Segment Routing Traffic Engineering With IS-IS

This chapter describes how segment routing traffic engineering (SR-TE) can be implemented using IS-IS.

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Restrictions for Segment Routing-Traffic Engineering With IS-IS

- SR-TE is not supported on broadcast interfaces; it is supported only point-to-point interfaces.
- The Cisco ASR routers support only a specific number of labels imposed on an outgoing packet. If the number of labels are greater than the specified number, the SR-TE tunnel creation fails. The Cisco ASR1000 routers support a maximum of 16 labels.
- Only one instance of protocol should be enabled for TE at a given point of time.
- You can use the verbatim keyword only on a label-switched path (LSP) that is configured with the explicit path option.
- Re-optimization is unsupported on the verbatim LSP.

Information About Segment Routing Traffic Engineering With IS-IS

A Traffic Engineered (TE) tunnel is a container of TE LSPs instantiated between the tunnel ingress and the tunnel destination. A TE tunnel can instantiate one or more SR-TE LSPs that are associated with the same tunnel. The SR-TE LSP path may not necessarily follow the same IGP path to a destination node. In this case, the SR-TE path can be specified through either a set of prefix-SIDs, or adjacency-SIDs of nodes, or both, and links to be traversed by the SR-TE LSP.

The head-end imposes the corresponding MPLS label stack on outgoing packets to be carried over the tunnel. Each transit node along the SR-TE LSP path uses the incoming top label to select the next-hop, pop or swap the label, and forward the packet to the next node with the remainder of the label stack, until the packet reaches

the ultimate destination. The set of hops or segments that define an SR-TE LSP path are provisioned by the operator.

SR-TE LSP Instantiation

A Traffic Engineered (TE) tunnel is a container of one or more instantiated TE LSPs. An SR-TE LSP is instantiated by configuring 'segment-routing' on the path-option of the TE tunnel. The traffic mapped to the tunnel is forwarded over the primary SR-TE instantiated LSP.

Multiple path-options can also be configured under the same tunnel. Each path-option is assigned a preference index or a path-option index that is used to determine the more favorable path-option for instantiating the primary LSP—the lower the path-option preference index, the more favorable the path-option. The other less favorable path-options under the same TE tunnel are considered secondary path-options and may be used once the currently used path-option is invalidated (for example, due to a failure on the path.

Note A forwarding state is maintained for the primary LSP only.

SR-TE LSP Explicit Null

MPLS-TE tunnel head-end does not impose explicit-null at the bottom of the stack. When penultimate hop popping (PHP) is enabled for SR prefix SIDs or when an adjacency SID is the last hop of the SR-TE LSP, the packet may arrive at the tail-end without a transport label. However, in some cases, it is desirable that the packet arrive at the tail-end with explicit-null label, and in such case, the head-end will impose an explicit-null label at the top of the label stack.

SR-TE LSP Path Verification

SR-TE tunnel functionality requires that the head-end perform initial verification of the tunnel path as well as the subsequent tracking of the reachability of the tunnel tail-end and traversed segments.

Path verification for SR-TE LSP paths is triggered whenever MPLS-TE is notified of any topology changes or SR SID updates.

The SR-TE LSP validation steps consist of the following checks:

Topology Path Validation

The head-end validates the path of an SR-TE LSP for connectivity against the TE topology. MPLS-TE head-end checks if links corresponding to the adjacency SIDs are connected in the TE topology.

For newly-instantiated SR-TE LSPs, if the head-end detects a discontinuity on any link of the SR-TE path, that path is considered invalid and is not used. If the tunnel has other path-options with valid paths, those paths are used to instantiate the tunnel LSP.

For TE tunnels with existing instantiated SR-TE LSP, if the head-end detects a discontinuity on any link, the head-end assumes a fault has occurred on that link. In this case, the local repair protection, such as the IP FRR, come in to effect. The IGPs continue to sustain the protected adjacency label and associated forwarding after the adjacency is lost for some time. This allows the head-ends enough time to reroute the tunnels onto different paths that are not affected by the same failure. The head-end starts a tunnel invalidation timer once it detects the link failure to attempt to reroute the tunnel onto other available path-options with valid paths.

If the TE tunnel is configured with other path-options that are not affected by the failure and are validated, the head-end uses one of those path-options to reroute (and re-optimize) the tunnel by instantiating a new primary LSP for the tunnel using the unaffected path.

If no other valid path-options exist under the same tunnel, or if the TE tunnel is configured with only one path-option that is affected by the failure, the head-end starts an invalidation timer after which it brings the tunnel state to ‘down’. This action avoids black-holing the traffic flowing over the affected SR-TE LSP, and allows services riding over the tunnel to reroute over different available paths at the head-end. There is an invalidation drop configuration that keeps the tunnel 'up', but drops the traffic when the invalidation timer expires.

