Configure SRv6 Traffic Engineering

This module provides information about Segment Routing over IPv6 (SRv6) Traffic Engineering, how to configure SRv6-TE, and how to steer traffic into an SRv6-TE policy.

Table 1: Feature History Table

Feature Name	Release Information	Feature Description
SRv6 Traffic Engineering	Release 24.4.1	Introduced in this release on: Fixed Systems(8200, 8700);Modular Systems (8800 [LC ASIC: P100]) (select variants only*) *This feature is now supported on: • 8212-32FH-M • 8711-32FH-M • 8712-MOD-M • 88-LC1-12TH24FH-E

Feature Name	Release Information	Feature Description
SRv6 Traffic Engineering	Release 7.10.1	

Feature Name	Release Information	Feature Description
		You can now control the traffic flows within the network by defining the explicit and dynamic paths for traffic flows using the Segment Identifier (SID) within the IPv6 packet header. Defining explicit and dynamic paths based on different attributes and constraints allow the router to optimize routing decisions and enhance resource utilization. SRv6-TE policies supports the following functionalities: • SRv6-TE with SRv6 micro-SIDs (uSIDs) • Explicit SRv6 policies • Automated steering for Layer 3-based BGP services (IPv4 L3VPN, IPv6 L3VPN, IPv4 BGP global, IPv6 BGP global) • SRv6-aware Path Computation Element (PCE) • PCEPv4 and PCEPv6 • Path computation optimization objectives (TE, IGP, latency) • Path computation constraints (affinity, disjointness) This feature introduces the following changes: **CLI:** • **policy srv6 locator** • **segment-routing traffic-eng srv6** • **srv6 locator** • **srv6 maximum-sid-depth** • **segment-lists segment-list** • **segment-lists srv6** **YANG Data Model:**

Feature Name	Release Information	Feature Description
		• Cisco-IOS-XR-segment-routing-ms-cfg (see GitHub, YANG Data Models Navigator)

SRv6-TE Overview

Segment Routing over IPv6 Traffic Engineering (SRv6-TE) allows you to steer traffic across a network based on specific policies and requirements and provides greater control over how traffic flows through the network.

SRv6-TE also allows you to create explicit paths through the network for specific traffic flows where a particular application or service requires a specific quality of service (QoS) level, such as low latency or high bandwidth.

SRv6-TE uses the concept of source routing, where the source calculates the path and encodes it in the packet header as a list of segments. This list of segments is added to an IPv6 routing header called the SRv6 Segment Routing Header (SRH) in the incoming packet. With SRv6-TE, the network does not need to maintain per-application and per-flow state on each node. Instead, only the head-end nodes on the edge of the network where the traffic enters the policy need to maintain a state.

The remaining nodes obey the forwarding instructions that are included in the packet. SRv6-TE can utilize network bandwidth more effectively than traditional MPLS RSVP-TE using ECMP within each segment. In addition, by using a single intelligent source it relieves remaining routers from the task of calculating the required path through the network.

Traffic engineering over SRv6 can be accomplished in the following ways:

- End-to-End Flexible Algorithm: This is used for traffic engineering intents achieved with Flexible Algorithm, including low latency, multi-plane disjointness, affinity inclusion/exclusion, and SRLG exclusion. See SRv6 Flexible Algorithm, on page 21.
- SRv6-TE Policy: This is used for traffic engineering intents beyond Flex Algo capabilities, such as path disjointness that rely on path computation by a PCE. In addition, this is used for user-configured explicit paths. SRv6-TE Policy, on page 6.

Usage Guidelines and Limitations

The following are the usage guidelines and limitations for SRv6 policy.

Supported Features

The following are the supported functionalities:

- SR-PM liveness detection over SRv6 policies
- SRv6 policies with SRv6 uSID segments
- SRv6 policies with PCE-delegated dynamic paths
- SRv6 policies with explicit paths
- SRv6 policies with single or multiple candidate paths (CP)
- SRv6 policies with a single SID list per CP
- SRv6 policies with multiple (weighted ECMP) SID lists per CP
- Path delegation and reporting with PCEPv4
- Path delegation and reporting with PCEPv6
- PCEPv4 and PCEPv6 sessions with different PCEs
- PCEs with PCEP state-sync sessions must be either PCEPv4 or PCEPv6.
- PCEP path delegation with the following optimization objective (metric) types:
  - IGP metric
  - TE metric
  - Delay (latency)
  - Hop-count
- PCEP path delegation with the following constraint types:
  - Affinity (include-any, include-all, exclude-any)
  - Path disjointness (link, node, SRLG, SRLG+node)
    - For path-computation on PCE, configuring both affinity and disjoint-path is not supported.
  - Segment protection-type:
    - Protected-only
    - Protected-preferred
    - Unprotected-only
    - Unprotected-preferred

- SRv6 policy with TI-LFA (protection of the first segment in the segment list at the head-end)
- Steering over SRv6 policies with Automated Steering for the following services:
  - L3 BGP-based services (IPv4 L3VPN, IPv6 L3VPN, IPv4 BGP global, IPv6 BGP global)
- To switch between an RSVP-TE or SR-TE configuration and an MPLS-TE configuration and vice versa, it is necessary to remove the configuration of the first process, say, RSVP-TE or SR-TE, in a separate commit operation and add the configuration of the next process, say, MPLS-TE, in another commit operation. This prevents any commit failures caused due to the delay in unconfiguring the first process before the next process configuration is applied.

Unsupported Features

The following functionalities are not supported:

- SRv6 policy counters
- PCE-initiated SRv6 policies via PCEP
- SRv6 policies with head-end computed dynamic paths
- PCE path delegation with segment-type Flex Algo constraint
- PCEPv4 and PCEPv6 sessions with same PCE
- Steering over SRv6 policies based on incoming BSID (remote automated steering)
- PCC with user-configured PCE groups
- SR-PM delay-measurement over SRv6 policies
- L3 services with BGP PIC over SRv6 policies
- SRv6 policy ping
- L2 BGP-based service (EVPN VPWS)

By default, 1K polices are supported. If MPLS tunnels are not configured on the router, use the following commands to get higher SRv6-TE scale:

- If the support for LDPoTE or SRoSR-TE MPLS features are not required, use the following command to configure higher RSVP-TE/SR-TE scale.

  hw-module profile cef te-tunnel highscale-no-ldp-over-te

- If the support for LDPoTE is required but not SRoSR-TE MPLS features, use the following command to configure higher tunnel scale.

  hw-module profile cef te-tunnel highscale-ldp-over-te-no-sr-over-srte

SRv6-TE Policy

SRv6-TE uses a “policy” to steer traffic through the network. An SRv6-TE policy path is expressed as a list of micro-segments that specifies the path, called a micro-segment ID (uSID) list. Each segment list is an end-to-end path from the source to the destination, and instructs the routers in the network to follow the specified path instead of following the shortest path calculated by the IGP. If a packet is steered into an SRv6-TE policy, the uSID list is pushed on the packet by the head-end. The rest of the network executes the instructions embedded in the uSID list.

An SRv6-TE policy is identified as an ordered list (head-end, color, end-point):

- Head-end – Where the SRv6-TE policy is instantiated
- Color – A numerical value that distinguishes between two or more policies to the same node pairs (Head-end – End point)
- End-point – The destination of the SRv6-TE policy

Every SRv6-TE policy has a color value. Every policy between the same node pairs requires a unique color value.

An SRv6-TE policy uses one or more candidate paths. A candidate path can be made up of a single SID-list or a set of weighted SID-lists (for weighted equal cost multi-path [WECMP]).

A SID list can be either the result of a dynamic path computation by a PCE or a user-configured explicit path. See SRv6-TE Policy Path Types for more information.

SRv6-TE Policy Path Types

The following SRv6-TE policy path types are supported:

Explicit Paths

An **explicit** path is a specified SID-list or set of SID-lists.

When configuring an explicit path using IP addresses of links along the path, the SRv6-TE process prefers the protected Adj-SID of the link, if one is available. In addition, when manual Adj-SIDs are configured, the SRv6-TE process prefers a manual-protected Adj-SID over a dynamic-protected Adj-SID.

You can configure the path to prefer the protected or unprotected Adj-SID, or to use only protected or unprotected Adj-SID. See Segment Protection-Type Constraint, on page 20.

You can enable SRv6-TE explicit segment list SID validation to allow the head-end node to validate the SIDs in an explicit SRv6-TE segment list against the SR-TE topology database. See SRv6-TE Explicit Segment List SID Validation, on page 11.

A segment list can use uSIDs or uSID carrier, or a combination of both.

Configure SRv6-TE Policy with Explicit Path

To configure an SRv6-TE policy with an explicit path, complete the following configurations:

1. Create the segment lists with SRv6 segments.
2. Create the SRv6-TE policy.

Create a segment list with SRv6 uSIDs:

```
Router(config)# segment-routing traffic-eng
Router(config-sr-te)# segment-lists
Router(config-sr-te-segment-lists)# srv6
Router(config-sr-te-sl-global-srv6)# sid-format usid-f3216
Router(config-sr-te-sl-global-srv6)# exit
```

```
Router(config-sr-te-segment-lists)# segment-list p1_r8_1
Router(config-sr-te-sl)# srv6
Router(config-sr-te-sl-srv6)# index 10 sid FCBB:BB00:10:feff::
Router(config-sr-te-sl-srv6)# index 15 sid FCBB:BB00:100:fe00::
Router(config-sr-te-sl-srv6)# index 20 sid FCBB:BB00:2::
Router(config-sr-te-sl-srv6)# index 30 sid FCBB:BB00:3::
Router(config-sr-te-sl-srv6)# index 40 sid FCBB:BB00:4::
Router(config-sr-te-sl-srv6)# index 50 sid FCBB:BB00:5::
Router(config-sr-te-sl-srv6)# index 60 sid FCBB:BB00:6::
```

Create the SRv6-TE policy:

```
Router(config-sr-te)# policy POLICY1
Router(config-sr-te-policy)# srv6 locator loc1 binding-sid dynamic behavior ub6-encaps-reduced
Router(config-sr-te-policy)# color 10 end-point ipv6 FCBB:BB00:2::1
Router(config-sr-te-policy)# candidate-paths
Router(config-sr-te-policy-path)# preference 100
Router(config-sr-te-policy-path-pref)# explicit segment-list p1_r8_1
Router(config-sr-te-pp-info)# exit
Router(config-sr-te-policy-path-pref)# exit
```

Running Configuration

```
Router# show running-config

. . .

segment-routing
 traffic-eng
  segment-lists
   srv6
    sid-format usid-f3216
   !
   segment-list p1_r8_1
    srv6
     index 10 sid FCBB:BB00:10:feff::
     index 15 sid FCBB:BB00:100:fe00::
     index 20 sid FCBB:BB00:2::
     index 30 sid FCBB:BB00:3:::
     index 40 sid FCBB:BB00:4::
     index 50 sid FCBB:BB00:5::
     index 60 sid FCBB:BB00:6::
    !
   !
  !
  policy POLICY1
   srv6
    locator loc1 binding-sid dynamic behavior ub6-encaps-reduced
   !
   color 10 end-point ipv6 fcbb:bb00:2::1
   candidate-paths
    preference 100
     explicit segment-list p1_r8_1
     !
    !
   !
  !
 !
!
```

Verification

Verify the SR-TE policy configuration using:

```
Router# show segment-routing traffic-eng policy name srte_c_10_ep_fcbb:bb00:2::1 d

SR-TE policy database
---------------------

Color: 10, End-point: fcbb:bb00:2::1
  Name: srte_c_10_ep_fcbb:bb00:2::1
  Status:
    Admin: up  Operational: down for 00:01:30 (since Oct 31 21:33:24.090)
  Candidate-paths:
    Preference: 100 (configuration) (inactive)
      Name: POLICY1
      Requested BSID: dynamic
      Constraints:
        Protection Type: protected-preferred
        Maximum SID Depth: 13
      Explicit: segment-list p1_r8_1 (inactive)
        Weight: 1, Metric Type: TE
          SID[0]: FCBB:BB00:10:feff::
          SID[1]: FCBB:BB00:100:fe00::
          SID[2]: FCBB:BB00:1::
          SID[3]: FCBB:BB00:1:fe00::
          SID[4]: FCBB:BB00:fe00::
          SID[5]: FCBB:BB00:5::
          SID[6]: FCBB:BB00:6::
      SRv6 Information:
        Locator: loc1
        Binding SID requested: Dynamic
        Binding SID behavior: End.B6.Encaps.Red
  Attributes:
    Forward Class: 0
    Steering labeled-services disabled: no
    Steering BGP disabled: no
    IPv6 caps enable: yes
    Invalidation drop enabled: no
    Max Install Standby Candidate Paths: 0
```

Candidate Paths with Weighted SID Lists

If a candidate path is associated with a set of segment lists, each segment list is associated with weight for weighted load balancing. Valid values for weight are from 1 to 4294967295; the default weight is 1.

If a set of segment lists is associated with the active path of the policy, then the steering is per-flow and weighted-ECMP (W-ECMP) based according to the relative weight of each segment list.

The fraction of the flows associated with a given segment list is *w*/*Sw*, where *w* is the weight of the segment list and *Sw* is the sum of the weights of the segment lists of the selected path of the SR policy.

When a composite candidate path is active, the fraction of flows steered into each constituent SR policy is equal to the relative weight of each constituent SR policy. Further load balancing of flows steered into a constituent SR policy is performed based on the weights of the segment list of the active candidate path of that constituent SR policy.

Configuration Example

```
Router(config)# segment-routing traffic-eng
```

```
Router(config-sr-te)# segment-lists
Router(config-sr-te-segment-lists)# srv6
Router(config-sr-te-sl-global-srv6)# sid-format usid-f3216
Router(config-sr-te-sl-global-srv6)# exit
Router(config-sr-te-segment-lists)# segment-list p1_r8_3
Router(config-sr-te-sl)# srv6
Router(config-sr-te-sl-srv6)# index 10 sid FCBB:BB00:10:fe01::
Router(config-sr-te-sl-srv6)# index 20 sid FCBB:BB00:1::
Router(config-sr-te-sl-srv6)# index 30 sid FCBB:BB00:1:fe00::
Router(config-sr-te-sl-srv6)# index 40 sid FCBB:BB00:fe00::
Router(config-sr-te-sl-srv6)# index 50 sid FCBB:BB00:5::
Router(config-sr-te-sl-srv6)# index 60 sid FCBB:BB00:6::
Router(config-sr-te-segment-lists)# segment-list igp_ucmp1
Router(config-sr-te-sl)# srv6
Router(config-sr-te-sl-srv6)# index 10 sid FCBB:BB00:1::
Router(config-sr-te-sl-srv6)# index 20 sid FCBB:BB00:4::
Router(config-sr-te-sl-srv6)# index 30 sid FCBB:BB00:5::
Router(config-sr-te-sl-srv6)# exit
Router(config-sr-te-sl)# exit
Router(config-sr-te-segment-lists)# exit

Router(config-sr-te)# policy po_r8_1001
Router(config-sr-te-policy)# srv6 locator loc1 binding-sid dynamic behavior ub6-encaps-reduced
Router(config-sr-te-policy)# color 1001 end-point ipv6 FCBB:BB00:2::1
Router(config-sr-te-policy)# candidate-paths
Router(config-sr-te-policy-path)# preference 1000
Router(config-sr-te-policy-path-pref)# explicit segment-list p1_r8_3
Router(config-sr-te-pp-info)# weight 4
Router(config-sr-te-pp-info)# exit
Router(config-sr-te-policy-path-pref)# explicit segment-list igp_ucmp1
Router(config-sr-te-pp-info)# weight 2
Router(config-sr-te-pp-info)# exit
```

Running Configuration

```
Router# show running-config

. . .

segment-routing
 traffic-eng
  segment-lists
   srv6
    sid-format usid-f3216
   !
   segment-list p1_r8_3
    srv6
     index 10 sid FCBB:BB00:10:fe01::
     index 20 sid FCBB:BB00:1::
     index 30 sid FCBB:BB00:1:fe00::
     index 40 sid FCBB:BB00:fe00::
     index 50 sid FCBB:BB00:5::
     index 60 sid FCBB:BB00:6::
    !
   !
   segment-list igp_ucmp1
    srv6
     index 10 sid FCBB:BB00:1::
     index 20 sid FCBB:BB00:4::
     index 30 sid FCBB:BB00:5::
    !
   !
```

```
  !
  policy po_r8_1001
   srv6
    locator loc1 binding-sid dynamic behavior ub6-encaps-reduced
   !
   color 1001 end-point ipv6 fcbb:bb00:2::1
   candidate-paths
    preference 1000
     explicit segment-list p1_r8_3
      weight 4
     !
     explicit segment-list igp_ucmp1
      weight 2
     !
    !
   !
  !
 !
!
```

SRv6-TE Explicit Segment List SID Validation

SRv6-TE explicit segment list SID validation evaluates whether the explicit segment list of an SR policy's candidate path is valid and therefore usable. The head-end node validates if the hops are in the SR-TE topology database.

When enabled, the segment list SID validation occurs before programming the SR policy and after an IGP topology change.

When the segment list validation fails, then the segment list is declared invalid. An SR policy candidate path is declared invalid when it has no valid segment lists. An SR policy is declared invalid when it has no valid candidate paths.

