Flags: RPF
Up: 00:00:38
Incoming Interface List
  TenGigE0/0/0/0 Flags: A, Up: 00:00:38
Outgoing Interface List
  Tunnel-mte2 Flags: F NS LI LVIF, Up: 00:00:38

```

You can also verify the multicast control state on the tail router.

```

RP/0/RP0/CPU0:router# show mrib vrf vpn_2 route

(10.0.0.100,232.0.0.1) RPF nbr: 10.1.1.1 Flags: RPF
Up: 00:03:55
Outgoing Interface List
  TenGigE0/0/0/6 Flags: F NS LI, Up: 00:03:55

```

This example shows how to check if the TE tunnel is established on the head router by using the **show mpls traffic-eng tunnels p2mp 2** command.

```

RP/0/RP0/CPU0:router# show mpls traffic-eng tunnels p2mp 2

Name: tunnel-mte2
Signalled-Name: head_mt2
Status:
  Admin: up Oper: up (Up for 00:09:37)
  Config Parameters:

```

```

Bandwidth: 0 kbps (CT0) Priority: 7 7 Affinity: 0x0/0xffff
Interface Bandwidth: 0 kbps
Metric Type: TE (global)
Fast Reroute: Not Enabled, Protection Desired: None
Record Route: Not Enabled
Reoptimization after affinity failure: Enabled
Destination summary: (1 up, 0 down, 0 disabled) Affinity: 0x0/0xffff
Auto-bw: disabled
Destination: 10.2.2.2
State: Up for 00:09:37
Path options:
  path-option 1 dynamic      [active]
Current LSP:
  lsp-id: 10002 p2mp-id: 2 tun-id: 2 src: 10.1.1.1 extid: 10.1.1.1
  LSP up for: 00:09:37 (since Fri May 25 22:32:03 UTC 2018)
  Reroute Pending: No
  Inuse Bandwidth: 0 kbps (CT0)
  Number of S2Ls: 1 connected, 0 signaling proceeding, 0 down      S2L Sub LSP:
Destination 2.2.2.2 Signaling Status: connected
  S2L up for: 00:09:37 (since Fri May 25 22:32:03 UTC 2018)
  Sub Group ID: 1 Sub Group Originator ID: 10.1.1.1
  Path option path-option 1 dynamic      (path weight 2)
  Path info (OSPF 1 area 0)
    10.0.0.5
    10.0.0.2
    10.2.2.2
  Reoptimized LSP (Install Timer Remaining 0 Seconds):
    None
  Cleaned LSP (Cleanup Timer Remaining 0 Seconds):
    None
Displayed 1 (of 101) heads, 0 (of 0) midpoints, 0 (of 0) tails
Displayed 1 up, 0 down, 0 recovering, 0 recovered heads
    
```

This example shows how to verify the label assignment on the head router using the **show mpls forwarding p2mp** command.