For intra-area SR-TE LSPs, the head-end has full visibility over the LSP path, and validates the path to the ultimate LSP destination. However, for inter-area LSPs, the head-end has partial visibility over the LSP path—only up to the first ABR. In this case, the head-end can only validate the path from the ingress to the first ABR. Any failure along the LSP beyond the first ABR node is invisible to the head-end, and other mechanisms to detect such failures, such as BFD over LSP are assumed.

SR SID Validation

SID hops of an SR-TE LSP are used to determine the outgoing MPLS label stack to be imposed on the outgoing packets carried over the SR-TE LSP of a TE tunnel. A database of global and local adjacency-SIDs is populated from the information received from IGPs and maintained in MPLS-TE. Using a SID that is not available in the MPLS TE database invalidates the path-option using the explicit-path. The path-option, in this case, is not used to instantiate the SR TE LSP. Also, withdrawing, adding, or modifying a SID in the MPLS-TE SID-database, results in the MPLS-TE head-end verifying all tunnels with SR path-options (in-use or secondary) and invokes proper handling.

LSP Egress Interface

When the SR-TE LSP uses an adjacency-SID for the first path hop, TE monitors the interface state and IGP adjacency state associated with the adjacency-SID and the node that the SR-TE LSP egresses on. If the interface or adjacency goes down, TE can assume a fault occurred on the SR-TE LSP path and take the same reactive actions described in the previous sections.

Note When the SR-TE LSP uses a prefix-SID for the first hop, TE cannot directly infer on which interface the tunnel egresses. TE relies on the IP reachability information of the prefix to determine if connectivity to the first hop is maintained.

IP Reachability Validation

MPLS-TE validates that the nodes corresponding to the prefix-SIDs are IP reachable before declaring the SR path valid. MPLS-TE detects path changes for the IP prefixes corresponding to the adjacency or prefix SIDs of the SR-TE LSP path. If the node announcing a specific SID loses IP reachability. due to a link or node failure, MPLS-TE is notified of the path change (no path). MPLS-TE reacts by invalidating the current SR-TE LSP path, and may use other path-options with a valid path, if any to instantiate a new SR-TE LSP.

Note Since IP-FRR does not offer protection against failure of a node that is being traversed by an SR-TE LSP (such as, a prefix-SID failure along the SR-TE LSP path), the head-end immediately reacts to IP route reachability loss for prefix-SID node by setting the tunnel state to ‘down’ and removes the tunnel forwarding entry if there are no other path-options with valid path for the affected tunnel.

Tunnel Path Affinity Validation

The affinity of a tunnel path can be specified using the command **tunnel mpls traffic-eng affinity** under the tunnel interface.

The head-end validates that the specified SR path is compliant with the configured affinity. This necessitates that the paths of each segment of the SR path be validated against the specified constraint. The path is declared invalid against the configured affinity constraints if at least a single segment of the path does not satisfy the configured affinity.

Tunnel Path Resource Avoidance Validation

You can specify a set of addresses to be validated as excluded from being traversed by SR-TE tunnel packets. To achieve this, the head-end runs the per-segment verification checks and validates that the specified node, prefix or link addresses are indeed excluded from the tunnel in the SR path. The tunnel resource avoidance checks can be enabled per path using the commands below. The list of addresses to be excluded are defined and the name of the list is referenced in the path-option.

```
interface tunnel100
 tunnel mpls traffic-eng path-option 1 explicit name EXCLUDE segment-routing
ip explicit-path name EXCLUDE enable
 exclude-address 192.168.0.2
 exclude-address 192.168.0.4
 exclude-address 192.168.0.3
!
```

Verbatim Path Support

MPLS TE LSPs usually require that all the nodes in the network are TE aware which means that they have IGP extensions to TE in place. However, some network administrators want the ability to build TE LSPs to traverse nodes that do not support IGP extensions to TE, but that do support RSVP extensions to TE. Verbatim LSPs are helpful when all or some of the intermediate nodes in a network do not support IGP extensions for TE.

When this feature is enabled, the IP explicit path is not checked against the TE topology database. Since the TE topology database is not verified, a Path message with IP explicit path information is routed using the shortest path first (SPF) algorithm for IP routing.

SR-TE Traffic Load Balancing

SR-TE tunnels support the following load-balancing options:

Load Balancing on Port Channel TE Links

Port Channel interfaces carry the SR-TE LSP traffic. This traffic load balances over port channel member links as well as over bundle interfaces on the head or mid of an SR-TE LSP.

Load Balancing on Single Tunnel

While using the equal cost multi path protocol (ECMP), the path to a specific prefix-SID may point to multiple next-hops. And if the SR-TE LSP path traverses one or more prefix-SIDs that have ECMP, the SR-TE LSP traffic load-balances on the ECMP paths of each traversed prefix-SID from the head-end or any midpoint traversed node along the SR-TE LSP path.