Usage Guidelines and Limitations

- Segment list SID validation can be enabled globally for all SRv6 explicit segment lists or for a specific SRv6 segment list.
- If SIDs in an explicit segment list are expected to not be found in the headend (for example, a multi-domain case), the topology check can be disabled for that segment list.
- The SR-TE topology should distributed from IGP (for intra-domain paths) or from BGP-LS (for multi-domain paths).
- The SRv6 segment list in an explicit candidate path of an SRv6 policy cannot be empty.
- All segments in a segment list must be of same data plane type: SRv6 or SR-MPLS.
- Top SID validation occurs by performing path resolution using the top SID.
- All SIDs in segment list are validated against local SID block and SID format.
- A segment list is validated against MSD.

Enable SID validation globally for all SRv6 explicit segment lists

Prior to enabling SRv6 explicit segment list SID validation, use the **show segment-routing traffic-eng topology** command to verify if the SR-TE topology is available on the headend PCC router.

To enable SID validation globally, use the **segment-routing traffic-eng segment-lists srv6 topology-check** command.

```
Router(config)# segment-routing traffic-eng
Router(config-sr-te)# segment-lists
Router(config-sr-te-segment-lists)# srv6
Router(config-sr-te-sl-global-srv6)# topology-check
```

To enable SID validation for a specific explicit SID list, use the **segment-routing traffic-eng segment-lists segment-list** *name* **srv6 topology-check** command.

```
Router(config)# segment-routing traffic-eng
Router(config-sr-te)# segment-lists
Router(config-sr-te-segment-lists)# segment-list p1_r8_1
Router(config-sr-te-sl)# srv6
Router(config-sr-te-sl-srv6)# topology-check
```

The following example shows how to enable SID validation globally and disable SID validation for a specific SRv6 explicit segment list:

```
Router(config)# segment-routing traffic-eng
Router(config-sr-te)# segment-lists
Router(config-sr-te-segment-lists)# srv6
Router(config-sr-te-sl-global-srv6)# topology-check
Router(config-sr-te-sl-global-srv6)# exit
Router(config-sr-te-segment-lists)# segment-list p1_r8_1
Router(config-sr-te-sl)# srv6
Router(config-sr-te-sl-srv6)# no topology-check
```

Running Configuration

```
segment-routing
 traffic-eng
  segment-lists
   srv6
    topology-check
   !
   segment-list p1_r8_1
    srv6
     no topology-check
    !
   !
  !
 !
!
```

Verification

```
Router# show segment-routing traffic-eng policy name srte_c_10_ep_fcbb:bb00:2::1 detail

SR-TE policy database
---------------------

Color: 10, End-point: fcbb:bb00:2::1
  Name: srte_c_10_ep_fcbb:bb00:2::1
  Status:
    Admin: up  Operational: down for 00:04:12 (since Nov  7 19:24:21.396)
  Candidate-paths:
```

```
    Preference: 100 (configuration) (inactive)
      Name: POLICY1
      Requested BSID: dynamic
      Constraints:
        Protection Type: protected-preferred
        Maximum SID Depth: 13
      Explicit: segment-list p1_r8_1 (inactive)
        Weight: 1, Metric Type: TE
          SID[0]: fccc:0:10:feff::
          SID[1]: fccc:0:100:fe00::
          SID[2]: fccc:0:1::
          SID[3]: fccc:0:1:fe00::
          SID[4]: fccc:0:fe00::
          SID[5]: fccc:0:5::
          SID[6]: fccc:0:6::
      SRv6 Information:
        Locator: loc1
        Binding SID requested: Dynamic
        Binding SID behavior: End.B6.Encaps.Red
  Attributes:
    Forward Class: 0
    Steering labeled-services disabled: no
    Steering BGP disabled: no
    IPv6 caps enable: yes
    Invalidation drop enabled: no
    Max Install Standby Candidate Paths: 0
```

Dynamic Paths

A **dynamic** path is based on an optimization objective and a set of constraints. The head-end computes a solution, resulting in a SID-list or a set of SID-lists. When the topology changes, a new path is computed. If the head-end does not have enough information about the topology, the head-end might delegate the computation to a Segment Routing Path Computation Element (SR-PCE). For information on configuring SR-PCE, see *Configure Segment Routing Path Computation Element* chapter.

An SRv6-TE policy initiates a single (selected) path in RIB/FIB. This is the preferred valid candidate path.

A candidate path has the following characteristics:

- It has a preference – If two policies have same {color, endpoint} but different preferences, the policy with the highest preference is selected.
- It is associated with a single Binding SID (uB6) – A uB6 SID conflict occurs when there are different SRv6 policies with the same uB6 SID. In this case, the policy that is installed first gets the uB6 SID and is selected.
- It is valid if it is usable.

A path is selected when the path is valid and its preference is the best among all candidate paths for that policy.

Note The protocol of the source is not relevant in the path selection logic.

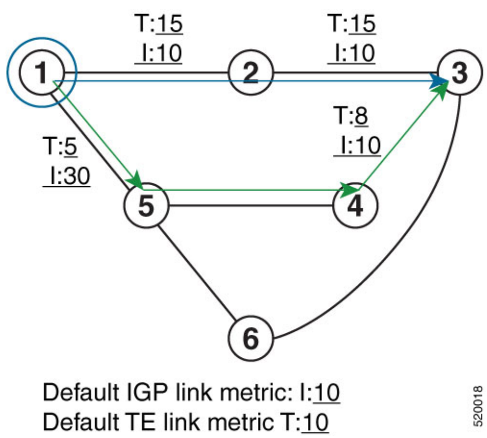
For a dynamic path that traverses a specific interface between nodes (segment), the algorithm may encode this segment using an Adjacency uSID (uA SID).

Optimization Objectives

Optimization objectives allow the head-end router to compute a uSID-list that expresses the shortest dynamic path according to the selected metric type:

- Hopcount — Use the least number of hops for path computation.
- IGP metric — Refer to the *Implementing IS-IS* and *Implementing OSPF* chapters in the *Routing Configuration Guide for Cisco 8000 Series Routers*
- TE metric — See the Configure Interface TE Metrics, on page 14 section for information about configuring TE metrics.
- Delay (latency) — See the Configure Performance Measurementchapter for information about measuring delay for links or SRv6 policies.

This example shows a dynamic path from head-end router 1 to end-point router 3 that minimizes IGP or TE metric:



- The blue path uses the minimum IGP metric: Min-Metric (1 → 3, IGP) = uSID-list {cafe:0:**3**::}; cumulative IGP metric: 20
- The green path uses the minimum TE metric: Min-Metric (1 → 3, TE) = uSID-list {cafe:0:**5**:**4**:**3**::}; cumulative TE metric: 23

Configure Interface TE Metrics

To configure the TE metric for interfaces, use the **metric** *value* command. The *value* range is from 0 to 2147483647.

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# interface type interface-path-id
Router(config-sr-te-if)# metric value
```

Running Configuration

The following configuration example shows how to set the TE metric for various interfaces:

```
segment-routing
 traffic-eng
```

```
  interface TenGigE0/0/0/0
   metric 100
  !
  interface TenGigE0/0/0/1
   metric 1000
  !
  interface TenGigE0/0/2/0
   metric 50
  !
 !
end
```

Constraints

Constraints allow the head-end router to compute a dynamic path according to the selected metric type:

> **Note** For path-computation on PCE, configuring both affinity and disjoint-path is not supported.

- Affinity — You can apply a color or name to links or interfaces by assigning affinity bit-maps to them. You can then specify an affinity (or relationship) between an SRv6 policy path and link colors. SRv6-TE computes a path that includes or excludes links that have specific colors,or combinations of colors. See the Named Interface Link Admin Groups and SRv6-TE Affinity Maps, on page 18section for information on named interface link admin groups and SRv6-TE Affinity Maps.
- Disjoint — SRv6-TE computes a path that is disjoint from another path in the same disjoint-group. Disjoint paths do not share network resources. Path disjointness may be required for paths between the same pair of nodes, between different pairs of nodes, or a combination (only same head-end or only same end-point).
- Segment protection-type behavior — You can control whether protected or unprotected segments are used when encoding the SID-list of an SRv6 policy candidate path. The types of segments that could be used when building a SID-list include uSIDs and adjacency SIDs (uA SID). See the Segment Protection-Type Constraint, on page 20 for details and usage guidelines.

Configure SRv6 Policy with Dynamic Path

To configure a SRv6-TE policy with a dynamic path, optimization objectives, and affinity constraints, complete the following configurations:

- Create the SRv6-TE Policy and configure the SRv6-TE policy color and IPv6 end-point address.
- (optional) Specify Customized Locator and Source Address

> **Note**
> - If you do not specify a customized per-policy locator and BSID behavior, the policy will use the global locator and BSID behavior.
> - If you do not specify a customized per-policy source address, the policy will use the local IPv6 source address.

- Enable Dynamic Path Computed by the SR-PCE

- Configure Dynamic Path Optimization Objectives
- Configure Dynamic Path Constraints

Note Disjoint-path and affinity constraints cannot be configured at the same time.

Configuration Example

The following example shows a configuration of an SRv6 policy at an SRv6-TE head-end router using the global locator and source address. The policy has a dynamic path with optimization objectives and affinity constraints computed by the SR-PCE.

```
Node1(config)# segment-routing
Node1(config-sr)# traffic-eng
Node1(config-sr-te)# srv6

/* Specify customized locator and source address */
Node1(config-sr-te-srv6)# locator Node1 binding-sid dynamic behavior ub6-encaps-reduced
Node1(config-sr-te-srv6)# exit
Node1(config-sr-te)# candidate-paths
Node1(config-sr-te-candidate-path)# all

/* Specify the customized IPv6 source address for candidate paths */
Node1(config-sr-te-candidate-path-type)# source-address ipv6 cafe:0:1::1
Node1(config-sr-te-candidate-path-type)# exit
Node1(config-sr-te-candidate-path)# exit

/* Create the SRv6-TE policy */
Node1(config-sr-te)# policy pol_node1_node4_te
Node1(config-sr-te-policy)# color 20 end-point ipv6 cafe:0:4::4

/* Enable dynamic path computed by the SR-PCE */
Node1(config-sr-te-policy)# candidate-paths
Node1(config-sr-te-policy-path)# preference 100
Node1(config-sr-te-policy-path-pref)# dynamic
Node1(config-sr-te-pp-info)# pcep
Node1(config-sr-te-path-pcep)# exit

/* Configure dynamic Path optimization objectives */
Node1(config-sr-te-pp-info)# metric type te
Node1(config-sr-te-pp-info)# exit

/* Configure dynamic path constraints*/
Node1(config-sr-te-policy-path-pref)# constraints
Node1(config-sr-te-path-pref-const)# affinity
Node1(config-sr-te-path-pref-const-aff)# exclude-any
Node1(config-sr-te-path-pref-const-aff-rule)# name brown
```

Running Confiuration

```
segment-routing
 traffic-eng
  srv6
   locator Node1 binding-sid dynamic behavior ub6-encaps-reduced
  !
  candidate-paths
   all
    source-address ipv6 cafe:0:1::1
```

```
    !
   !
   policy pol_node1_node4_te
    color 20 end-point ipv6 cafe:0:4::4
    candidate-paths
     preference 100
      dynamic
       pcep
       !
       metric
        type te
       !
      !
      constraints
       affinity
        exclude-any
         name brown
        !
       !
      !
     !
    !
   !
  !
 !
```

The following example shows a configuration of a manual SRv6 policy at an SRv6-TE head-end router with customized locator and source address. The policy has a dynamic path with optimization objectives and affinity constraints computed by the SR-PCE.

```
Node1(config)# segment-routing
Node1(config-sr)# traffic-eng
Node1(config-sr-te)# policy pol_node1_node4_te
Node1(config-sr-te-policy)# source-address ipv6 cafe:0:1::1
Node1(config-sr-te-policy)# srv6
Node1(config-sr-te-policy-srv6)# locator Node1 binding-sid dynamic behavior ub6-encaps-reduced
Node1(config-sr-te-policy-srv6)# exit
Node1(config-sr-te-policy)# color 20 end-point ipv6 cafe:0:4::4
Node1(config-sr-te-policy)# candidate-paths
Node1(config-sr-te-policy-path)# preference 100
Node1(config-sr-te-policy-path-pref)# dynamic
Node1(config-sr-te-pp-info)# pcep
Node1(config-sr-te-path-pcep)# exit
Node1(config-sr-te-pp-info)# metric type te
Node1(config-sr-te-pp-info)# exit
Node1(config-sr-te-policy-path-pref)# constraints
Node1(config-sr-te-path-pref-const)# affinity
Node1(config-sr-te-path-pref-const-aff)# exclude-any
Node1(config-sr-te-path-pref-const-aff-rule)# name brown
```

Running Config

```
segment-routing
 traffic-eng
  policy pol_node1_node4_te
   srv6
    locator Node1 binding-sid dynamic behavior ub6-encaps-reduced
   !
   source-address ipv6 cafe:0:1::1
   color 20 end-point ipv6 cafe:0:4::4
   candidate-paths
    preference 100
     dynamic
```

```
      pcep
      !
      metric
       type te
      !
     !
     constraints
      affinity
       exclude-any
        name brown
       !
      !
     !
    !
   !
  !
 !
!
```

Verification

```
Node1# show segment-routing traffic-eng policy color 20

SR-TE policy database
---------------------
Color: 20, End-point: cafe:0:4::4
  Name: srte_c_20_ep_cafe:0:4::4
  Status:
    Admin: up  Operational: down for 00:00:09 (since Nov  5 20:10:26.158)
  Candidate-paths:
    Preference: 100 (configuration)
      Name: pol_node1_node4_te
      Requested BSID: dynamic
      PCC info:
        Symbolic name: cfg_pol_node1_node4_te_discr_100
        PLSP-ID: 1
        Protection Type: unprotected-preferred
        Maximum SID Depth: 13
      Dynamic (pce cafe:0:2::2) (valid)
        Metric Type: NONE,   Path Accumulated Metric: 0
      SRv6 Information:
        Locator: Node1
        Binding SID requested: Dynamic
        Binding SID behavior: End.B6.encaps.Red
  Attributes:
    Forward Class: 0
    Steering labeled-services disabled: no
    Steering BGP disabled: no
    IPv6 caps enable: yes
    Invalidation drop enabled: no
```

Named Interface Link Admin Groups and SRv6-TE Affinity Maps

Named Interface Link Admin Groups and SRv6-TE Affinity Maps provide a simplified and more flexible means of configuring link attributes and path affinities to compute paths for SRv6-TE policies.

In the traditional TE scheme, 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).

Named Interface Link Admin Groups and SRv6-TE Affinity Maps let 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 in the CLI. Furthermore, you can define constraints using *include-any*, *include-all*, and *exclude-any* arguments, where each statement can contain up to 10 colors.

Note You can configure affinity constraints using attribute flags or the Flexible Name Based Policy Constraints scheme; however, when configurations for both schemes exist, only the configuration pertaining to the new scheme is applied.

Configure Named Interface Link Admin Groups and SRv6-TE Affinity Maps

Configure affinity maps on the following routers:

- Routers with interfaces that have an associated admin group attribute.
- Routers that act as SRv6-TE head-ends for SR policies that include affinity constraints.

Perform the following to configure affinity maps :

- Assign affinity to interfaces

  Define affinity maps

Configuration Example for Link Admin Group

The following example shows how to assign affinity to interfaces and to define affinity maps. This configuration is applicable to any router (SRv6-TE head-end or transit node) with colored interfaces.

To assign affinity to interfaces, use the **segment-routing traffic-eng interface** *interface* **affinity name** command .

Configure on routers with interfaces that have an associated admin group attribute.

```
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# interface HundredGigE0/0/0/0
Router(config-sr-if)# affinity
Router(config-sr-if-affinity)# name brown
Router(config-sr-if-affinity)# exit
Router(config-sr-if)# exit
```

To define affinity maps, use the **segment-routing traffic-eng affinity-map name bit-position** *bit-position* command. The *bit-position* range is from 0 to 255.