```
RP/0/RP0/CPU0:router# show mpls forwarding p2mp
```

Local Label	Outgoing Label	Prefix or ID	Outgoing Interface	Next Hop	Bytes Switched
64106	64008	P2MP TE: 2	TenGigE0/0/0/2	10.0.0.5	0

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.



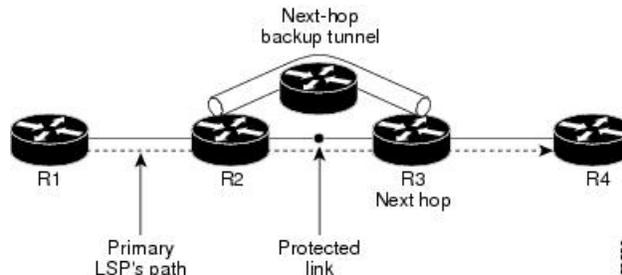
Note If FRR is greater than 50ms, it might lead to a loss of traffic.

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.

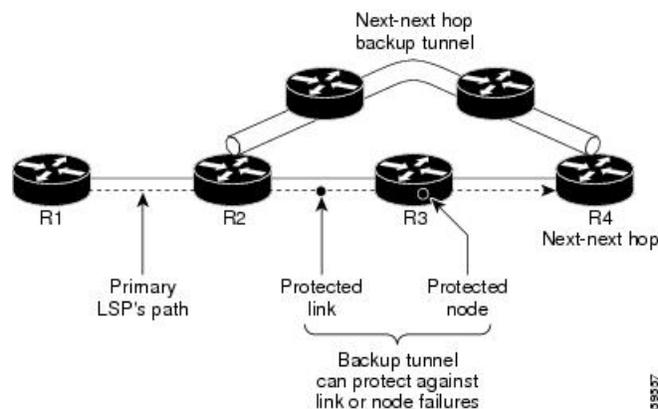
Figure 4: Link Protection



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 5: 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.

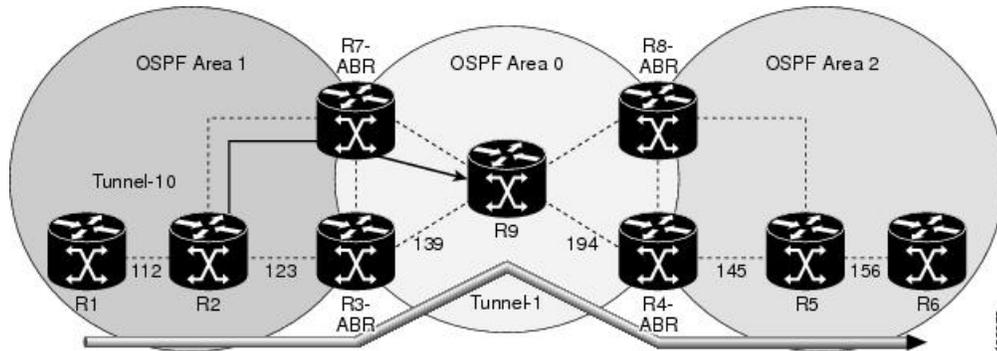
MPLS Traffic Engineering Interarea Tunneling

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.

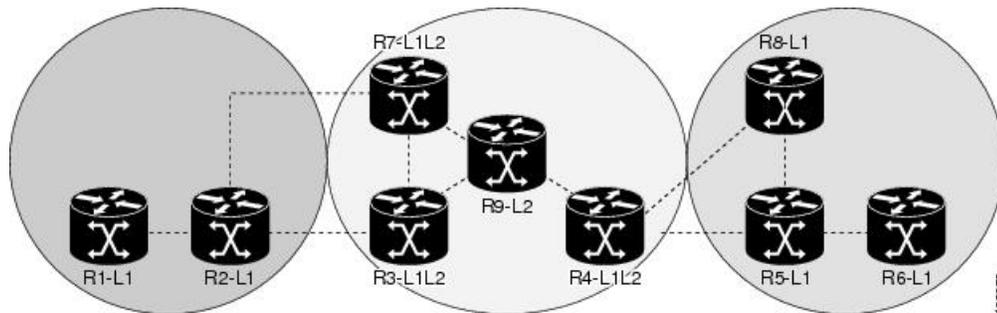
The following figure shows a typical interarea TE network using OSPF.

Figure 6: Interarea (OSPF) TE Network Diagram



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

Figure 7: Interlevel (IS-IS) TE Network Diagram



As shown in the [Figure 7: Interlevel \(IS-IS\) TE Network Diagram, on page 38](#), 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.

Policy-Based Tunnel Selection

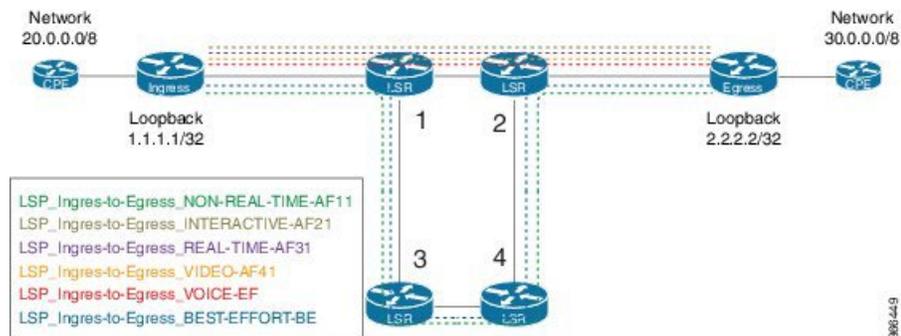
Policy-Based Tunnel Selection (PBTS) is a mechanism that lets you direct traffic into specific TE tunnels based on different classification criteria. PBTS will benefit Internet service providers (ISPs) that carry voice and data traffic through their MPLS and MPLS/VPN networks and would have to route this traffic to provide optimized voice service.

PBTS works by selecting tunnels based on the classification criteria of the incoming packets, which are based on the IP precedence or differentiated services code point (DSCP), or the Type of Service (ToS) fields in the packets. The traffic forwarding decisions are made based on the traffic classes AND the destination network addresses instead of only considering the destination network.

Default-class configured for paths is always zero (0). If there is no TE for a given forward-class, then the default-class (0) will be tried. If there is no default-class, then the packet is tried against the lowest configured forward-class tunnels. PBTS supports up to seven (exp 1 - 7) EXP values associated with a single TE-tunnel.

The following figure illustrates PBTS Network Topology:

Figure 8: Policy-Based Tunnel Selection Implementation



- Tunnels are created between Ingress and Egress nodes through LSR 1-2 and LSR 1-3-4-2 paths.
- High priority traffic takes the path: Ingress->LSR1->LSR2->Egress.

- Low priority traffic takes the path: Ingress->LSR1->LSR3->LSR4->LSR2->Egress

PBTS Function Details

The following PBTS functions are supported on the router:

- Classify the Ingress traffic into different classes by creating rules using PBR configuration.
- Classify packets using DSCP/IP precedence for both IPv4 and IPv6 traffic.
- After classification, set the desired forward-class to each type of Ingress traffic.
- Define one or many MPLS-TE tunnels in the destination using Tunnel configuration.
- Associate the MPLS-TE tunnels to a specific forward-class under Tunnel configuration.
- Enable PBTS on the Ingress interface by applying the service policy that uses the configured classification rules.

The following list gives PBTS support information:

- PBTS is supported only on Ipv4/Ipv6 incoming traffic only.
- A maximum of eight forward-classes per destination prefix is supported.
- A maximum of 64 TE-tunnels within each forward class is supported.
- A maximum of 64 TE-tunnels can be configured on a given destination.
- Incoming labeled traffic is not supported.
- PBTS with L2VPN/L3VPN traffic is not supported.

PBTS Forward Class

A class-map is defined for various types of packets and these class-maps are associated with a forward-class. A class-map defines the matching criteria for classifying a particular type of traffic and a forward-class defines the forwarding path these packets should take.

After a class-map is associated with a forwarding-class in the policy map, all the packets that match the class-map are forwarded as defined in the policy-map. The egress traffic engineering (TE) tunnel interfaces that the packets should take for each forwarding-class is specified by associating the TE interface explicitly (or implicitly in case of default value) with the forward-group.

When the TE interfaces are associated with the forward-class, they can be exported to the routing protocol module using the **auto-route** command. This will then associate the route in the FIB database with these tunnels. If the TE interface is not explicitly associated with a forward-class, it gets associated with a default-class (0). All non-TE interfaces will be routed to the forwarding plane (with forward-class set to default-class) by the routing protocol.