Load Balancing on Multiple Tunnels

Multiple TE tunnels can be used as next-hop paths for routes to specific IP prefixes either by configuring static route on multiple tunnels, or auto-route announcing multiple parallel tunnels to the same destination. In such cases, the tunnels share the traffic load equally or load balance traffic on multiple parallel tunnels. It is also possible to allow Unequal Load Balance (UELB) with an explicit per tunnel configuration at the tunnel head-end. In this case, the tunnel load-share is passed from MPLS-TE to forwarding plane.

The tunnel load-share feature continues to work for TE tunnels that instantiate the SR-TE LSPs.

SR-TE Tunnel Re-optimization

TE tunnel re-optimization occurs when the head-end determines that there is a more optimal path available than the one currently used. For example, in case of a failure along the SR-TE LSP path, the head-end could detect and revert to a more optimal path by triggering re-optimization.

Tunnels that instantiate SR-TE LSP can re-optimize without affecting the traffic carried over the tunnel.

Re-optimization can occur because:

- the explicit path hops used by the primary SR-TE LSP explicit path are modified,
- the head-end determines the currently used path-option are invalid due to either a topology path disconnect, or a missing SID in the SID database that is specified in the explicit-path
- a more favorable path-option (lower index) becomes available

When the head-end detects a failure on a protected SR adjacency-SID that is traversed by an SR-TE LSP, it starts the invalidation timer. If the timer expires and the head-end is still using the failed path because it is unable to reroute on a different path, the tunnel state is brought ‘down’ to avoid black-holing the traffic. Once the tunnel is down, services on the tunnel converge to take a different path.

The following is a sample output of a manual re-optimization example. In this example, the path-option is changed from ‘10’ to ‘20’.

```
Router# mpls traffic-eng reoptimize tunnel 1 path-option 20
The targeted path-option is not in lock down mode. Continue? [no]: yes
Router# show mpls traffic-eng tunnels tunnel1
Name: R1_t1                           (Tunnel1) Destination: 6.6.6.6
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 20, (SEGMENT-ROUTING) type explicit IP_PATH (Basis for Setup)
    path option 10, (SEGMENT-ROUTING) type dynamic
  Config Parameters:
    Bandwidth: 0        kbps (Global)  Priority: 6  6   Affinity: 0x0/0xFFFF
    Metric Type: IGP (interface)
    Path Selection:
     Protection: any (default)
    Path-invalidation timeout: 45000 msec (default), Action: Tear
    AutoRoute: enabled  LockDown: disabled Loadshare: 10 [200000000]
    auto-bw: disabled
    Fault-OAM: disabled, Wrap-Protection: disabled, Wrap-Capable: No
  Active Path Option Parameters:
    State: explicit path option 20 is active
    BandwidthOverride: disabled  LockDown: disabled  Verbatim: disabled
  History:
    Tunnel:
      Time since created: 6 days, 19 hours, 9 minutes
      Time since path change: 14 seconds
      Number of LSP IDs (Tun_Instances) used: 1819
    Current LSP: [ID: 1819]
      Uptime: 17 seconds
```

```
      Selection: reoptimization
    Prior LSP: [ID: 1818]
      ID: path option unknown
      Removal Trigger: reoptimization completed
  Tun_Instance: 1819
  Segment-Routing Path Info (isis level-1)
    Segment0[Node]: 4.4.4.4, Label: 114
    Segment1[Node]: 5.5.5.5, Label: 115
    Segment2[Node]: 6.6.6.6, Label: 116
```

SR-TE With Lockdown Option

The **lockdown** option prevents SR-TE from re-optimizing to a better path. However, it does not prevent signaling the existence of a new path.

```
interface Tunnel1
 ip unnumbered Loopback1
 tunnel mode mpls traffic-eng
 tunnel destination 6.6.6.6
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 6 6
 tunnel mpls traffic-eng path-option 10 segment-routing lockdown
 tunnel mpls traffic-eng path-selection metric igp
 tunnel mpls traffic-eng load-share 10
Router# show mpls traffic-eng tunnels tunnel1
Name: csr551_t1                           (Tunnel1) Destination: 6.6.6.6
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 10, (LOCKDOWN) type segment-routing (Basis for Setup)
  Config Parameters:
    Bandwidth: 0        kbps (Global)  Priority: 6  6   Affinity: 0x0/0xFFFF
    Metric Type: IGP (interface)
    Path Selection:
     Protection: any (default)
    Path-invalidation timeout: 45000 msec (default), Action: Tear
    AutoRoute: enabled  LockDown: enabled  Loadshare: 10 [200000000]
    auto-bw: disabled
    Fault-OAM: disabled, Wrap-Protection: disabled, Wrap-Capable: No
  Active Path Option Parameters:
    State: segment-routing path option 10 is active
    BandwidthOverride: disabled  LockDown: enabled   Verbatim: disabled
  History:
    Tunnel:
      Time since created: 6 days, 19 hours, 22 minutes
      Time since path change: 1 minutes, 26 seconds
      Number of LSP IDs (Tun_Instances) used: 1822
    Current LSP: [ID: 1822]
      Uptime: 1 minutes, 26 seconds
      Selection: reoptimization
    Prior LSP: [ID: 1821]
      ID: path option unknown
      Removal Trigger: configuration changed
  Tun_Instance: 1822
  Segment-Routing Path Info (isis  level-1)
    Segment0[Node]: 6.6.6.6, Label: 116
```