```
Router(config-sr-te)# affinity-map
Router(config-sr-te-affinity-map)# name brown bit-position 1
```

Running Configuration

```
segment-routing
 traffic-eng
  interface HundredGigE0/0/0/0
   affinity
    name brown
   !
```

```
  !
  affinity-map
   name brown bit-position 1
  !
end
```

Segment Protection-Type Constraint

This feature introduces the ability to control whether protected or unprotected segments are used when encoding the SID-list of an SRv6 policy candidate path. The types of segments that could be used when building a SID-list include uSIDs and adjacency SIDs (uA SID).

A prefix SID is a global segment representing a prefix that identifies a specific node. A prefix SID is programmed with a backup path computed by the IGP using TI-LFA.

An adjacency SID is a local segment representing an IGP adjacency. An adjacency SID can be programmed with or without protection. Protected adjacency SIDs are programmed with a link-protectant backup path computed by the IGP (TI-LFA) and are used if the link associated with the IGP adjacency fails.

Prefix SIDs and adjacency SIDs can be leveraged as segments in a SID-list in order to forward a packet along a path traversing specific nodes and/or over specific interfaces between nodes. The type of segment used when encoding the SID-list will determine whether failures along the path would be protected by TI-LFA. Depending on the offering, an operator may want to offer either unprotected or protected services over traffic engineered paths.

The following behaviors are available with the segment protection-type constraint:

- **protected-only** — The SID-list must be encoded using protected segments.
- **protected-preferred** — The SID-list should be encoded using protected segments if available; otherwise, the SID-list may be encoded using unprotected Adj-SIDs. This is the default behavior when no segment protection-type constraint is specified.
- **unprotected-only** — The SID-list must be encoded using unprotected Adj-SID.
- **unprotected-preferred** — The SID-list should be encoded using unprotected Adj-SID if available, otherwise SID-list may be encoded using protected segments.

Usage Guidelines and Limitations

Observe the following guidelines and limitations for the platform:

- This constraint applies to candidate-paths of manual SR policies with dynamically computed paths.
- PCEP has been augmented (vendor-specific object) to allow a PCC to indicate the segment protection-type constraint to the PCE.
- When the segment protection type constraint is protected-only or unprotected-only, the path computation must adhere to the constraint. If the constraint is not satisfied, the SRv6 policy will not come up on such candidate path.
- When the segment protection-type constraint is unprotected-only, the entire SID-list must be encoded with unprotected Adj-SIDs.
- When the segment protection-type constraint is protected-only, the entire SID-list must be encoded with protected Adj-SIDs or Prefix SIDs.

Configuring Segment Protection-Type Constraint

To configure the segment protection-type behavior, use the **constraints segments protection** command.

The following example shows how to configure the policy with a SID-list that must be encoded using protected segments:

```
Router(config-sr-te)# policy POLICY1
Router(config-sr-te-policy)# color 10 end-point ipv6 2:2::22
Router(config-sr-te-policy)# candidate-paths
Router(config-sr-te-policy-path)# preference 100
Router(config-sr-te-policy-path-pref)# constraints
Router(config-sr-te-path-pref-const)# segments
Router(config-sr-te-path-pref-const-seg)# protection protected-only
```

The following example shows how to configure the SRv6 ODN policy that must be encoded using protected segments:

```
Router(config)# segment-routing traffic-eng
Router(config-sr-te)# on-demand color 20
Router(config-sr-te-color)# constraints
Router(config-sr-te-color-const)# segments
Router(config-sr-te-color-const-seg)# protection protected-only
```

SRv6 Flexible Algorithm

SRv6 Flexible Algorithm allows operators to customize IGP shortest path computation according to their own needs. An operator can assign custom SRv6 locators to realize forwarding beyond link-cost-based shortest path. As a result, Flexible Algorithm provides a traffic-engineered path automatically computed by the IGP to any destination reachable by the IGP.

With SRv6 Flexible Algorithm, a PE can advertise BGP service routes (global, VPN) that include the SRv6 locator (Algo 0 or Flex Algo) of the intended transport SLA.

For information about configuring Flexible Algorithm, see Configuring SRv6 IS-IS Flexible Algorithm.

In the example below, the SR domain has 2 network slices. Each slice is assigned a /32 uSID Locator Block.

A slice can be realized with a user-defined Flex-Algo instances (for example, Flex Algo 128 = min-delay)

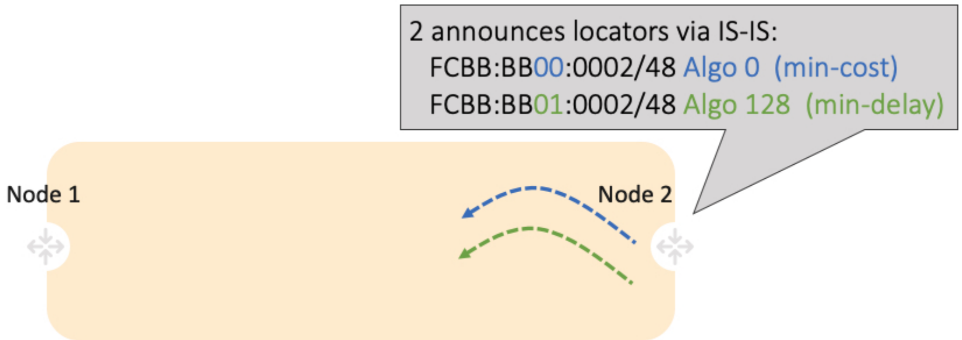
- Min-Cost Slice — FCBB:BB**00**/32
- Min-Delay Slice — FCBB:BB**01**/32

SR node2 gets a Shortest-Path Endpoint uSID (uN) from each slice:

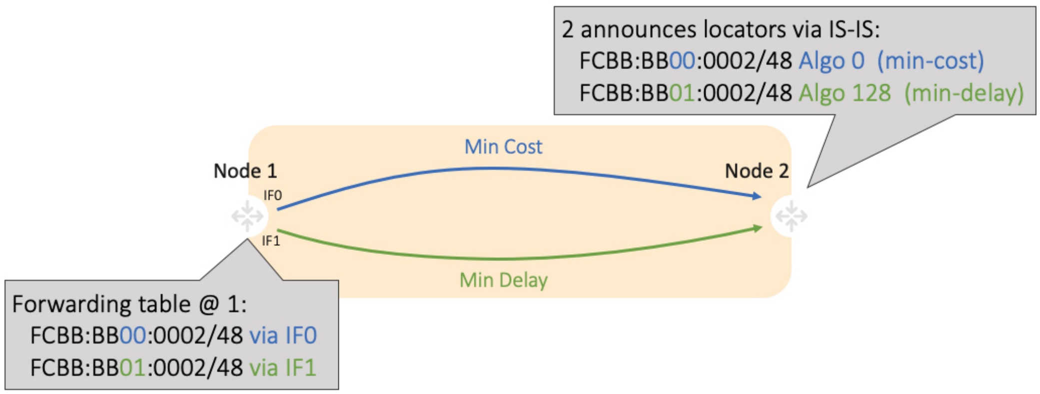
- uN **min-cost** of Node2 — FCBB:BB**00**:0002/48
- uN **min-delay** of Node2 — FCBB:BB**01**:0002/48

Node2 announces locators via IS-IS:

- FCBB:BB**00**:0002/48 Algo **0** (min-cost)
- FCBB:BB**01**:0002/48 Algo **128** (min-delay)



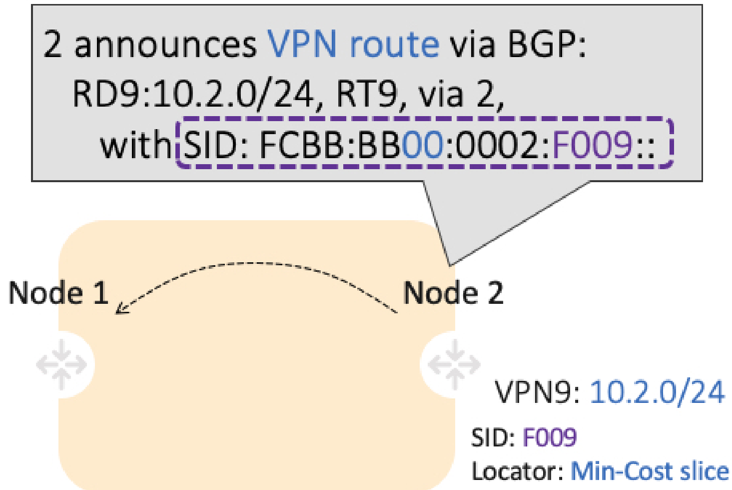
IS-IS in Node1 computes shortest paths for each locator and programs them in the FIB:



Node1 and Node2 are PEs of a common VPN. PEs advertise VPN routes via BGP with different transport SLAs. For example, traffic to a set of prefixes is to be delivered over the min-cost slice, while for another set of prefixes is to be delivered over the min-delay slice. To achieve this, the egress PE's service route advertisement includes the locator of the intended transport SLA type.

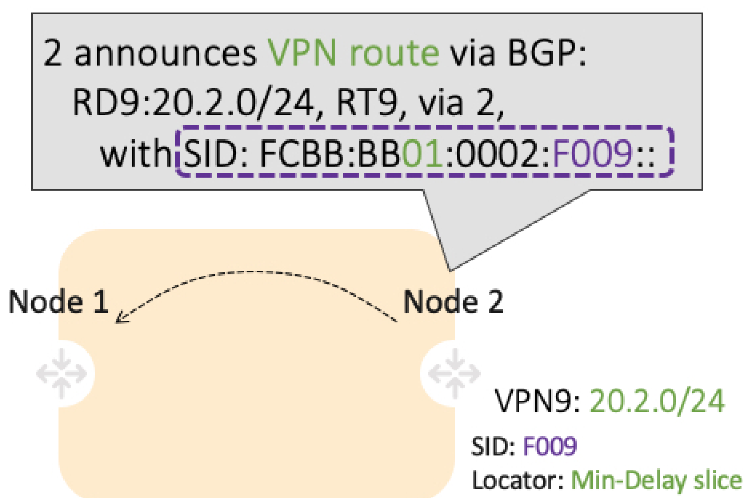
Use-case: VPN over Min-Cost Slice (Control Plane Behavior)

- Intuitive uSID program for routes advertised by Node2:
  - Within the Min-Cost Slice (FCBB:BB**00**)
  - Follow the shortest-path to Node2 (**0002**)
  - Execute VPN9 decapsulation function at Node2 (**F009**)
- Hardware Efficiency
  - Egress PE Node2 processes multiple uSIDs with a single /64 lookup
  - FCBB:BB**00**:**0002**:**F009**/64



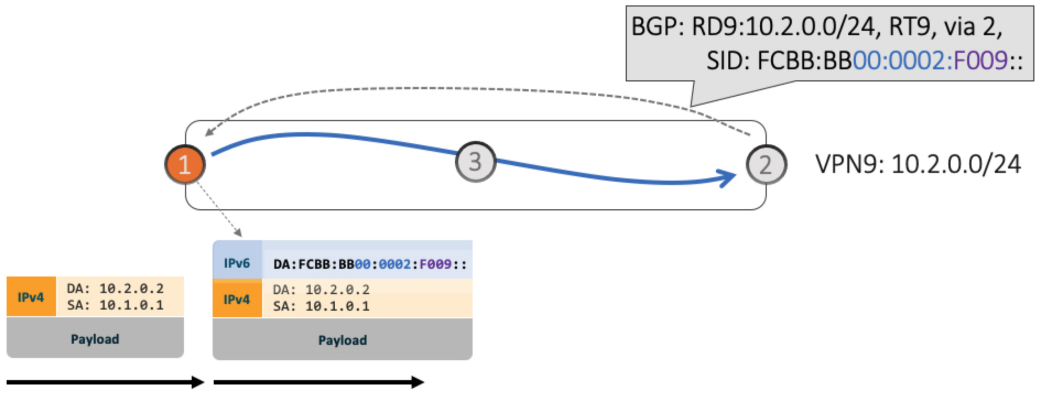
Use-case: VPN over Min-Delay Slice (Control Plane Behavior)

- Intuitive uSID program for routes advertised by Node2:
  - Within the Min-Delay Slice (FCBB:BB**01**)
  - Follow the shortest-path to Node2 (**0002**)
  - Execute VPN9 decapsulation at Node2 (**F009**)
- Hardware Efficiency
  - Egress PE 2 processes multiple uSIDs with a single /64 lookup
  - FCBB:BB**01**:**0002**:**F009**/64



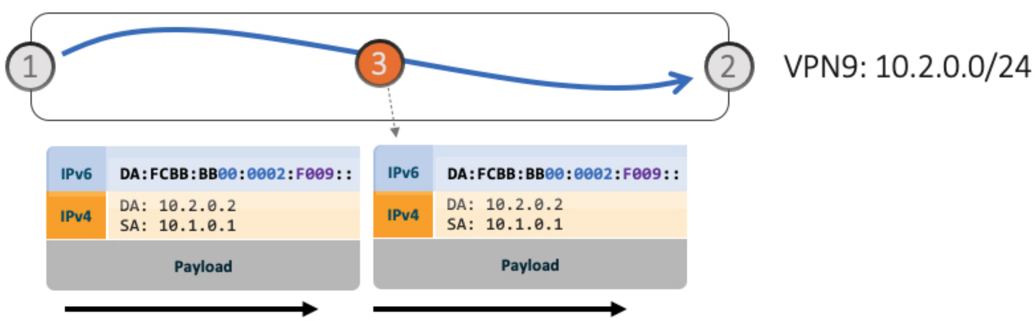
Use-case: VPN over Min-Cost Slice (Data Plane Behavior)

1. Ingress PE (Node 1) learns via BGP that prefix 10.2.0.0/24 in VPN9 is reachable via SID FCBB:BB**00**:**0002**:**F009**
2. Node 1 programs the prefix with "VPN Encaps" behavior
3. When receiving traffic with DA IP matching the prefix 10.2.0.0/24 FIB entry, Node 1 encapsulates the incoming packet into IPv6 with DA of FCBB:BB**00**:**0002**:**F009**

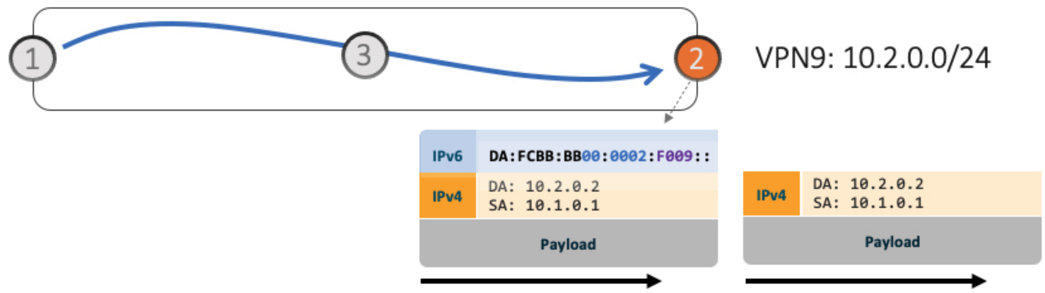


4. SRv6 allows for seamless deployment where any transit node (SRv6-capable or not) simply routes based on a /48 longest prefix match lookup.

   For example, transit node (Node 3) forwards traffic along the Algo 0 (min-cost) shortest path for the remote prefix FCBB:BB00:0002::/48.

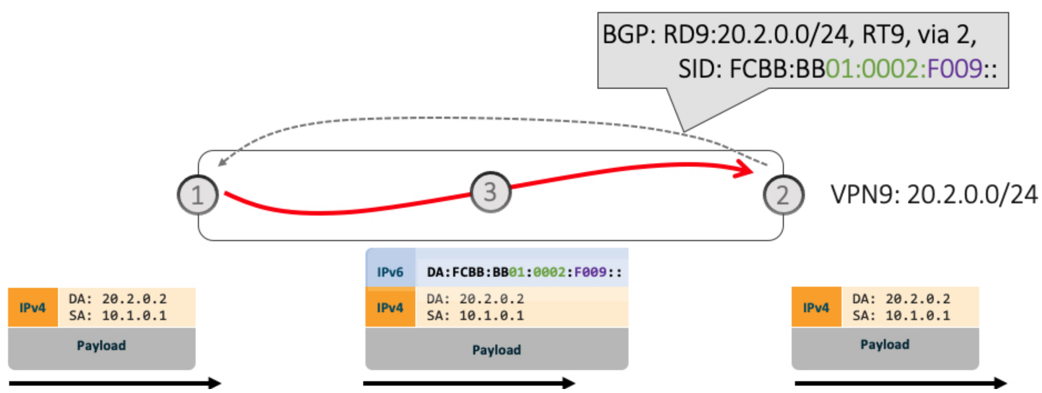


5. Egress PE (Node 2) matches local SID FCBB:BB00:0002:F009/64. Node 2 applies "VPN Decaps" behavior into VRF9 by removing the IPv6 encapsulation and looking up the payload's DA on the corresponding VPN table.



Use-case: VPN over Min-Delay Slice (Data Plane Behavior)

1. Ingress PE (Node 1) learns via BGP that prefix 20.2.0.0/24 in VPN9 is reachable via SID FCBB:BB**01**:**0002**:**F009**
2. Node 1 programs the prefix with “VPN Encaps” behavior
3. When receiving traffic with DA IP matching the prefix 20.2.0.0/24 FIB entry, Node 1 encapsulates the incoming packet into IPv6 with DA of FCBB:BB**01**:**0002**:**F009**
4. Transit node (Node 3) forwards traffic along the Algo 128 (min-delay) shortest path for the remote prefix FCBB:BB01:0002::/48.
5. Egress PE (Node 2) matches local SID FCBB:BB01:0002:F009/64. Node 2 applies “VPN Decaps” behavior into VRF9 by removing the IPv6 encapsulation and looking up the payload’s DA on the corresponding VPN table.

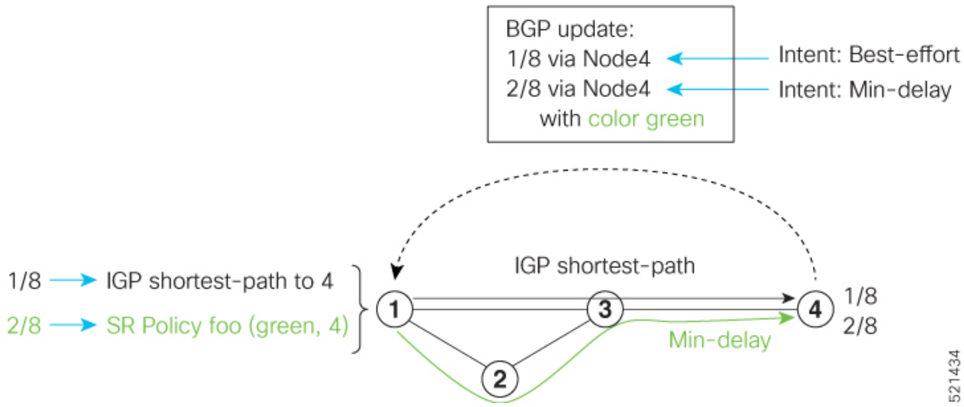


Automated Steering

Automated steering (AS) allows service traffic to be automatically steered onto the required transport SLA path programmed by an SRv6 policy.

With AS, BGP automatically steers traffic onto an SRv6 policy based on the next-hop and color of a BGP service route. The color of a BGP service route is specified by a color extended community attribute. This color is used as a transport SLA indicator, such as min-delay or min-cost.

When the next-hop and color of a BGP service route matches the end-point and color of an SRv6 policy, BGP automatically installs the route resolving onto the BSID of the matching SRv6 policy. Recall that an SRv6 policy on a head-end is uniquely identified by an end-point and color.



When a BGP route has multiple extended-color communities, each with a valid SRv6 policy, the BGP process installs the route on the SRv6 policy giving preference to the color with the highest numerical value.

The granularity of AS behaviors can be applied at multiple levels, for example:

- At a service level—When traffic destined to all prefixes in a given service is associated to the same transport path type. All prefixes share the same color.
- At a destination/prefix level—When traffic destined to a prefix in a given service is associated to a specific transport path type. Each prefix could be assigned a different color.
- At a flow level—When flows destined to the same prefix are associated with different transport path types.

Protocols

A segment routing path can be derived from various mechanisms. This section specifies extensions to the Path Computation Element Communication Protocol (PCEP) that allow a stateful PCE to compute Traffic Engineering (TE) paths as well as a PCC to request a path subject to certain constraints and optimization criteria in SR networks.

Path Computation Element Protocol

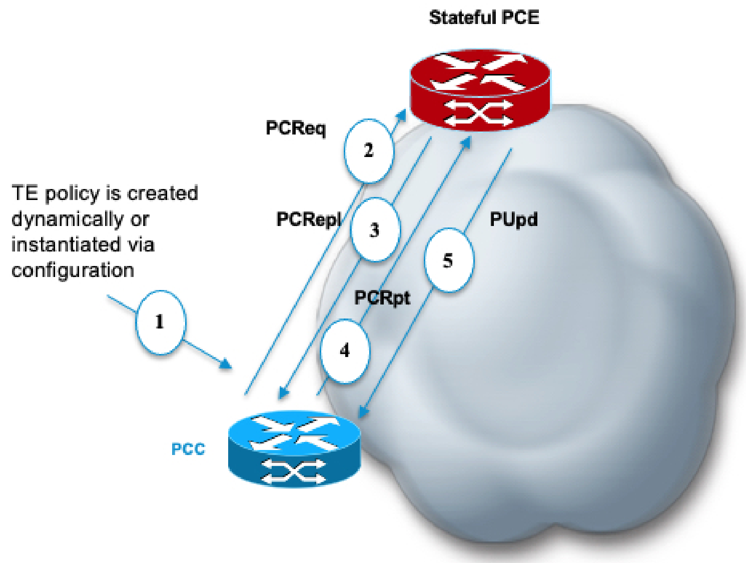
The path computation element protocol (PCEP) describes a set of procedures by which a path computation client (PCC) can report and delegate control of head-end label switched paths (LSPs) sourced from the PCC to a PCE peer. The PCE can request the PCC to update and modify parameters of LSPs it controls. The stateful model also enables a PCC to allow the PCE to initiate computations allowing the PCE to perform network-wide orchestration.

A PCEP channel is established over TCP and has its own light-weight Keep-Alive (KA) mechanism

Upon configuring a PCE peer, a PCC opens a PCEP session to the PCE, and the PCE accepts the PCEP sessions if the following conditions are satisfied:

- The total number of PCEP sessions does not exceed the limit on the total number of PCEP sessions on the PCE.
- The KA interval indicated by PCC is acceptable to the PCE.

Sample Workflow with Stateful PCEP



1. The PCC is configured to instantiate an SRv6-TE policy.
2. The PCC sends a PCEP Path Computation Request (PCReq) to the PCE, requesting a path by specifying path attributes, optimization objectives, and constraints.
3. The PCE stores the request, computes a TE metric shortest-path, and returns the computed SID list in a PCEP Path Computation Reply (PCRepl).
4. The PCC allocates a BSID and activates the SR Policy using the SID list computed by the PCE. The PCC sends a Path Computation Report (PCRpt) to the PCE, delegating the SR Policy to the PCE and including BSID.
5. The PCE updates the paths when required (for example, following a multi-domain topology change that impacts connectivity).

Configure the Head-End Router as PCEP PCC

Configure the head-end router as PCEP Path Computation Client (PCC) to establish a connection to the PCE. The PCC and PCE addresses must be routable so that TCP connection (to exchange PCEP messages) can be established between PCC and PCE.

Perform the following to configure the Head-End Router as PCEP PCC:

- Configure the PCC to establish a Connection to the PCE
- Enable SR-TE related syslogs.
- Set the Maximum SID Depth (MSD) signaled during PCEP session establishment to 5.

- Enable PCEP reporting for all policies in the node.

Configuration Example

The following example shows how to configure an SR-TE head-end router with the following functionality:

```
/* Enable the SR-TE head-end router as a PCEP client (PCC) with 2 PCEP servers (PCE) with
different precedence values.*/
Node1(config-sr)# traffic-eng
Node1(config-sr-te)# pcc
Node1(config-sr-te-pcc)# source-address ipv6 cafe:0:1::1
Node1(config-sr-te-pcc)# pce address ipv6 cafe:0:2::2
Node1(config-pcc-pce)# precedence 10
Node1(config-pcc-pce)# exit
Node1(config-sr-te-pcc)# pce address ipv6 cafe:0:3::3
Node1(config-pcc-pce)# precedence 20
Node1(config-pcc-pce)# exit

/* Enable PCEP reporting for all policies in the node.*/
Node1(config-sr-te-pcc)# report-all
Node1(config-sr-te-pcc)# exit

/* Set the maximum SID Depth (MSD) */
Node1(config-sr-te)# srv6
Node1(config-sr-te-srv6)# maximum-sid-depth 5
Node1(config-sr-te-srv6)# exit

/* Enable SR-TE related syslogs */
Node1(config-sr-te)# logging
Node1(config-sr-te-log)# policy status
Node1(config-sr-te-log)# exit
Node1(config-sr-te)#
```

Show Running Configuration

```
segment-routing
 traffic-eng
  srv6
   maximum-sid-depth 5
  !
  logging
   policy status
  !
  pcc
   source-address ipv6 cafe:0:1::1
   pce address ipv6 cafe:0:2::2
    precedence 10
   !
   pce address ipv6 cafe:0:3::3
    precedence 20
   !
   report-all
  !
 !
!
```

Verification

```
Node1# show segment-routing traffic-eng pcc ipv6 peer brief

             Address   Precedence        State    Learned From
-------------------- ------------ ------------ ---------------
         cafe:0:2::2           10           up          config
         cafe:0:3::3           20           up          config


Node1# show segment-routing traffic-eng pcc ipv6 peer detail

PCC's peer database:
--------------------

Peer address: cafe:0:2::2
  Precedence: 10, (best PCE)
  State up
  Capabilities: Stateful, Update, Segment-Routing, Instantiation
  PCEP has been up for: 01:22:23
  Local keepalive timer is 30 seconds
  Remote keepalive timer is 30 seconds
  Local dead timer is 120 seconds
  Remote dead timer is 120 seconds
  Authentication: None
  Statistics:
    Open messages:      rx 1        |  tx 1
    Close messages:     rx 0        |  tx 0
    Keepalive messages: rx 164      |  tx 163
    Error messages:     rx 0        |  tx 0
    Report messages:    rx 0        |  tx 110
    Update messages:    rx 36       |  tx 0

Peer address: cafe:0:3::3
  Precedence: 20
  State up
  Capabilities: Stateful, Update, Segment-Routing, Instantiation
  PCEP has been up for: 01:21:48
  Local keepalive timer is 30 seconds
  Remote keepalive timer is 30 seconds
  Local dead timer is 120 seconds
  Remote dead timer is 120 seconds
  Authentication: None
  Statistics:
    Open messages:      rx 1        |  tx 1
    Close messages:     rx 0        |  tx 0
    Keepalive messages: rx 164      |  tx 162
    Error messages:     rx 0        |  tx 0
    Report messages:    rx 0        |  tx 82
    Update messages:    rx 0        |  tx 0
```

You can customize the Maximum SID Depth (MSD) signaled by PCC during PCEP session establishment.

For cases with path computation at PCE, a PCC can signal its MSD to the PCE in the following ways:

- During PCEP session establishment – The signaled MSD is treated as a node-wide property.

  MSD is configured under **segment-routing traffic-eng maximum-sid-depth** command.

  The MSD is expressed as a number uSIDs. The number of uSID is expressed as a number of carriers and the number of uSID per carrier.

- During PCEP LSP path request – The signaled MSD is treated as an LSP property.

- Local SR Policy: MSD is configured using the **segment-routing traffic-eng policy** command.

> **Note** If the configured MSD values are different, the per-LSP MSD takes precedence over the per-node MSD.

After path computation, the resulting uSID stack size is verified against the MSD requirement.

- If the uSID stack size is larger than the MSD and path computation is performed by PCE, then the PCE returns a "no path" response to the PCC.
- If the uSID stack size is larger than the MSD and path computation is performed by PCC, then the PCC will not install the path.

> **Note** A sub-optimal path (if one exists) that satisfies the MSD constraint could be computed in the following cases:
>
> - For a dynamic path with TE metric, when the PCE is configured with the **pce segment-routing te-latency** command or the PCC is configured with the **segment-routing traffic-eng te-latency** command.
> - For a dynamic path with LATENCY metric
> - For a dynamic path with affinity constraints
>
> For example, if the PCC MSD is 4 and the optimal path (with an accumulated metric of 100) requires 5 uSIDs, but a sub-optimal path exists (with accumulated metric of 110) requiring 4 uSIDs, then the sub-optimal path is installed.

Customize the SR-TE Path Calculation

To enable ECMP-aware path computation for TE metric, use the **te-latency** command.

> **Note** ECMP-aware path computation is enabled by default for IGP and LATENCY metrics.

```
Router(config-sr-te)# te-latency
```

Configure PCEP Authentication

With PCEP authentication, you can establish a secure PCEP session with a PCE with one of the following methods:

- TCP Message Digest 5 (MD5) authentication: TCP Message Digest 5 (MD5) authentication is used for authenticating PCEP (TCP) sessions by using a clear text or encrypted password. This feature introduces support for TCP Authentication Option (TCP-AO), which replaces the TCP MD5 option.

  Any TCP segment coming from the PCC that does not contain a MAC matching the configured password will be rejected. Specify if the password is encrypted or clear text.

  ```
  Router(config-sr-te-pcc)# pce address ipv6 ipv6-PCE-address[password {clear | encrypted}
   LINE]
  ```

- TCP-AO: TCP-AO uses Message Authentication Codes (MACs), which provides the following:
  - Protection against replays for long-lived TCP connections
  - More details on the security association with TCP connections than TCP MD5
  - A larger set of MACs with minimal system and operational changes

  TCP-AO is compatible with Master Key Tuple (MKT) configuration. TCP-AO also protects connections when using the same MKT across repeated instances of a connection. TCP-AO protects the connections by using traffic key that are derived from the MKT, and then coordinates changes between the endpoints.

  Any TCP segment coming from the PCC that does not contain a MAC matching the configured key chain will be rejected. Use the **include-tcp-options** keyword to include other TCP options in the header for MAC calculation.

```
Router(config-sr-te-pcc)# pce address ipv6 ipv6-PCE-address tcp-ao key-chain
[include-tcp-options]
```

Note TCP-AO and TCP MD5 are never permitted to be used simultaneously. TCP-AO supports IPv6, and is fully compatible with the proposed requirements for the replacement of TCP MD5.

Configure PCEP-Related Timers

To better understand how the PCE-initiated SR policy timers operate, consider the following example:

- PCE A instantiates SR policy P at head-end N.
- Head-end N delegates SR policy P to PCE A and programs it in forwarding.
- If head-end N detects that PCE A is no longer reachable, then head-end N starts the PCE-initiated **orphan** and **state** timers for SR policy P.
- If PCE A reconnects before the **orphan** timer expires, then SR policy P is automatically delegated back to its original PCE (PCE A).
- After the **orphan** timer expires, SR policy P will be eligible for delegation to any other surviving PCE(s).
- If SR policy P is not delegated to another PCE before the **state** timer expires, then head-end N will remove SR policy P from its forwarding.

You can use the following PCEP-Related Timers:

- To specify how often keepalive messages are sent from PCC to its peers, use the **timers keepalive** command. The range is from 0 to 255 seconds; the default value is 30.

```
Router(config-sr-te-pcc)# timers keepalive seconds
```

- To specify how long the remote peers wait before bringing down the PCEP session if no PCEP messages are received from this PCC, use the **timers deadtimer** command. The range is from 1 to 255 seconds; the default value is 120.

```
Router(config-sr-te-pcc)# timers deadtimer seconds
```

- To specify how long a delegated SR policy can remain up without an active connection to a PCE, use the **timers delegation-timeout** command. The range is from 0 to 3600 seconds; the default value is 60.

```
Router(config-sr-te-pcc)# timers delegation-timeout seconds
```

- To specify the amount of time that a PCE-initiated SR policy will remain delegated to a PCE peer that is no longer reachable by the PCC, use the **timers initiated orphans** command. The range is from 10 to 180 seconds; the default value is 180.

```
Router(config-sr-te-pcc)# timers initiated orphans seconds
```

- To specify the amount of time that a PCE-initiated SR policy will remain programmed while not being delegated to any PCE, use the **timers initiated state** command . The range is from 15 to 14440 seconds (24 hours); the default value is 600.

```
Router(config-sr-te-pcc)# timers initiated state seconds
```

Note Multicast follows the same timer for Point-to-Multipoint (P2MP) policies:

- The default interval is 10 minutes.
- You can set the internal timer to '0' to ensure that forwarding states remain active indefinitely, even if the PCE is down for more than 5 minutes.
- If the PCE is down for more than 5 minutes, it is because the PCE is going down or the reachability to PCE going down.

Configure PCEP Redundancy Type

To enable PCC-centric high-availability model, use the **redundancy pcc-centric** command. The PCC-centric model changes the default PCC delegation behavior to the following:

- After LSP creation, LSP is automatically delegated to the PCE that computed it.
- If this PCE is disconnected, then the LSP is redelegated to another PCE.
- If the original PCE is reconnected, then the delegation fallback timer is started. When the timer expires, the LSP is redelegated back to the original PCE, even if it has worse preference than the current PCE.

```
Router(config-sr-te-pcc)# redundancy pcc-centric
```

SR-TE Application Programming Interface (API)

Table 2: Feature History Table

Feature Name	Release Information	Feature Description
SR-TE Application Programming Interface (API)	Release 24.4.1	Introduced in this release on: Fixed Systems (8700 [ASIC: K100]) (select variants only*) * This feature is supported on Cisco 8712-MOD-M routers.

Feature Name	Release Information	Feature Description
SR-TE Application Programming Interface (API)	Release 7.11.1	This feature introduces an API solution that simplifies the task of building SR-TE controllers and managing SRTE policies. It does so by defining gRPC API services that allow applications to request SR policy operations. The solution leverages the gRPC Service API and GPB Data models, providing a unified, scalable, and secure method for network programming. This feature introduces these changes: **New CLI** • grpc segment-routing traffic-eng policy-service **YANG Data Models:** EMSD Yang model is updated to have this config under "segment-routing" container. • Native model: `Cisco-IOS-XR-man-ems-cfg.yang` • UM model: `Cisco-IOS-XR-um-grpc-cfg.yang` (see GitHub, YANG Data Models Navigator)

SDN controllers and applications with SR traffic-engineering capabilities require a mechanism to create, monitor, and control SRv6-TE (IPv6) policies with different properties, such as optimization objectives, constraints, and segment-lists.

This feature introduces an API solution that simplifies building SR-TE controllers by defining gRPC API services to request SR policy operations. These services allow for SR policy operations, potentially including the creation, modification, or deletion of such policies. It's a more efficient and modernized approach to managing and controlling SR-TE policies.

Google-defined remote procedure call (gRPC) is an open-source RPC framework. It is based on Protocol Buffers (Protobuf), which is an open-source binary serialization protocol. gRPC provides a flexible, efficient, automated mechanism for serializing structured data, like XML, but is smaller and simpler to use. You can define the structure using protocol buffer message types in `.proto` files. Each protocol buffer message is a small logical record of information, containing a series of name-value pairs.

The client applications use this protocol to request information from the router and make configuration changes to the router. The process for using data models involves:

- Obtaining the data models.
- Establishing a connection between the router and the client using gRPC communication protocol.
- Managing the configuration of the router from the client using data models.

Note Refer to Use gRPC Protocol to Define Network Operations with Data Models in the *Programmability Configuration Guide for Cisco 8000 Series Routers*.

Usage Guidelines and Limitations

- The API is supported for SRv6-TE policies.
- The API is not supported on the SR PCE.

SR-TE gRPC API

The SR-TE gRPC API uses the protocol buffers definition interface language (IDL) to manage the lifecycle (creation, modification, deletion) of SR-TE policies signaled by a controller/PCE and programmed at a headend.

The gRPC requests are encoded and sent to the SR-TE headend router (gRPC server) using JSON. The router can invoke the RPC calls defined in the IDL to program the SR-TE policies.

The gRPC service specifications for SR-TE, including the definitions of messages and the data model, are housed in a proto file. This SR-TE gRPC API proto file and a sample client are available in the following Github repository: https://github.com/ios-xr/SR-TE

SR-TE gRPC API proto file provides the following RPCs:

gRPC Operation	Description
SRTEPolicyAdd	Create and modify an SR-TE policy and its identifiers and attributes (for ex: color, endpoint, head-end, candidate paths).
SRTEPolicyDelete	Delete an SR-TE policy or any of its candidate paths.

Enabling the SR-TE gRPC API on the Headend Router

Use the following commands to enable the SR-TE gRPC API:

```
RP/0/RP0/CPU0:ios(config)# grpc
RP/0/RP0/CPU0:ios(config-grpc)# segment-routing
RP/0/RP0/CPU0:ios(config-grpc-sr)# traffic-eng
RP/0/RP0/CPU0:ios(config-grpc-sr-te)# policy-service
RP/0/RP0/CPU0:ios(config-grpc-sr-te)# commit
```

Note Refer to Use gRPC Protocol to Define Network Operations with Data Models in the *Programmability Configuration Guide for Cisco 8000 Series Routers* for other gRPC parameters.

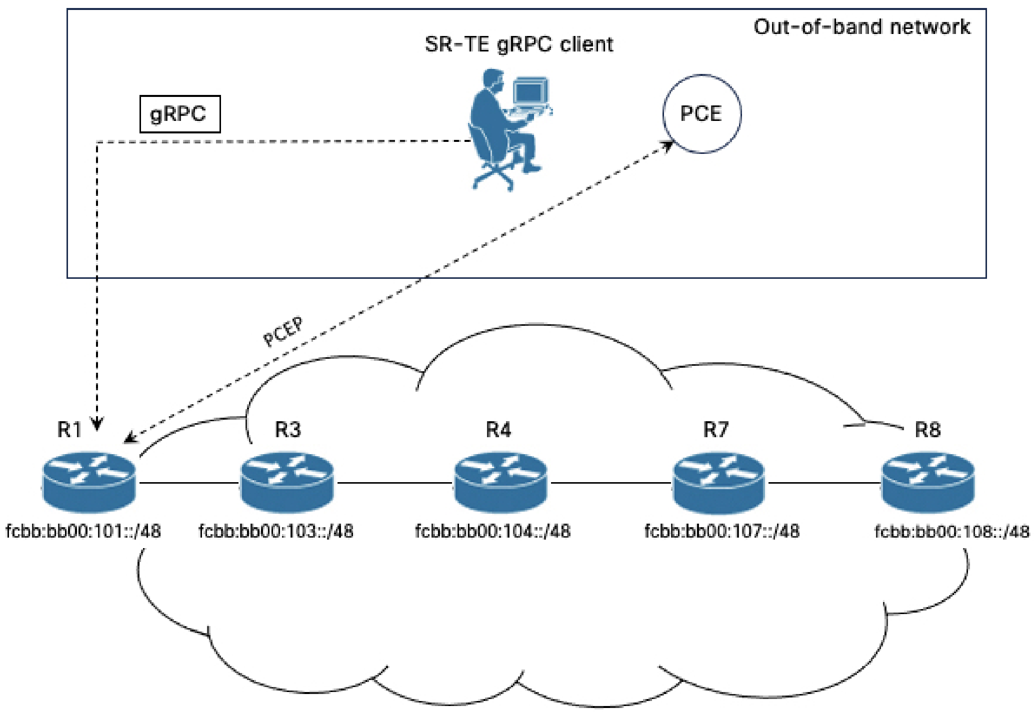
Verify

Use the show segment-routing traffic-eng service-api clients command to display the SR-TE gRPC API client and its status:

```
RP/0/RSP0/CPU0:ios# show segment-routing traffic-eng service-api clients
. . .

Client name: emsd (Protocol type: gRPC)
  Role: Active
  ID: 960268627
  State: Up
  Throttled: No
  Statistics:
    Client ever connected: Yes
    Connected: 00:00:12 (since Wed Nov 15 15:02:14 PST 2023)
    Number of add requests: 0
    Number of delete requests: 0
. . .
```

Examples

In the following examples, R1 is the SR-TE headend and the gRPC server. The headend router implements the server-side of the gRPC communication, handling requests from gRPC clients.



In these examples, an SR-TE gRPC client written in Python is used to emulate the controller node. These clients send commands to create, modify, or delete SRTE policies, and the headend router executes these commands and returns the responses.

Example 1: Programming an SRv6-TE Policy with Explicit Path via gRPC API

1. Configure the SRv6-TE policy.

In this example, the SRv6-TE policy uses explicit paths with a segment list. The following JSON file is passed as an input to the SR-TE gRPC client to program an SRv6-TE policy with an explicit path at the head-end router.

```
controller:grpc$ more sample_srv6_explicit_path_req.json
{
 "policies": [
  {
   "key": {
    "color": 6,
    "endpoint": "2001:0:108::1",
    "headend": "2001:0:101::1"
   },
   "CPs": [
    {
     "explicit": [
      {
       "segmentList": {
        "name": "test-srv6",
        "segments": {
         "typeB": [
          "fcbb:bb00:104::",
          "fcbb:bb00:108::"
         ]
        }
       }
      }
     ],
     "preference": 10,
     "dataplane": 1,
     "key": {
      "originatorID": {
       "ASN": 64000,
       "nodeID": "1.1.1.101"
      },
      "discriminator": 100,
      "originatorProtocol": 40
     }
    }
   ],
   "bindingSIDAllocation": 1,
   "srv6BindingSID": {
    "locatorName": "LOC_BEST_EFFORT",
    "behavior": 71
   }
  }
 ]
}
```

Execute the command/JSON file on the SR-TE gRPC client:

```
controller-grpc$ srte_client -u <user> -p <password> --policy-add
-j sample_srv6_explicit_path_req.json -a <sr-te-headend-ip-addr>:57400
Response: ['{"ReturnCode": 0, "Key": {"Color": 6, "Headend": "2001:0:101::1",
"Endpoint": "2001:0:108::1"}}']
```

Note Observe the console message indicating the policy state is "UP":

```
RP/0/RP0/CPU0:Nov 15 15:11:23.784 PST: xtc_agent[1304]: %OS-XTC-5-SR_POLICY_UPDOWN :
SR policy 'srte_c_6_ep_2001:0:108::1' (color 6, end-point 2001:0:108::1) state changed to
UP
```

2. Verify the configuration.

   Use the following **show** commands to verify the configuration.

```
RP/0/RP0/CPU0:R1# show segment-routing traffic-eng policy color 6

SR-TE policy database
---------------------

Color: 6 End-point: 2001:0:108::1
  Name: srte_c_6_ep_2001:0:108::1
  Status:
    Admin: up  Operational: up for 00:01:00 (since Nov 15 15:11:23.784)
  Candidate-paths:
    Preference: 10 (gRPC) (active)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: gRPC_srte_c_6_ep_2001:0:108::1_c_6_ep_2001:0:108::1_discr_100
        PLSP-ID: 1
      Constraints:
        Protection Type: protected-preferred
        Maximum SID Depth: 7
      Explicit: segment-list grpc_sl_1 (valid)
        Weight: 1, Metric Type: TE
          SID[0]: fcbb:bb00:104::/48
                  Format: f3216
                  LBL:32 LNL:16 FL:0 AL:80
          SID[1]: fcbb:bb00:108::/48
                  Format: f3216
                  LBL:32 LNL:16 FL:0 AL:80
      SRv6 Information:
        Locator: LOC_BEST_EFFORT
        Binding SID requested: Dynamic
        Binding SID behavior: uB6 (Insert.Red)
  Attributes:
    Binding SID: fcbb:bb00:101:e005::
    Forward Class: Not Configured
    Steering labeled-services disabled: no
    Steering BGP disabled: no
    IPv6 caps enable: yes
    Invalidation drop enabled: no
    Max Install Standby Candidate Paths: 0


RP/0/RP0/CPU0:R1# show cef ipv6 fcbb:bb00:101:e005::/64

fcbb:bb00:101:e005::/64, version 927, SRv6 Endpoint uB6 (Insert.Red), internal 0x1000001
 0x200 (ptr 0x8b1495e8) [1], 0x400 (0x8a460958), 0x0 (0xa0e205e8)
 Updated Nov 15 15:11:23.786
 local adjacency to TenGigE0/0/0/0

 Prefix Len 64, traffic index 0, precedence n/a, priority 0
  gateway array (0x8a2f3708) reference count 1, flags 0x400000, source rib (7), 0 backups

                [2 type 3 flags 0x8401 (0x8a396cf8) ext 0x0 (0x0)]
  LW-LDI[type=3, refc=1, ptr=0x8a460958, sh-ldi=0x8a396cf8]
  gateway array update type-time 1 Nov 15 15:11:23.786
 LDI Update time Nov 15 15:11:23.787
 LW-LDI-TS Nov 15 15:11:23.787
 Accounting: Disabled
   via fe80::28a:96ff:feaa:ac00/128, TenGigE0/0/0/0, 8 dependencies, weight 1, class 0,
 protected, ECMP-backup (Local-LFA) [flags 0x600]
    path-idx 0 bkup-idx 1 NHID 0x0 [0xa0ffa0a0 0x0]
    next hop fe80::28a:96ff:feaa:ac00/128
    SRv6 H.Insert.Red SID-list {fcbb:bb00:104::}
```

```
   via fe80::d66a:35ff:fef3:2000/128, TenGigE0/0/0/1, 8 dependencies, weight 1, class
0, protected, ECMP-backup (Local-LFA) [flags 0x600]
    path-idx 1 bkup-idx 0 NHID 0x0 [0xa0ffa190 0x0]
    next hop fe80::d66a:35ff:fef3:2000/128
    SRv6 H.Insert.Red SID-list {fcbb:bb00:104::}

    Weight distribution:
    slot 0, weight 1, normalized_weight 1, class 0
    slot 1, weight 1, normalized_weight 1, class 0
    Load distribution: 0 1 (refcount 2)

    Hash  OK  Interface                 Address
    0     Y   TenGigE0/0/0/0            fe80::28a:96ff:feaa:ac00
    1     Y   TenGigE0/0/0/1            fe80::d66a:35ff:fef3:2000
```

Example 2: Programming an SRv6-TE Policy with Dynamic Path (Delegated to PCE) via gRPC API

1. Configure the SRv6-TE policy.

   In this example, the SRv6-TE policy uses dynamic paths delegated to the PCE.

   The following JSON file is passed as an input to the SR-TE gRPC client to program an SRv6-TE policy with a dynamic path.

```
controller:grpc$ more sample_srv6_dynamic_path_req.json
{
 "policies": [
  {
   "key": {
    "color": 7,
    "endpoint": "2001:0:108::1",
    "headend": "2001:0:101::1"
   },
   "CPs": [
    {
     "dynamic": {
      "delegate": true,
      "ometric": 0
     },
     "preference": 10,
     "dataplane": 1,
     "key": {
      "originatorID": {
       "ASN": 64000,
       "nodeID": "1.1.1.101"
      },
      "discriminator": 100,
      "originatorProtocol": 40
     }
    }
   ],
   "bindingSIDAllocation": 1,
   "srv6BindingSID": {
    "locatorName": "LOC_BEST_EFFORT",
    "behavior": 71
   }
  }
 ]
}
```

   Execute the command/JSON file on the SR-TE gRPC client:

```
controller-grpc$ srte_client -u <user> -p <password> --policy-add
-j sample_srv6_dynamic_path_req.json -a <sr-te-headend-ip-addr>:57400
```

```
Response: ['{"ReturnCode": 0, "Key": {"Color": 7, "Headend": "2001:0:101::1",
"Endpoint": "2001:0:108::1"}}']
```

Note Observe the console message indicating the policy state is "UP":

```
RP/0/RP0/CPU0:Nov 15 15:25:23.671 PST: xtc_agent[1304]: %OS-XTC-5-SR_POLICY_UPDOWN :
SR policy 'srte_c_7_ep_2001:0:108::1' (color 7, end-point 2001:0:108::1) state changed to
UP
```

2. Verify the configuration.

   Use the following **show** commands to verify the configuration.

```
RP/0/RP0/CPU0:R1# show segment-routing traffic-eng pol color 7

SR-TE policy database
---------------------

Color: 7, End-point: 2001:0:108::1
  Name: srte_c_7_ep_2001:0:108::1
  Status:
    Admin: up  Operational: up for 00:01:06 (since Nov 15 15:25:23.671)
  Candidate-paths:
    Preference: 10 (gRPC) (active)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: gRPC_srte_c_7_ep_2001:0:108::1_c_7_ep_2001:0:108::1_discr_100
        PLSP-ID: 3
      Constraints:
        Protection Type: protected-preferred
        Maximum SID Depth: 7
      Dynamic (pce 2001:0:109::1) (valid)
        Metric Type: TE,   Path Accumulated Metric: 44
          SID[0]: fcbb:bb00:103::/48 Behavior: uN (PSP/USD) (48)
                  Format: f3216
                  LBL:32 LNL:16 FL:0 AL:80
                  Address: 2001:0:103::1
          SID[1]: fcbb:bb00:104::/48 Behavior: uN (PSP/USD) (48)
                  Format: f3216
                  LBL:32 LNL:16 FL:0 AL:80
                  Address: 2001:0:104::1
          SID[2]: fcbb:bb00:107::/48 Behavior: uN (PSP/USD) (48)
                  Format: f3216
                  LBL:32 LNL:16 FL:0 AL:80
                  Address: 2001:0:107::1
          SID[3]: fcbb:bb00:108::/48 Behavior: uN (PSP/USD) (48)
                  Format: f3216
                  LBL:32 LNL:16 FL:0 AL:80
                  Address: 2001:0:108::1
      SRv6 Information:
        Locator: LOC_BEST_EFFORT
        Binding SID requested: Dynamic
        Binding SID behavior: uB6 (Insert.Red)
  Attributes:
    Binding SID: fcbb:bb00:101:e006::
    Forward Class: Not Configured
    Steering labeled-services disabled: no
    Steering BGP disabled: no
    IPv6 caps enable: yes
    Invalidation drop enabled: no
```

```
    Max Install Standby Candidate Paths: 0

RP/0/RP0/CPU0:R1# show cef ipv6 fcbb:bb00:101:e006::/64

fcbb:bb00:101:e006::/64, version 936, SRv6 Endpoint uB6 (Insert.Red), internal 0x1000001
 0x200 (ptr 0x8b149100) [1], 0x400 (0x8a460918), 0x0 (0xa0e20598)
 Updated Nov 15 15:25:23.672
 local adjacency to TenGigE0/0/0/1

 Prefix Len 64, traffic index 0, precedence n/a, priority 0
  gateway array (0x8a2f3618) reference count 1, flags 0x500000, source rib (7), 0 backups

               [2 type 3 flags 0x8401 (0x8a396e58) ext 0x0 (0x0)]
  LW-LDI[type=3, refc=1, ptr=0x8a460918, sh-ldi=0x8a396e58]
  gateway array update type-time 1 Nov 15 15:25:23.672
 LDI Update time Nov 15 15:25:23.672
 LW-LDI-TS Nov 15 15:25:23.672
 Accounting: Disabled
   via fe80::28a:96ff:feaa:ac00/128, TenGigE0/0/0/0, 10 dependencies, weight 1, class
0, backup (Local-LFA) [flags 0x300]
    path-idx 0 NHID 0x0 [0x8a0c5a00 0x0]
    next hop fe80::28a:96ff:feaa:ac00/128
    local adjacency
    SRv6 H.Insert.Red SID-list {fcbb:bb00:103:104:107::}
   via fe80::d66a:35ff:fef3:2000/128, TenGigE0/0/0/1, 10 dependencies, weight 1, class
0, protected [flags 0x400]
    path-idx 1 bkup-idx 0 NHID 0x0 [0xa0ffa190 0x0]
    next hop fe80::d66a:35ff:fef3:2000/128
    SRv6 H.Insert.Red SID-list {fcbb:bb00:103:104:107::}

    Weight distribution:
    slot 0, weight 1, normalized_weight 1, class 0
    Load distribution: 0 (refcount 2)

    Hash  OK  Interface                 Address
    0     Y   TenGigE0/0/0/1            fe80::d66a:35ff:fef3:2000

RP/0/RP0/CPU0:R1# show segment-routing traffic-eng forwarding pol color 7

SR-TE Policy Forwarding database
--------------------------------

Color: 7, End-point: 2001:0:108::1
  Name: srte_c_7_ep_2001:0:108::1
  Binding SID: fcbb:bb00:101:e006::
  Active LSP:
    Candidate path:
      Preference: 10 (gRPC)
    Segment lists:
      SL[0]:
        Name: dynamic
        SL ID: 0xa000002
        Switched Packets/Bytes: ?/?
        Paths:
          Path[0]:
            Outgoing Interfaces: TenGigE0/0/0/0
            Next Hop: fe80::28a:96ff:feaa:ac00
            FRR Pure Backup: Yes
            ECMP/LFA Backup: Yes
            SID stack (Top -> Bottom): {fcbb:bb00:103::/48, fcbb:bb00:104::/48,
fcbb:bb00:107::/48}
          Path[1]:
            Outgoing Interfaces: TenGigE0/0/0/1
```

```
            Next Hop: fe80::d66a:35ff:fef3:2000
            FRR Pure Backup: No
            ECMP/LFA Backup: No
            SID stack (Top -> Bottom): {fcbb:bb00:103::/48, fcbb:bb00:104::/48,
fcbb:bb00:107::/48}

  Policy Packets/Bytes Switched: ?/?
```

Example 3: Delete the Policy

1. On the cRPC client, run the following command to delete the policy configuration:

```
controller-grpc$ srte_client -u <user> -p <password> --policy-delete
-j sample_srv6_explicit_path_req.json -a <sr-te-headend-ip-addr>:57400
Response: ['{"ReturnCode": 0, "Key": {"Color": 6, "Headend": "2001:0:101::1",
"Endpoint": "2001:0:108::1"}}']

controller-grpc$ srte_client -u <user> -p <password> --policy-delete
-j sample_srv6_explicit_path_req.json -a <sr-te-headend-ip-addr>:57400
Response: ['{"ReturnCode": 0, "Key": {"Color": 7, "Headend": "2001:0:101::1",
"Endpoint": "2001:0:108::1"}}']
```

Note Observe the console message indicating the policy state is “DOWN”:

```
RP/0/RP0/CPU0:Nov 15 15:30:14.180 PST: xtc_agent[1304]: %OS-XTC-5-SR_POLICY_UPDOWN :
SR policy 'srte_c_6_ep_2001:0:108::1' (color 6, end-point 2001:0:108::1) state changed to
DOWN (path invalidated)

RP/0/RP0/CPU0:Nov 15 15:30:27.181 PST: xtc_agent[1304]: %OS-XTC-5-SR_POLICY_UPDOWN :
SR policy 'srte_c_7_ep_2001:0:108::1' (color 7, end-point 2001:0:108::1) state changed to
DOWN (path invalidated)
```

2. Verify the delete operation.