SR-TE Tunnel Protection

Protection for SR TE tunnels can take any of the following alternatives:

IP-FRR Local Repair Protection

On an SR-TE LSP head-end or mid-point node, IP-FRR is used to compute and program the backup protection path for the prefix-SID or adjacency-SID label.

With IP-FRR, backup repair paths are pre-computed and pre-programmed by IGPs *before* a link or node failure. The failure of a link triggers its immediate withdrawal from the TE topology (link advertisement withdrawal). This allows the head-end to detect the failure of an SR-TE LSP traversing the failed adjacency-SID.

When a protected adjacency-SID fails, the failed adjacency-SID label and associated forwarding are kept functional for a specified period of time (5 to 15 minutes) to allow all SR TE tunnel head-ends to detect and react to the failure. Traffic using the adjacency-SID label continues to be FRR protected even if there are subsequent topology updates that change the backup repair path. In this case, the IGPs update the backup repair path while FRR is active to reroute traffic on the newly-computed backup path.

When the primary path of a protected prefix-SID fails, the PLR reroutes to the backup path. The head-end remains transparent to the failure and continues to use the SR-TE LSP as a valid path.

IP-FRR provides protection for adjacency and prefix-SIDs against link failures only.

Tunnel Path Protection

Path protection is the instantiation of one or more standby LSPs to protect against the failure of the primary LSP of a single TE tunnel.

Path protection protects against failures by pre-computing and pre-provisioning secondary paths that are failure diverse with the primary path-option under the same tunnel. This protection is achieved by computing a path that excludes prefix-SIDs and adjacency-SIDs traversed by the primary LSP or by computing a path that excludes SRLGs of the primary SR-TE LSP path.

In the event of a failure of the primary SR-TE LSP, at least one standby SR-TE LSP is used for the tunnel. Multiple secondary path-options can be configured to be used as standby SR-TE LSPs paths.

Unnumbered Support

IS-IS description of an unnumbered link does not contain remote interface ID information. The remote interface ID of an unnumbered link is required to include the unnumbered link as part of the SR-TE tunnel.

How to Configure Segment Routing Traffic Engineering With IS-IS

Perform the following steps to configure Segment Routing Traffic Engineering (SR-TE) with IS-IS.

Configuring Path Option for a TE Tunnel

The **segment-routing** keyword indicates that the specified path is programmed as an SR path:

```
Device(config)# interface tunnel 100
Device(config-if)# tunnel mpls traffic-eng path-option 1 explicit name foo segment-routing
Device(config-if)# tunnel mpls traffic-eng path-option 2 dynamic segment-routing
Device(config-if)# tunnel mpls traffic-eng path-option 3 segment-routing
```

Note With IP unnumbered interfaces dynamic path is not supported.

When the path-option type for an operational SR tunnel is changed from SR to non-SR (for example, **dynamic**), the existing forwarding entry of the tunnel is deleted.

Segment Routing can be enabled or disabled on an existing secondary or an in-use path-option. If the tunnel uses a signaled RSVP-TE explicit path-option and segment routing is enabled on that tunnel, the RSVP-TE LSP is torn, and the SR-TE LSP is instantiated using the same path-option. Conversely, if segment routing is disabled on a path-option that is in use by the primary LSP, the tunnel goes down intermittently and a new RSVP-TE LSP will be signaled using the same explicit path.

If the segment-routing path-option is enabled on a secondary path-option (that is, not in-use by the tunnel's primary LSP), the tunnel is checked to evaluate if the newly specified SR-TE LSP path-option is valid and more favorable to use for the tunnel primary LSP.

Configuring SR Explicit Path Hops

The following SR-TE explicit path hops are supported:

- IP addresses
- MPLS labels
- Mix of IP addresses and MPLS labels

For intra-area LSPs, the explicit path can be specified as a list of IP addresses.

```
Device(config)# ip explicit-path name foo
Device(config-ip-expl-path)# index 10 next-address 1.1.1.1 node address
Device(config-ip-expl-path)# index 20 next-address 12.12.12.2 link address
```

Note When using IP unnumbered interfaces, you cannot specify next hop address as an explicit path index. It should be node address or label.