```
RP/0/RSP0/CPU0:ios# show segment-routing traffic-eng service-api clients

Client name: emsd (Protocol type: gRPC)
  Role: Active
  ID: 440080357
  State: Up
  Throttled: No
  Statistics:
    Client ever connected: Yes
    Connected: 00:28:00 (since Wed Nov 15 15:02:14 PST 2023)
    Number of add requests: 2
    Number of delete requests: 2
```

Reporting of SR-TE Policies Using BGP-Link State

Table 3: Feature History Table

Feature Name	Release Information	Feature Description
Reporting of SR-TE Policies Using BGP-Link State	Release 24.4.1	Introduced in this release on: Fixed Systems(8700)(select variants only*) *Reporting of SR-TE Policies Using BGP-Link State feature is now supported on the Cisco 8712-MOD-M routers.
Reporting of SR-TE Policies Using BGP-Link State	Release 24.1.1	BGP- Link State (LS) is a mechanism by which LS and Traffic Engineering (TE) information can be collected from networks and shared with external components (such as, Segment Routing Path Computation Element (SR-PCE) or Crossword Optimization Engine (COE)) using the BGP routing protocol. This feature gathers the Traffic Engineering Policy information that is locally available in a node and advertises it in BGP-LS for SR-MPLS and SRv6. The operators can now take informed decisions based on the information that is gathered on their network's path computation, reoptimization, service placement, network visualization, and so on. The feature introduces these changes: **CLI:** • **distribute link-state** **YANG Data Model:** • New XPaths for `module Cisco-IOS-XR-infra-xtc-agent-cfg.yang` (see GitHub, YANG Data Models Navigator)

This function is achieved using a BGP Network Layer Reachability Information (NLRI) encoding format. BGP-LS consumes structured IGP data (for example, router-id, remote-IP-address of a link, local-IP address of a link, link identifier, and so on). and creates BGP-LS (NLRI) or attributes that BGP or other components like Cisco IOS XR Traffic Controller (XTC) can consume. Current implementation of BGP-LS can report topology using Nodes, Links, and Prefixes.

Modern Segment Routing (SR) networks often use SR Traffic Engineering (SR-TE) to influence the path that each specific traffic takes over the network. SR-TE tunnels can be provisioned manually on the tunnel head, but often they are calculated and provisioned by the central controller. Often operator of the network wants the ability to force the traffic over specific nodes and links.

Now the operators have the option to collect reports of the SR-TE and Policy information that is locally available in a node and advertise it into BGP-LS updates, which can be used by external components. Refer the IEFT for examples. This feature is implemented so that the operators have control over their network's path computation, reoptimization, service placement, network visualization, and so on.

Note Circuit Style (CS) SR policies are reported but without the CS policies' specific attributes, like the bidirectional constraints, per-hop behavior, and so on.

Restrictions to Reporting of SRTE Policies using BGP-LS

Some important points to be aware related to this feature are as follows:

- This feature has high availability, ensuring BGP-LS reporting at all times.
- This feature works with PCE State Sync. The policy information learned via the state-sync channel is not advertised in BGP-LS by the PCE.
- The feature works with PCE redundancy. Both PCEs advertise the BGP-LS policy information. The consumers can select only one policy based on the BGP best path logic.

Configure Reporting of SRTE Policies using BGP-LS

The reporting of policies to BGP-LS is disabled by default. Configuring the **distribute link-state** under the SR-PCE or SR-TE configuration enables this feature. Once enabled, all the existing SR policies or Candidate Path (CPs) are encoded to BGP-LS. You can disable this feature by removing the configuration and all the SR policies or CPs are withdrawn from BGP which deletes all of the previously encoded SR policies or CPs.

Note When SR policies that are reporting in BGP-LS are enabled by the operator, the Head End only reports the Active Candidate Path (CPs) (CPs installed in the forwarding). There are monitoring use cases that require reporting of inactive CPs. The following CLI is needed to report inactive CPs.

For both SR-TE and SR-PCE, you need to use the global CLI to enable the reporting of policies or Circuit Style (CS) to BGP-LS:

Configuration Example

Configure the following command to enable reporting and syncing of SR policies in BGP-LS at the Head End:

```
Router# config
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# distribute link-state
Router(config-sr-te-distribute-ls)# report-candidate-path-inactive
Router(config-sr-te-distribute-ls)# commit
Router(config-sr-te-distribute-ls)# exit
```

> **Note** The **report-candidate-path-inactive** command is an optional command to report inactive CPs.

Running Configuration

This is a sample running configuration which shows that you have configured BGP-LS reporting feature.

```
segment-routing
 traffic-eng
  distribute link-state
   report-candidate-path-inactive
  !
 !
!
```

Verification

Use the **show pce segment-routing traffic-eng policy private** and **show pce distributed-ls events** to verify the configuration.

```
Router#show pce segment-routing traffic-eng policy private

PCE's policy database:
----------------------
PCC Address: 192.168.2.1
  Color: 100, Endpoint: 192.0.2.1
    Name: srte_c_100_ep_192.0.2.1
    Self Pointer: 0x317d7f0
    Active C-path Pointer: 0x317d9b0
    Candidate-paths:
      Symbolic-name: cfg_foo_discr_100 (Active)
        PLSP-ID: 1
        NB-API Notification pending flag: 0
        Self Pointer: 0x317d9b0
        Tunnel Pointer: 0x317d4e0
        Policy Pointer: 0x317d7f0
        Cached distribute LS element:
          Sense: TRUE
          Refcount: 1
          Is on queue: FALSE
          Node identifiers:
            Protocol: 9 router ID: 192.0.2.1
          Policy identifiers:
            Color: 100 Endpoint: 192.0.2.1
            Flags: 0x00
          Candidate path identifiers:
            Originator: 0.0.0.0 protocol: 3 ASN: 0
            Flags: 0x00
            Discriminator: 100
          Candidate path attributes:
            Name: foo
            Policy name: srte_c_100_ep_192.0.2.1
            State:
              Priority: 0 flags: 0x5800 (active, evaluated, valid-sid-list)
              Preference: 100
            BSID:
              Flags: 0x4000 (alloc)
              BSID: 24021
              Specified BSID: 0
```

```
            Constraints:
              Bitfield: 0x0020 flags: 0x4000 (protected-only) MT-ID: 0
              Algorithm: 0
              Bandwidth: 0 kbps
              Metric constraints[0]:
                Type: 0 flags: 0x80 (optimization)
                Margin: 0 bound: 0
              Metric constraints[1]:
                Type: 4 flags: 0x10 (bound)
                Margin: 0 bound: 10
            Segment lists:
              Segment list[0]:
                Flags: 0x3800 (computed, verified, first-seg-resolved) MT-ID: 0 algorithm:
 0 weight: 0
                Metric[0]:
                  Type: 0 flags: 0x10 (value)
                  Margin: 0 bound: 0 value: 10
                Segments:
                  Segment[0]:
                    Bitfield: 0x0000 type: 3 flags: 0x8000 (sid-present)
                    SID: 102000
                    Descriptor:
                      Algorithm: 0
                      Local address: 192.0.2.1 [0] remote address: 0.0.0.0 [0]
```

```
Router#show pce distribute-ls events

Distribute LS events:
----------------
Event history (oldest first):
  Time                     Event
  Apr 11 01:50:48.985     [UID: 0] SR CP NLRI: node ID: SR RID 192.0.2.1, ls_id 0, asn 0,
bitf 0x00000200 policy ID: endpoint: 192.168.0.2 color: 100 CP ID: originator: config 0.0.0.0
 asn: 0 discriminator: 100 (oper: add)
  Apr 11 01:50:50.046     [UID: 1] SR CP NLRI: node ID: SR RID 192.0.2.1, ls_id 0, asn 0,
bitf 0x00000200 policy ID: endpoint: 192.168.0.2 color: 100 CP ID: originator: config 0.0.0.0
 asn: 0 discriminator: 100 (oper: add)
RP/0/0/CPU0:rtrX#show pce distribute-ls summary
Tue Apr 11 02:03:36.289 PDT
Distribution enabled: yes
Connected to LS-LIB: yes
Encode queue size: 0
Estimated encoding rate: 17280/s
NLRIs encoded to LS-LIB:
  SR candidate path: 2 added, 0 removed, 0 errored, 0 replaced
Element stats:
  SR candidate path: 1 (watermark: 2)
Throttle timer:
  Running: no
```

Below is the example show output for SRv6.

```
Router# show segment-routing traffic-eng policy color 200 private

SR-TE policy database
---------------------

Color: 200, End-point: 192::2 ID: 2
  Name: srte_c_200_ep_192::2
  Status:
    Admin: up  Operational: up for 00:01:07 (since Mar  6 11:17:42.580)
  Candidate-paths:
    Preference: 100 (configuration) (active)
      Originator: ASN 0 node-address <None> discriminator: 100
```

```
Name: bar
Requested BSID: dynamic
PCC info:
  Symbolic name: cfg_bar_discr_100
  PLSP-ID: 2
  Is orphan: no
  State timer:
    Running: no
Constraints:
  Protection Type: protected-preferred
  Maximum SID Depth: 10
ID: 1
Source: 192::1
Stale: no
Checkpoint flags: 0x00000000
Path Type: SRV6
Performance-measurement:
  Reverse-path segment-list:
  Delay-measurement: Disabled
  Liveness-detection: Disabled
Dynamic (pce 192.168.0.3) (valid)
  Metric Type: IGP,   Path Accumulated Metric: 10
  IGP area: 0
    SID[0]: fccc:ccc1:2::/48 Behavior: uN (PSP/USD) (48)
            Format: f3216
            LBL:32 LNL:16 FL:0 AL:80
            Address: 192::2
SRv6 Information:
  Locator: loc1Algo0
  Binding SID requested: Dynamic
  Binding SID behavior: uB6 (Insert.Red)
Cached distribute LS element:
  Sense: TRUE
  Refcount: 1
  Is on queue: FALSE
  Node identifiers:
    Protocol: 9 router ID: 192::1
  Policy identifiers:
    Color: 200 Endpoint: 192::2
    Flags: 0x80 (endpoint-v6)
  Candidate path identifiers:
    Originator: 0.0.0.0 protocol: 3 ASN: 0
    Flags: 0x00
    Discriminator: 100
  Candidate path attributes:
    Name: bar
    Policy name: srte_c_200_ep_192::2
    State:
      Priority: 0 flags: 0x5A00 (active, evaluated, valid-sid-list, delegated)
      Preference: 100
    SRv6 BSID:
      Flags: 0x8000 (alloc)
      BSID: fccc:ccc1:1:e018::
      Specified BSID: ::
      Endpoint:
        Endpoint function: 71 flags: 0x00 algorithm: 0
      Structure:
       Locator block length: 32 locator node length: 16 function length: 16 arguments
length: 0
    Constraints:
      Bitfield: 0x0020 flags: 0xC000 (dataplane-v6, protected) MT-ID: 0
      Algorithm: 0
      Bandwidth: 0 kbps
```

```
          Metric constraints[0]:
            Type: 0 flags: 0x80 (optimization)
            Margin: 0 bound: 0
          Metric constraints[1]:
            Type: 4 flags: 0x10 (bound)
            Margin: 0 bound: 10
        Segment lists:
          Segment list[0]:
            Flags: 0xB800 (dataplane-v6, computed, verified, first-seg-resolved) MT-ID:
0 algorithm: 0 weight: 1
            Metric[0]:
              Type: 0 flags: 0x10 (value)
              Margin: 0 bound: 0 value: 10
            Segments:
              Segment[0]:
                Bitfield: 0x0003 type: 9 flags: 0x8000 (sid-present)
                SID: fccc:ccc1:2::
                Descriptor:
                  Algorithm: 0
                  Local address: 192::2 [0] remote address: :: [0]
                Endpoint:
                  Endpoint function: 48 flags: 0x00 algorithm: 0
                Structure:
                  Locator block length: 32 locator node length: 16 function length: 0
arguments length: 80
  LSPs:
    LSP[0]:
      LSP-ID: 2 policy ID: 2 (active)
      State: Programmed
      Binding SID: fccc:ccc1:1:e018::
      Install timer:
        Running: no
      Cleanup timer:
        Running: no
      Delete timer:
        Running: no
      Revert timer:
        Running: no
      SM chain:
        Init -> Egress paths
        Egress paths pending -> BSID RW
        BSID rewrite pending -> Success
      Forwarding flags: 0x00000008
      Candidate path ID: 1
      Flags:
      SL-ID:
        Sent/Received/Transferred: 1/1/0
      SLs:
        SL[0]:
          Name: dynamic
          Type: Dynamic PCE
          Checkpoint id: 1
          NH SRV6 SID: fccc:ccc1:2::
          SL ID: 0xa000001
          Flags:
          Normalized Weight: 1
          ENS: 1
          Paths:
            Path[0]:
              Interface version: 1
              Flags:
              Outgoing interface: Gi0/2/0/0
              Weight: 1
```

```
                SID stack:
                Total SID count: 0
                Underlay Normalized Weight: 1
              Path[1]:
                Interface version: 1
                Flags:
                Outgoing interface: Gi0/2/0/1
                Weight: 1
                SID stack:
                Total SID count: 0
                Underlay Normalized Weight: 1
              Path[2]:
                Interface version: 1
                Flags:
                Outgoing interface: Gi0/2/0/2
                Weight: 1
                SID stack:
                Total SID count: 0
                Underlay Normalized Weight: 1
    Attributes:
      Binding SID: fccc:ccc1:1:e018::
      Forward Class: Not Configured
      Steering labeled-services disabled: no
      Steering BGP disabled: no
      IPv6 caps enable: yes
      Invalidation drop enabled: no
      Max Install Standby Candidate Paths: 0
      Path Type: SRV6
    Notification to clients:
      Binding SID: fccc:ccc1:1:e018::
      Bandwidth : 0 Kbps (0 Kbps)
      State: UP
      Flags: [add] [ipv6_caps]
      Metric Type: IGP
      Metric Value: 10
      Admin Distance: 30
    ifhandle: 0x00000000
    Source: 192::1
    Transition count: 1
    LSPs created count: 1
    Reoptimizations completed count: 1
    Retry Action Flags: 0x00000000, ()
    Last Retry Timestamp: never (0 seconds ago)
    Policy reference: 0x1222c10
    Event history (oldest first):
      Time                      Event
      Mar  6 11:17:40.563     POLICY CREATE
      Mar  6 11:17:40.564     (x3) CP PCRPT: 1 hops:
      Mar  6 11:17:41.071     CP PCUPD: CP-ID: 1, path change: true, notify: true, hops:
fccc:ccc1:2::
      Mar  6 11:17:41.072     CP PCRPT: 1 hops: fccc:ccc1:2::
      Mar  6 11:17:41.072     LSP CREATE: 2, need BSID RW: true, BSID: ::
      Mar  6 11:17:41.072     CP CHANGE: PREF: 100 [PROTO: 30, ORIGIN: 0/<None>, DISC: 100]
      Mar  6 11:17:42.579     SRv6 BSID RW REQ: ID 2
      Mar  6 11:17:42.580     SRv6 BSID RW RES: ID 2 Status: success
      Mar  6 11:17:42.580     LSP PCRPT: 2, hops: fccc:ccc1:2::
      Mar  6 11:17:42.580     CP PCRPT REMOVE: 1
      Mar  6 11:17:42.580     IM STATE CHANGE: UNKNOWN to UP, count: 0


Router# show pce segment-routing traffic-eng policy private

PCE's policy database:
```

```
----------------------

PCC Address: 192.168.2.1
  Color: 200, Endpoint: 192::2
    Name: srte_c_200_ep_192::2
    Self Pointer: 0x26cd890
    Active C-path Pointer: 0x26cda00
    Candidate-paths:
      Symbolic-name: cfg_bar_discr_100 (Active)
        PLSP-ID: 2
        NB-API Notification pending flag: 0
        Self Pointer: 0x26cda00
        Tunnel Pointer: 0x26cd580
        Policy Pointer: 0x26cd890
        Cached distribute LS element:
          Sense: TRUE
          Refcount: 1
          Is on queue: FALSE
          Node identifiers:
            Protocol: 9 router ID: 192::1
          Policy identifiers:
            Color: 200 Endpoint: 192::2
            Flags: 0x80 (endpoint-v6)
          Candidate path identifiers:
            Originator: 0.0.0.0 protocol: 3 ASN: 0
            Flags: 0x00
            Discriminator: 100
          Candidate path attributes:
            Name: bar
            Policy name: srte_c_200_ep_192::2
            State:
              Priority: 0 flags: 0x5A00 (active, evaluated, valid-sid-list, delegated)
              Preference: 100
            SRv6 BSID:
              Flags: 0x8000 (alloc)
              BSID: fccc:ccc1:1:e018::
              Specified BSID: ::
              Endpoint:
                Endpoint function: 71 flags: 0x00 algorithm: 0
              Structure:
              Locator block length: 32 locator node length: 16 function length: 16 arguments
 length: 0
            Constraints:
              Bitfield: 0x0020 flags: 0xC000 (dataplane-v6, protected) MT-ID: 0
              Algorithm: 0
              Bandwidth: 0 kbps
              Metric constraints[0]:
                Type: 0 flags: 0x80 (optimization)
                Margin: 0 bound: 0
              Metric constraints[1]:
                Type: 4 flags: 0x10 (bound)
                Margin: 0 bound: 10
            Segment lists:
              Segment list[0]:
               Flags: 0xB800 (dataplane-v6, computed, verified, first-seg-resolved) MT-ID:
 0 algorithm: 0 weight: 0
                Metric[0]:
                  Type: 0 flags: 0x10 (value)
                  Margin: 0 bound: 0 value: 10
                Segments:
                  Segment[0]:
                    Bitfield: 0x0003 type: 9 flags: 0x8000 (sid-present)
                    SID: fccc:ccc1:2::
```

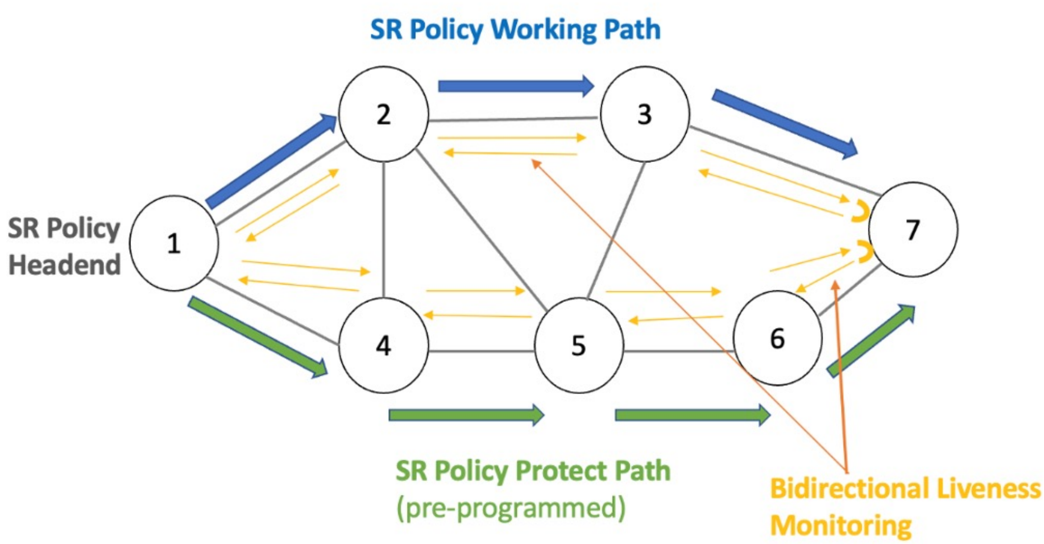
```
                    Descriptor:
                      Algorithm: 0
                      Local address: 192::2 [0] remote address: :: [0]
                    Endpoint:
                      Endpoint function: 48 flags: 0x00 algorithm: 0
                    Structure:
                      Locator block length: 32 locator node length: 16 function length: 0
arguments length: 80


Router# show bgp link-state link-state | i \\[SP\\]

*>i[SP][SR][I0x0][N[c100][b0.0.0.0][q192.168.0.1][te192::1]][C[po0x3][f0x80][e192::2][c10xc8][as0][oa0.0.0.0][di100]]/792
*>
[SP][SR][I0x0][N[c100][b0.0.0.0][q192.168.0.3][te192::1]][C[po0x3][f0x80][e192::2][c10xc8][as0][oa0.0.0.0][di100]]/792




Router# show bgp link-state link-state
[SP][SR][I0x0][N[c100][b0.0.0.0][q192.168.0.1][te192::1]][C[po0x3][f0x80][e192::2][c10xc8][as0][oa0.0.0.0][di100]]/792
BGP routing table entry for
[SP][SR][I0x0][N[c100][b0.0.0.0][q192.168.0.1][te192::1]][C[po0x3][f0x80][e192::2][c10xc8][as0][oa0.0.0.0][di100]]/792
Versions:
  Process           bRIB/RIB   SendTblVer
  Speaker                128          128
Last Modified: Mar  6 11:17:43.000 for 00:04:09
Last Delayed at: ---
Paths: (1 available, best #1)
  Not advertised to any peer
  Path #1: Received by speaker 0
  Not advertised to any peer
  Local
    192.168.2.1 (metric 20) from 192.168.2.1 (192.168.0.1)
      Origin IGP, localpref 100, valid, internal, best, group-best
      Received Path ID 0, Local Path ID 1, version 128
      Link-state:
                  SRTE-CP-State: Priority: 0 Flags: 0x5a00 Preference: 100
                  SR-Policy-CP-name: bar
                  SR-Policy-name: srte_c_200_ep_192::2
                  SRTE-CP-Constraints: Flags: 0xc000 Mtid: 0 Algorithm: 0
                  SRTE-CP-Constraints-Metric: Type: 0 Flags: 0x80 Margin: 0
                  Bound: 0
                  SRTE-CP-Constraints-Metric: Type: 4 Flags: 0x10 Margin: 0
                  Bound: 10
                  SRTE-Segment-List: Flags: 0xb800 Mtid: 0 Algorithm: 0
                  Weight: 1
                 SRTE-Segment: Segment-Type: 9 Flags: 0x8000 SID: fccc:ccc1:2:: Algorithm:
 0
                   Local-node: 192::2
                  SRv6-Endpoint-Fn: 48 Flags: 0x0 Algo: 0
                  SRv6-SID-Struct: LBL: 32 LNL: 16 FL: 0 AL: 80
                  SRTE-Segment-List-Metric: Type: 0 Flags: 0x10 Margin: 0
                  Bound: 0 Value: 10
                  SRTE-CP-SRV6-BSID: Flags: 0x8000 BSID: fccc:ccc1:1:e018::
                   Specified BSID: ::
                  SRv6-Endpoint-Fn: 71 Flags: 0x0 Algo: 0
                  SRv6-SID-Struct: LBL: 32 LNL: 16 FL: 16 AL: 0
```

SR-TE Policy Path Protection

Table 4: Feature History Table

Feature Name	Release Information	Feature Description
SR-TE Policy Path Protection	Release 24.4.1	Introduced in this release on: Fixed Systems (8700 [ASIC: P100]) (select variants only*) You can now configure pre-programmed SR-TE policy Working and Protect candidate paths, and provide fast failure detection through SR Policy Liveness Monitoring probes. If there is a liveness failure on the Working candidate path, the headend triggers a switchover to the Protect candidate path. With this release, you can operate IP-centric (with ECMP and TI-LFA) and TDM-centric (with circuits and path protection) services over a common SR network. This eliminates the need for multiple parallel networks and reduces capital expenditures (CapEx) and operating expenditures (OpEx). * This feature is supported on Cisco 8712-MOD-M routers.

To provide SR policy path protection, headend router and liveness monitoring functions are introduced. The functions are explained with the *1:1* (*one-to-one*) *path protection with SR policy liveness monitoring* use case for TDM-centric networks. Pointers:



Note Path protection and local TI-LFA FRR are mutually exclusive functions.

- An SR-TE policy is enabled on the headend router. The headend router 1 sends traffic to endpoint router 7. The Working candidate path **Blue** spans routers 1-2-3-7, and the Protect candidate path **Green** spans routers 1-4-5-6-7.
- The headend Router maintains an independent liveness session on each candidate path using loopback measurement mode. After verifying liveness, it pre-programs Working and Protect paths in forwarding.
- The paths are manually configured in explicit segment lists using MPLS labels to ensure that unprotected adjacency SIDs are utilized.
- The headend router sends traffic over the Working candidate path, and detects any liveness failure. When there is a failure, it sends direct switchover notifications to the FIB, and triggers a switchover to the protected path.
- In 1:1 (***one-to-one***) path protection, when the Working candidate path fails, the Protect candidate path sends traffic.

Note SR-TE policy path protection and SR-TE path invalidation drop inter-working is not supported.

Liveness Monitoring

- SR PM Liveness probes are performed over Working and Protect candidate paths.
- TWAMP Light (RFC 5357) is used for performance measurement and liveness monitoring.
- Separate PM liveness monitoring sessions are created for working and protect candidate-paths.
- Independent PM sessions are created at both endpoints of the SR Policy.
- Loopback measurement-mode (timestamps t1/t4) is used for liveness monitoring. Probe packets are not punted on the responder node. Round-trip delay is computed as (t4 – t1).
- From headend router 1, PM probe query packets are sent with forward and reverse (7->3->2->1) direction paths of the SR Policy's candidate-path in the header of the probe packet. Similarly, PM probe query packets are sent along the Protect path.
- For liveness monitoring:
    - Liveness is declared UP as soon as one probe packet is received back on all segment-lists of the candidate-path.
    - Liveness failure is detected when last N (user-configured value) consecutive probe packets are lost on any segment-list.
    - Fault in the forward and reverse direction of the segment-list (co-routed path) triggers liveness failure notification to SRTE and FIB. FIB triggers protection switchover upon PM notification (running on high priority thread).

Configuration

- In this example, an SR-TE policy **foo** is created on the headend router and path-protection is enabled for the policy.

```
RP/0/RSP0/CPU0:ios# configure
RP/0/RSP0/CPU0:ios(config)# segment-routing traffic-eng policy foo
RP/0/RSP0/CPU0:ios(config-sr-te-policy)# color 10 end-point ipv4 192.168.0.3
RP/0/RSP0/CPU0:ios(config-sr-te-policy)# path-protection
RP/0/RSP0/CPU0:ios(config-sr-te-path-pref-protection)#exit
```

- Under **candidate-paths**, the Protect and Working paths are specified through explicit segment lists.
- The Protect path's preference is 50, and it is lower than the Working path preference of 100. The forward (1->4->5->6->7) and reverse (7->6->5->4->1) Protect paths, and the forward (1->2->3->7) and reverse (7->3->2->1) Working paths are enabled as explicit segment lists.
- When the Working path is invalid, the Protect path becomes active. After the Working path has recovered, the Protect path remains active until the default lock duration (of 300 seconds) expires. You can configure a different lock duration using the **lock duration** command.

  The duration range is 0 (disabled) to 3000 seconds. If the lock duration is 0 (disabled), then the Working path becomes active as soon as it recovers. If the duration is not specified, the Protect path remains active.

```
RP/0/RSP0/CPU0:ios(config-sr-te-policy)# candidate-paths
RP/0/RSP0/CPU0:ios(config-sr-te-policy-path)#preference 50
RP/0/RSP0/CPU0:ios(config-sr-te-policy-path-pref)#lock duration 30
RP/0/RSP0/CPU0:ios(config-sr-te-policy-path-pref)# explicit segment-list sl-protect-fwd
```

Type **Exit** three times to go to the SR-TE policy configuration mode.

```
RP/0/RSP0/CPU0:ios(config-sr-te-policy)#candidate-paths
RP/0/RSP0/CPU0:ios(config-sr-te-policy-path)#preference 100
RP/0/RSP0/CPU0:ios(config-sr-te-policy-path-pref)# explicit segment-list sl-working-fwd
RP/0/RSP0/CPU0:ios(config-sr-te-pp-info)# commit
```

Working and Protect Segment Lists Configuration

Configure explicit segment lists for the candidate paths.

Note Segment lists must use only unprotected (dynamic or manual) Adjacency SID and BSIDs (as non-first-SID).

```
RP/0/RSP0/CPU0:ios# configure
RP/0/RSP0/CPU0:ios(config)# segment-routing traffic-eng
RP/0/RSP0/CPU0:ios(config-sr-te)# segment-list sl-working-fwd
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# index 1 mpls label 24000
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# index 2 mpls label 24004
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# exit
RP/0/RSP0/CPU0:ios(config-sr-te)# segment-list sl-working-bck
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# index 1 mpls label 24002
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# index 2 mpls label 24006
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# exit
RP/0/RSP0/CPU0:ios(config-sr-te)# segment-list sl-protect-fwd
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# index 1 mpls label 24000
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# index 2 mpls label 30201
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# exit
RP/0/RSP0/CPU0:ios(config-sr-te)# segment-list sl-protect-bck
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# index 1 mpls label 24002
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# index 2 mpls label 30201
RP/0/RSP0/CPU0:ios(config-sr-te-sl)# commit
```

Performance Measurement Configuration For SR-TE Policy

- Enable SR-TE policy specific performance measurement configurations.

- Create a liveness profile for the Working and Protect paths.

```
RP/0/RSP0/CPU0:ios# configure
RP/0/RSP0/CPU0:ios(config)# segment-routing traffic-eng policy foo
RP/0/RSP0/CPU0:ios(config-sr-te-policy)#performance-measurement
RP/0/RSP0/CPU0:ios(config-sr-te-policy-perf-meas)#liveness-detection
RP/0/RSP0/CPU0:ios(config-sr-te-policy-live-detect)# liveness-profile backup name
profile-PROTECT
RP/0/RSP0/CPU0:ios(config-sr-te-policy-live-detect)# liveness-profile name profile-WORKING
```

- The default Invalidation action is Down and it triggers path protection switching. The other action is None, which is enabled here.

```
RP/0/RSP0/CPU0:ios(config-sr-te-policy-live-detect)#invalidation-action none
RP/0/RSP0/CPU0:ios(config-sr-te-policy-live-detect)#commit
```

Performance Measurement Global Profile Configuration

- Create a Working candidate path liveness profile.

```
RP/0/RSP0/CPU0:ios(config)#performance-measurement
RP/0/RSP0/CPU0:ios(config-perf-meas)#liveness-profile sr-policy name profile-WORKING
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy)# probe
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy-probe)# measurement-mode loopback
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy-probe)# tx-interval 30000
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy-probe)# commit
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy-probe)# exit
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy)# liveness-detection multiplier 4
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy)# commit
```

Type **Exit** to access the Performance Measurement config mode.

- Create a Protect candidate path liveness profile.

```
RP/0/RSP0/CPU0:ios(config-perf-meas)# liveness-profile sr-policy name profile-PROTECT
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy)# probe
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy-probe)# measurement-mode loopback
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy-probe)# tx-interval 100000
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy-probe)# commit
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy-probe)# exit
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy)# liveness-detection multiplier 3
RP/0/RSP0/CPU0:ios(config-pm-ld-srpolicy)# commit
```

Verification

Use the **show segment-routing traffic-eng policy candidate-path** command to display Working and Protect candidate-path details.