The explicit path can also be specified as segment-routing SIDs:

```
Device(config)# ip explicit-path name foo
Device(config-ip-expl-path)# index 10 next-label 20
```

Note IP addresses cannot be used after using the label in MIXED_PATH.

Configuring Affinity on an Interface

Perform the following steps to configure affinity on an interface:

```
interface GigabitEthernet2
 ip address 192.168.2.1 255.255.255.0
 ip router isis 1
```

```
 negotiation auto
 mpls traffic-eng tunnels
 mpls traffic-eng attribute-flags 0x1
 isis network point-to-point
 ip rsvp bandwidth
```

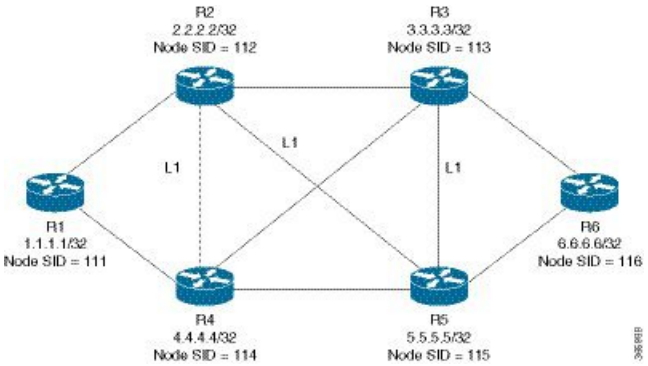
Enabling Verbatim Path Support

To enable verbatim with SR-TE you can use the following example. In the example, tunnel destination 11.11.11.11 is in different area and an explicit path with name multihop is defined with SR-TE path option.

```
R6#
interface Tunnel4
ip unnumbered Loopback66
tunnel mode mpls traffic-eng
tunnel destination 11.11.11.11
tunnel mpls traffic-eng path-option 1 explicit name multihop segment-routing verbatim
!
ip explicit-path name multihop enable
index 1 next-label 16003
index 2 next-label 16002
index 3 next-label 16001
!
End
```

Use Case: Segment Routing Traffic Engineering Basic Configuration

Consider the following topology to understand the SR-TE configuration:



To configure at the head-end router, R1:

```
!
mpls traffic-eng tunnels
!
segment-routing mpls
connected-prefix-sid-map
  address-family ipv4
   1.1.1.1/32 index 111  range 1
  exit-address-family
!
set-attributes
  address-family ipv4
  sr-label-preferred
exit-address-family
```

```
!
interface Loopback1
ip address 1.1.1.1 255.255.255.255
ip router isis 1
!
int gig0/0
ip address 11.11.11.1 255.255.255.0
ip router isis 1
mpls traffic-eng tunnels
isis network point-to-point
!
router isis 1
net 49.0001.0010.0100.1001.00
is-type level-1
metric-style wide
segment-routing mpls
segment-routing prefix-sid-map advertise-local
mpls traffic-eng router-id  Loopback1
mpls traffic-eng level-1
!
end
```

To enable SR-TE Explicit path (Node SID based), enable the following CLI on R1:

```
Head end SR-TE configuration R1#
!
interface tunnel1
ip unnumbered Loopback1
tunnel mode mpls traffic-eng
tunnel destination 6.6.6.6
tunnel mpls traffic-eng autoroute announce
tunnel mpls traffic-eng priority 6 6
tunnel mpls traffic-eng path-option 10 explicit name Node_PATH segment-routing
!
ip explicit-path name Node_PATH
 next-label  16114
next-label  16115
next-label  16116
```

To verify proper operation of SR-TE tunnel 1 on R1 enable the following CLI:

```
Tunnel verification on (R1)# show mpls traffic-eng tun tun 1 detail
Name: R1_t1                             (Tunnel1) Destination: 6.6.6.6
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 10, (SEGMENT-ROUTING) type explicit Node_PATH (Basis for Setup)
  Config Parameters:
    Bandwidth: 0        kbps (Global)  Priority: 6  6   Affinity: 0x0/0xFFFF
    Metric Type: IGP (interface)
Verbatim: disabled
Number of LSP IDs (Tun_Instances) used: 1815
    Current LSP: [ID: 1815]
      Uptime: 2 seconds
Removal Trigger: configuration changed
    Segment-Routing Path Info (isis  level-1)
    Segment0[Node]: 4.4.4.4, Label: 16114
    Segment1[Node]: 5.5.5.5, Label: 16115
    Segment2[Node]: 6.6.6.6, Label: 16116
```

To configure at the tail-end router, R6:

```
interface GigabitEthernet2
```

```
ip address 100.101.1.1 255.255.255.0
ip router isis 1
negotiation auto
mpls traffic-eng tunnels
router isis 1
 net 49.0001.0060.0600.6006.00
 ispf level-1
 metric-style wide
 log-adjacency-changes
 segment-routing mpls

segment-routing prefix-sid-map advertise-local
 mpls traffic-eng router-id Loopback1
 mpls traffic-eng level-1
```

Explicit Path SR-TE Tunnel 1

Consider tunnel 1 based only on IP addresses:

```
ip explicit-path name IP_PATH1
 next-address 2.2.2.2
 next-address 3.3.3.3
 next-address 6.6.6.6
!
interface Tunnel1
 ip unnumbered Loopback1
 tunnel mode mpls traffic-eng
 tunnel destination 6.6.6.6
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 6 6
 tunnel mpls traffic-eng path-option 10 explicit name IP_PATH1 segment-routing
 tunnel mpls traffic-eng path-selection metric igp
 tunnel mpls traffic-eng load-share 10
end
```

Explicit Path SR-TE Tunnel 2

Consider tunnel 2 based on node SIDs

```
ip explicit-path name IA_PATH
 next-label 114
 next-label 115
 next-label 116
!
interface Tunnel2
 ip unnumbered Loopback1
 tunnel mode mpls traffic-eng
 tunnel destination 6.6.6.6
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 6 6
 tunnel mpls traffic-eng bandwidth 10000 class-type 1
 tunnel mpls traffic-eng path-option 10 explicit name NODE_PATH segment-routing
 tunnel mpls traffic-eng path-selection metric igp
 tunnel mpls traffic-eng load-share 10
end
```

Explicit Path SR-TE Tunnel 3

Consider that tunnel 3 is based on a mix of IP addresses and label

```
ip explicit-path name MIXED_PATH enable
 next-address 2.2.2.2
 next-address 3.3.3.3
 next-label 115
 next-label 116
!
interface Tunnel3
 ip unnumbered Loopback1
 tunnel mode mpls traffic-eng
 tunnel destination 6.6.6.6
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 6 6
 tunnel mpls traffic-eng path-option 10 explicit name MIXED_PATH segment-routing
 tunnel mpls traffic-eng path-selection metric igp
 tunnel mpls traffic-eng load-share 10
```

Note In the case of mixed path, IP next-hop cannot be used after using Node SIDs in the path. The following path will not be valid:

```
ip explicit-path name MIXED_PATH enable
next-label 115
next-label 116
next-address 2.2.2.2
```

Dynamic Path SR-TE Tunnel 4

Consider that tunnel 4is based on adjacency SIDs

```
interface Tunnel4
 ip unnumbered Loopback1
 tunnel mode mpls traffic-eng
 tunnel destination 6.6.6.6
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 6 6
 tunnel mpls traffic-eng bandwidth 10000 class-type 1
 tunnel mpls traffic-eng path-option 10 dynamic segment-routing
 tunnel mpls traffic-eng path-selection metric igp
 tunnel mpls traffic-eng load-share 10
end
```

Dynamic Path SR-TE Tunnel 5

Consider that tunnel 5 is based on Node SIDs

```
 interface Tunnel5
 ip unnumbered Loopback1
 tunnel mode mpls traffic-eng
 tunnel destination 6.6.6.6
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 6 6
 tunnel mpls traffic-eng path-option 10 segment-routing
 tunnel mpls traffic-eng path-selection metric igp
 tunnel mpls traffic-eng load-share 10
```

Verifying Configuration of the SR-TE Tunnels

Use the **show mpls traffic-eng tunnels** *tunnel-number* command to verify the configuration of the SR-TE tunnels.

Verifying Tunnel 1

```
Name: R1_t1                            (Tunnel1) Destination: 6.6.6.6
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 10, (SEGMENT-ROUTING) type explicit IP_PATH (Basis for Setup)
  Config Parameters:
    Bandwidth: 0        kbps (Global)  Priority: 6  6   Affinity: 0x0/0xFFFF
    Metric Type: IGP (interface)
    Path Selection:
     Protection: any (default)
    Path-invalidation timeout: 45000 msec (default), Action: Tear
    AutoRoute: enabled  LockDown: disabled Loadshare: 10 [200000000]
    auto-bw: disabled
    Fault-OAM: disabled, Wrap-Protection: disabled, Wrap-Capable: No
  Active Path Option Parameters:
    State: explicit path option 10 is active
    BandwidthOverride: disabled  LockDown: disabled  Verbatim: disabled
  History:
    Tunnel:
      Time since created: 6 days, 19 hours
      Time since path change: 2 seconds
      Number of LSP IDs (Tun_Instances) used: 1814
    Current LSP: [ID: 1814]
      Uptime: 2 seconds
      Selection: reoptimization
    Prior LSP: [ID: 1813]
      ID: path option unknown
      Removal Trigger: configuration changed
  Tun_Instance: 1814
  Segment-Routing Path Info (isis  level-1)
    Segment0[Node]: 4.4.4.4, Label: 114
    Segment1[Node]: 5.5.5.5, Label: 115
    Segment2[Node]: 6.6.6.6, Label: 116
```

Verifying Tunnel 2

```
Name: R1_t2                            (Tunnel1) Destination: 6.6.6.6
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 10, (SEGMENT-ROUTING) type explicit IA_PATH (Basis for Setup)
  Config Parameters:
    Bandwidth: 0        kbps (Global)  Priority: 6  6   Affinity: 0x0/0xFFFF
    Metric Type: IGP (interface)
    Path Selection:
     Protection: any (default)
    Path-invalidation timeout: 45000 msec (default), Action: Tear
    AutoRoute: enabled  LockDown: disabled Loadshare: 10 [200000000]
    auto-bw: disabled
    Fault-OAM: disabled, Wrap-Protection: disabled, Wrap-Capable: No
  Active Path Option Parameters:
    State: explicit path option 10 is active
    BandwidthOverride: disabled  LockDown: disabled  Verbatim: disabled
  History:
    Tunnel:
```

```
      Time since created: 6 days, 19 hours, 1 minutes
      Time since path change: 1 seconds
      Number of LSP IDs (Tun_Instances) used: 1815
    Current LSP: [ID: 1815]
      Uptime: 1 seconds
    Prior LSP: [ID: 1814]
      ID: path option unknown
      Removal Trigger: configuration changed
  Tun_Instance: 1815
  Segment-Routing Path Info (isis  level-1)
    Segment0[ - ]: Label: 114
    Segment1[ - ]: Label: 115
    Segment2[ - ]: Label: 116
```

Verifying Tunnel 3

```
Name: R1_t3                           (Tunnel1) Destination: 6.6.6.6
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 10, (SEGMENT-ROUTING) type explicit MIXED_PATH (Basis for Setup)
  Config Parameters:
    Bandwidth: 0        kbps (Global)  Priority: 6  6   Affinity: 0x0/0xFFFF
    Metric Type: IGP (interface)
    Path Selection:
     Protection: any (default)
    Path-invalidation timeout: 45000 msec (default), Action: Tear
    AutoRoute: enabled  LockDown: disabled Loadshare: 10 [200000000]
    auto-bw: disabled
    Fault-OAM: disabled, Wrap-Protection: disabled, Wrap-Capable: No
  Active Path Option Parameters:
    State: explicit path option 10 is active
    BandwidthOverride: disabled  LockDown: disabled  Verbatim: disabled
  History:
    Tunnel:
      Time since created: 6 days, 19 hours, 2 minutes
      Time since path change: 2 seconds
      Number of LSP IDs (Tun_Instances) used: 1816
    Current LSP: [ID: 1816]
      Uptime: 2 seconds
      Selection: reoptimization
    Prior LSP: [ID: 1815]
      ID: path option unknown
      Removal Trigger: configuration changed
  Tun_Instance: 1816
  Segment-Routing Path Info (isis  level-1)
    Segment0[Node]: 2.2.2.2, Label: 112
    Segment1[Node]: 3.3.3.3, Label: 113
    Segment2[ - ]: Label: 115
    Segment3[ - ]: Label: 116
```

Verifying Tunnel 4

```
Name: R1_t4                           (Tunnel1) Destination: 6.6.6.6
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 10, (SEGMENT-ROUTING) type dynamic (Basis for Setup, path weight 30)
  Config Parameters:
    Bandwidth: 0        kbps (Global)  Priority: 6  6   Affinity: 0x0/0xFFFF
    Metric Type: IGP (interface)
    Path Selection:
     Protection: any (default)
```

```
    Path-invalidation timeout: 45000 msec (default), Action: Tear
    AutoRoute: enabled  LockDown: disabled Loadshare: 10 [200000000]
    auto-bw: disabled
    Fault-OAM: disabled, Wrap-Protection: disabled, Wrap-Capable: No
  Active Path Option Parameters:
    State: dynamic path option 10 is active
    BandwidthOverride: disabled  LockDown: disabled  Verbatim: disabled
  History:
    Tunnel:
      Time since created: 6 days, 19 hours
      Time since path change: 2 seconds
      Number of LSP IDs (Tun_Instances) used: 1813
    Current LSP: [ID: 1813]
      Uptime: 2 seconds
    Prior LSP: [ID: 1806]
      ID: path option unknown
      Removal Trigger: configuration changed
  Tun_Instance: 1813
  Segment-Routing Path Info (isis  level-1)
    Segment0[Link]: 192.168.2.1 - 192.168.2.2, Label: 17
    Segment1[Link]: 192.168.4.2 - 192.168.4.1, Label: 25
    Segment2[Link]: 192.168.8.1 - 192.168.8.2, Label: 300
```

Verifying Tunnel 5

```
Name: R1_t5                           (Tunnel1) Destination: 6.6.6.6
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 10, type segment-routing (Basis for Setup)
  Config Parameters:
    Bandwidth: 0        kbps (Global)  Priority: 6  6   Affinity: 0x0/0xFFFF
    Metric Type: IGP (interface)
    Path Selection:
     Protection: any (default)
    Path-invalidation timeout: 45000 msec (default), Action: Tear
    AutoRoute: enabled  LockDown: disabled Loadshare: 10 [200000000]
    auto-bw: disabled
    Fault-OAM: disabled, Wrap-Protection: disabled, Wrap-Capable: No
  Active Path Option Parameters:
    State: segment-routing path option 10 is active
    BandwidthOverride: disabled  LockDown: disabled  Verbatim: disabled
  History:
    Tunnel:
      Time since created: 6 days, 19 hours, 4 minutes
      Time since path change: 14 seconds
      Number of LSP IDs (Tun_Instances) used: 1817
    Current LSP: [ID: 1817]
      Uptime: 14 seconds
      Selection: reoptimization
    Prior LSP: [ID: 1816]
      ID: path option unknown
      Removal Trigger: configuration changed
  Tun_Instance: 1817
  Segment-Routing Path Info (isis  level-1)
    Segment0[Node]: 6.6.6.6, Label: 116
```

Verifying Verbatim Path Support

To verify proper operation and SR-TE tunnel state use following CLI:

```
R6#sh mpl traffic-eng tunnels tunnel 4

Name: R6_t4                               (Tunnel4) Destination: 11.11.11.11
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected
    path option 1, (SEGMENT-ROUTING) type explicit (verbatim) multihop (Basis for Setup)

  Config Parameters:
    Bandwidth: 0        kbps (Global)  Priority: 7  7   Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    Path Selection:
     Protection: any (default)
    Path-selection Tiebreaker:
      Global: not set   Tunnel Specific: not set   Effective: min-fill (default)
    Hop Limit: disabled [ignore: Verbatim Path Option]
    Cost Limit: disabled
    Path-invalidation timeout: 10000 msec (default), Action: Tear
    AutoRoute: disabled LockDown: disabled Loadshare: 0 [0] bw-based
    auto-bw: disabled
    Fault-OAM: disabled, Wrap-Protection: disabled, Wrap-Capable: No
  Active Path Option Parameters:
    State: explicit path option 1 is active
    BandwidthOverride: disabled  LockDown: disabled  Verbatim: enabled

  History:
    Tunnel:
      Time since created: 16 minutes, 40 seconds
      Time since path change: 13 minutes, 6 seconds
      Number of LSP IDs (Tun_Instances) used: 13
    Current LSP: [ID: 13]
      Uptime: 13 minutes, 6 seconds
      Selection: reoptimization
    Prior LSP: [ID: 12]
      ID: path option unknown
      Removal Trigger: configuration changed (severe)
  Tun_Instance: 13
  Segment-Routing Path Info (IGP information is not used)
    Segment0[First Hop]: 0.0.0.0, Label: 16003
    Segment1[ - ]: Label: 16002
    Segment2[ - ]: Label: 16001
```

Additional References for Segment Routing Traffic Engineering With IS-IS

Related Documents

Related Topic	Document Title
Cisco IOS Commands	Cisco IOS Master Command List, All Releases

Feature Information for Segment Routing -Traffic Engineering With IS-IS

The following table provides release information about the feature or features described in this module. This table lists only the software release that introduced support for a given feature in a given software release train. Unless noted otherwise, subsequent releases of that software release train also support that feature.

Use Cisco Feature Navigator to find information about platform support and Cisco software image support. To access Cisco Feature Navigator, go to www.cisco.com/go/cfn. An account on Cisco.com is not required.

Table 1: Feature Information for Segment Routing -Traffic Engineering With IS-IS

Feature Name	Releases	Feature Information
Segment Routing-Traffic Engineering With IS-IS	Cisco IOS XE Everest 16.4.1 Cisco IOS XE Fuji 16.7.1	The following commands were introduced or modified: **mpls traffic-eng nsr**, **show mpls traffic-eng tunnels tunnel1**, **show isis fast-reroute ti-lfa tunnel**, **show frr-manager client client-name ISIS interfaces detail**, **show ip cef 6.6.6.6 internal** In Cisco IOS XE Fuji 16.7.1, this feature is supported on Cisco 4000 Series Integrated Service Routers.