```
RP/0/RSP0/CPU0:ios# show segment-routing traffic-eng policy candidate-path name foo

SR-TE policy database
---------------------

Color: 10, End-point: 192.168.0.3s
  Name: srte_c_10_ep_192.168.0.3
  Status:
    Admin: up  Operational: Up for 00:11:55 (since Dec 15 07:02:08.709)
  Candidate-paths:
    Preference: 100 (configuration) (active)
      Name: foo
      Requested BSID: dynamic
```

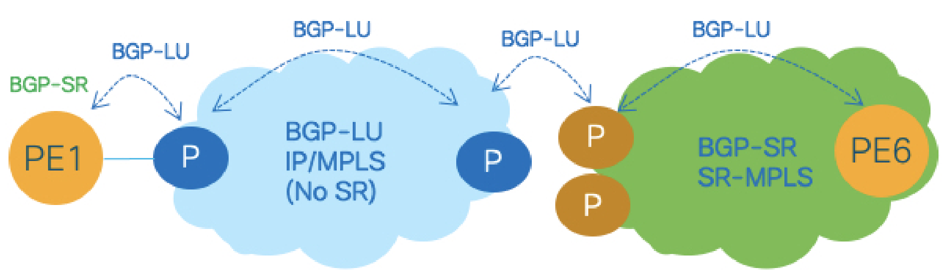
```
      Protection Type: protected-preferred
      Maximum SID Depth: 10
    Explicit: segment-list sl-working-fwd (active)
      Weight: 1, Metric Type: TE
        24000
        24004
    Protection Information:
      Role: WORKING
      Path Lock: Timed
      Lock Duration: 300(s)
  Preference: 50 (configuration) (active)
    Name: foo
    Requested BSID: dynamic
      Protection Type: protected-preferred
      Maximum SID Depth: 10
    Explicit: segment-list sl-protect-fwd (active)
      Weight: 1, Metric Type: TE
        24000
        30201
    Protection Information:
      Role: PROTECT
      Path Lock: Timed
      Lock Duration: 30(s)
..
```

Explicit Path with a BGP Prefix SID as First Segment

Table 5: Feature History Table

Feature Name	Release Information	Feature Description
SR-TE Explicit Path with a BGP Prefix SID as First Segment	Release 24.4.1	Introduced in this release on: Fixed Systems (8700 [ASIC: K100]) (select variants only*) This feature allows you to configure an SR-TE policy with an explicit path that uses a remote BGP prefix SID as its first segment. This path is achieved by leveraging the recursive resolution of the first SID, which is a BGP-Label Unicast (BGP-LU) SID. BGP-LU labels are used as the first SID in the SR policy to determine the egress paths for the traffic and program the SR-TE forwarding chain accordingly. This allows users to enable Segment Routing to leverage their existing BGP infrastructure and integrate it with the required Segment Routing functionalities. * This feature is supported on Cisco 8712-MOD-M routers.

The figure below shows a network setup where a PE router (PE1) is using BGP-SR as the routing protocol and is connected to a classic BGP-LU domain. The classic BGP-LU domain is also connected to other domains running BGP-SR

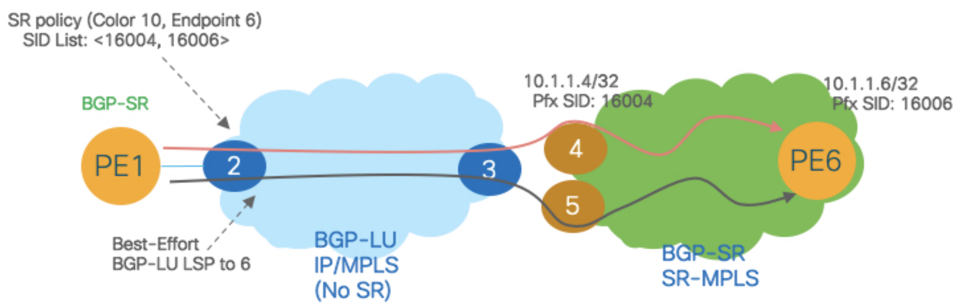


In BGP-SR, a BGP Prefix-SID is advertised along with a prefix in BGP Labeled Unicast (BGP-LU). This Prefix-SID attribute contains information about the label value and index for the route. This allows for interworking between the classic BGP-LU and BGP-SR domains.

The figure below illustrates a best-effort BGP-LU Label Switched Path (LSP) from PE1 to PE6, passing through transit Label Switching Router (LSR) nodes 2, 3, and 5.

With this setup, the operator can create an alternate path using an SR-TE policy at the ingress BGP-SR PE (PE1). The explicit path for this alternate path will follow a different transit node, using the BGP prefix SID for that transit node as the first segment.

For example, in the figure below, the SID-list shows that the explicit path uses the BGP prefix SID of transit LSR node 4 (16004) followed by the BGP prefix SID of PE6 (16006). The PE1 router resolves the first segment of this explicit path to the outgoing interface towards Node 2, using the outgoing label advertised by Node 2 for the BGP-LU prefix 10.1.1.4/32.



Example

The following output shows the BGP-LU routes learned at the head-end (PE1 in the illustration above). Consider the IP prefix 1.1.1.4/32. A BGP-LU local label is assigned from the SRGB with a prefix SID index of 4, resulting in the value 16004. Additionally, the classic BGP-LU upstream neighbor (P2) advertises an outgoing label of 78000 for this IP prefix.

```
RP/0/RP0/CPU0:R1# show bgp ipv4 unicast labels

BGP router identifier 1.1.1.1, local AS number 1
BGP generic scan interval 60 secs
Non-stop routing is enabled
BGP table state: Active
Table ID: 0xe0000000   RD version: 13
BGP main routing table version 13
BGP NSR Initial initsync version 6 (Reached)
BGP NSR/ISSU Sync-Group versions 0/0
BGP scan interval 60 secs

Status codes: s suppressed, d damped, h history, * valid, > best
              i - internal, r RIB-failure, S stale, N Nexthop-discard
Origin codes: i - IGP, e - EGP, ? - incomplete
   Network            Next Hop        Rcvd Label      Local Label

*> 1.1.1.1/32         0.0.0.0         nolabel         3
*> 1.1.1.2/32         10.1.2.2        3               24007
*> 1.1.1.3/32         10.1.2.2        78005           24002
*> 1.1.1.4/32         10.1.2.2        78000           16004
*> 1.1.1.5/32         10.1.2.2        78002           16005
*> 1.1.1.6/32         10.1.2.2        78001           16006

...

RP/0/RP0/CPU0:R1# show bgp ipv4 labeled-unicast 1.1.1.4/32

BGP routing table entry for 1.1.1.4/32
Versions:
  Process           bRIB/RIB  SendTblVer
  Speaker                 74          74
```

```
    Local Label: 16004
Last Modified: Sep 29 19:52:18.155 for 00:07:22
Paths: (1 available, best #1)
  Advertised to update-groups (with more than one peer):
    0.2
  Path #1: Received by speaker 0
  Advertised to update-groups (with more than one peer):
    0.2
  3
    10.1.2.2 from 10.1.2.2 (1.1.1.2)
      Received Label 78000
      Origin IGP, metric 0, localpref 100, valid, external, best, group-best
      Received Path ID 0, Local Path ID 1, version 74
      Origin-AS validity: not-found
      Label Index: 4
```

The following output shows the corresponding label forwarding entry for BGP prefix SID 16004 with corresponding outgoing label and outgoing interface.

```
RP/0/RP0/CPU0:R1# show mpls forwarding labels 16002

Local  Outgoing    Prefix             Outgoing     Next Hop        Bytes
Label  Label       or ID              Interface                    Switched
------ ----------- ------------------ ------------ --------------- ------------
16004  78000       SR Pfx (idx 2)     Te0/0/0/0    10.1.2.2        44
```

The configuration below depicts an SR policy (color 100 and end-point 1.1.1.6) with an explicit path to PE6 using the BGP prefix SID of transit LSR node 4 (16004) as its first segment followed by the BGP prefix SID of PE6 (16006).

```
RP/0/RP0/CPU0:R1# configure
RP/0/RP0/CPU0:R1(config)# segment-routing
RP/0/RP0/CPU0:R1(config-sr)# traffic-eng
RP/0/RP0/CPU0:R1(config-sr-te)# segment-list SL-R4-R6
RP/0/RP0/CPU0:R1(config-sr-te-sl)# index 10 mpls label 16004
RP/0/RP0/CPU0:R1(config-sr-te-sl)# index 20 mpls label 16006
RP/0/RP0/CPU0:R1(config-sr-te-sl)# exit

RP/0/RP0/CPU0:R1(config-sr-te)# policy POL-to-R6
RP/0/RP0/CPU0:R1(config-sr-te-policy)# color 100 end-point ipv4 1.1.1.6
RP/0/RP0/CPU0:R1(config-sr-te-policy)# candidate-paths
RP/0/RP0/CPU0:R1(config-sr-te-policy-path)# preference 100
RP/0/RP0/CPU0:R1(config-sr-te-policy-path-pref)# explicit segment-list SL-R4-R6

RP/0/RP0/CPU0:R1# show running-configuration

segment-routing
 traffic-eng
  segment-list SL-R4-R6
   index 10 mpls label 16004
   index 20 mpls label 16006
  !
  policy POL-to-R6
   color 100 end-point ipv4 1.1.1.6
   candidate-paths
    preference 100
     explicit segment-list SL-R4-R6
     !
    !
   !
```

```
  !
 !
!
```

The following output depicts the forwarding information for the SR policy including the outgoing interface and outgoing label stack.

Observe how the first segment configured (MPLS label 16004) is replaced in the forwarding with the label advertised by the BGP-LU neighbor of the SRTE head-end (MPLS label value 78000).

```
RP/0/RP0/CPU0:R1# show segment-routing traffic-eng forwarding policy color 100

SR-TE Policy Forwarding database
--------------------------------

Color: 100, End-point: 1.1.1.6
  Name: srte_c_100_ep_1.1.1.6
  Binding SID: 24006
  Active LSP:
    Candidate path:
      Preference: 100 (configuration)
      Name: POL-to-R6
    Local label: 24005
    Segment lists:
      SL[0]:
        Name: SL-R4-R6
        Switched Packets/Bytes: 100/10000
          [MPLS -> MPLS]: 100/10000
        Paths:
          Path[0]:
            Outgoing Label: 78000
            Outgoing Interfaces: TenGigE0/0/0/0
            Next Hop: 10.1.2.2
            Switched Packets/Bytes: 100/10000
              [MPLS -> MPLS]: 100/10000
            FRR Pure Backup: No
            ECMP/LFA Backup: No
            Internal Recursive Label: Unlabelled (recursive)
            Label Stack (Top -> Bottom): { 78000, 16006 }

  Policy Packets/Bytes Switched: 100/9600
```

With the SR-TE policy installed, the head-end can apply SR-TE automated steering principles when programming BGP service overlay routes.

In the following output, BGP prefix 10.0.0.0/8 with next-hop 1.1.1.6 and color 100 is automatically steered over the SR policy configured above (color 100 and end-point 1.1.1.6).

```
RP/0/RP0/CPU0:R1# show bgp

BGP router identifier 1.1.1.1, local AS number 1
BGP generic scan interval 60 secs
Non-stop routing is enabled
BGP table state: Active
Table ID: 0xe0000000   RD version: 13
BGP main routing table version 13
BGP NSR Initial initsync version 6 (Reached)
BGP NSR/ISSU Sync-Group versions 0/0
BGP scan interval 60 secs

Status codes: s suppressed, d damped, h history, * valid, > best
              i - internal, r RIB-failure, S stale, N Nexthop-discard
Origin codes: i - IGP, e - EGP, ? - incomplete
```

```
   Network           Next Hop           Metric LocPrf Weight Path
. . .
*> 10.0.0.0/8       1.1.1.6 C:100           0             0 3 i
```

LDP over Segment Routing Policy

Table 6: Feature History Table

Feature Name	Release Information	Feature Description
LDP over Segment Routing Policy	Release 24.4.1	Introduced in this release on: Fixed Systems (8700 [ASIC: P100) (select variants only*) The LDP over Segment Routing Policy feature enables an LDP-targeted adjacency over a Segment Routing (SR) policy between two routers. This feature extends the existing MPLS LDP address family neighbor configuration to specify an SR policy as the targeted end-point. * This feature is supported on Cisco 8712-MOD-M routers.

The LDP over Segment Routing Policy feature enables an LDP-targeted adjacency over a Segment Routing (SR) policy between two routers. This feature extends the existing MPLS LDP address family neighbor configuration to specify an SR policy as the targeted end-point.

LDP over SR policy is supported for locally configured SR policies with IPv4 end-points.

For more information about MPLS LDP, see the "Implementing MPLS Label Distribution Protocol" chapter in the *MPLS Configuration Guide*.

For more information about Autoroute, see the *Autoroute Announce for SR-TE* section.

Note Before you configure an LDP targeted adjacency over SR policy name, you need to create the SR policy under Segment Routing configuration. The SR policy interface names are created internally based on the color and endpoint of the policy. LDP is non-operational if SR policy name is unknown.

The following functionality applies:

1. Configure the SR policy – LDP receives the associated end-point address from the interface manager (IM) and stores it in the LDP interface database (IDB) for the configured SR policy.
2. Configure the SR policy name under LDP – LDP retrieves the stored end-point address from the IDB and uses it. Use the auto-generated SR policy name assigned by the router when creating an LDP targeted

adjacency over an SR policy. Auto-generated SR policy names use the following naming convention: **srte_c_***color_val***_ep_***endpoint-address*. For example, **srte_c_1000_ep_10.1.1.2**

Configuration Example

```
/* Enter the SR-TE configuration mode and create the SR policy. This example corresponds
to a local SR policy with an explicit path. */
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# segment-list sample-sid-list
Router(config-sr-te-sl)# index 10 address ipv4 10.1.1.7
Router(config-sr-te-sl)# index 20 address ipv4 10.1.1.2
Router(config-sr-te-sl)# exit
Router(config-sr-te)# policy sample_policy
Router(config-sr-te-policy)# color 1000 end-point ipv4 10.1.1.2
Router(config-sr-te-policy)# candidate-paths
Router(config-sr-te-policy-path)# preference 100
Router(config-sr-te-policy-path-pref)# explicit segment-list sample-sid-list
Router(config-sr-te-pp-info)# end

/* Configure LDP over an SR policy */
Router(config)# mpls ldp
Router(config-ldp)# address-family ipv4
Router(config-ldp-af)# neighbor sr-policy srte_c_1000_ep_10.1.1.2 targeted
Router(config-ldp-af)#
```

Note Do one of the following to configure LDP discovery for targeted hellos:

- Active targeted hellos (SR policy head end):

```
mpls ldp
 interface GigabitEthernet0/0/0/0
 !
!
```

- Passive targeted hellos (SR policy end-point):

```
mpls ldp
 address-family ipv4
  discovery targeted-hello accept
 !
!
```

Running Configuration

```
segment-routing
 traffic-eng
  segment-list sample-sid-list
   index 10 address ipv4 10.1.1.7
   index 20 address ipv4 10.1.1.2
  !
  policy sample_policy
   color 1000 end-point ipv4 10.1.1.2
   candidate-paths
    preference 100
     explicit segment-list sample-sid-list
     !
```

```
    !
   !
  !
 !
!

mpls ldp
 address-family ipv4
  neighbor sr-policy srte_c_1000_ep_10.1.1.2 targeted
  discovery targeted-hello accept
 !
!
```

Verification

```
Router# show mpls ldp interface brief
Interface       VRF Name            Config Enabled IGP-Auto-Cfg TE-Mesh-Grp cfg
--------------- ------------------- ------ ------- ------------ ---------------
Te0/3/0/0/3     default             Y      Y       0            N/A
Te0/3/0/0/6     default             Y      Y       0            N/A
Te0/3/0/0/7     default             Y      Y       0            N/A
Te0/3/0/0/8     default             N      N       0            N/A
Te0/3/0/0/9     default             N      N       0            N/A
srte_c_1000_    default             Y      Y       0            N/A


Router# show mpls ldp interface
Interface TenGigE0/3/0/0/3 (0xa000340)
   VRF: 'default' (0x60000000)
   Enabled via config: LDP interface
Interface TenGigE0/3/0/0/6 (0xa000400)
   VRF: 'default' (0x60000000)
   Enabled via config: LDP interface
Interface TenGigE0/3/0/0/7 (0xa000440)
   VRF: 'default' (0x60000000)
   Enabled via config: LDP interface
Interface TenGigE0/3/0/0/8 (0xa000480)
   VRF: 'default' (0x60000000)
   Disabled:
Interface TenGigE0/3/0/0/9 (0xa0004c0)
   VRF: 'default' (0x60000000)
   Disabled:
Interface srte_c_1000_ep_10.1.1.2 (0x520)
   VRF: 'default' (0x60000000)
   Enabled via config: LDP interface


Router# show segment-routing traffic-eng policy color 1000

SR-TE policy database
---------------------

Color: 1000, End-point: 10.1.1.2
  Name: srte_c_1000_ep_10.1.1.2
  Status:
    Admin: up  Operational: up for 00:02:00 (since Jul  2 22:39:06.663)
  Candidate-paths:
    Preference: 100 (configuration) (active)
      Name: sample_policy
      Requested BSID: dynamic
      PCC info:
        Symbolic name: cfg_sample_policy_discr_100
        PLSP-ID: 17
      Explicit: segment-list sample-sid-list (valid)
```

```
      Weight: 1, Metric Type: TE
        16007 [Prefix-SID, 10.1.1.7]
        16002 [Prefix-SID, 10.1.1.2]
  Attributes:
    Binding SID: 80011
    Forward Class: 0
    Steering BGP disabled: no
    IPv6 caps enable: yes


Router# show mpls ldp neighbor 10.1.1.2 detail

Peer LDP Identifier: 10.1.1.2:0
  TCP connection: 10.1.1.2:646 - 10.1.1.6:57473
  Graceful Restart: No
  Session Holdtime: 180 sec
  State: Oper; Msgs sent/rcvd: 421/423; Downstream-Unsolicited
  Up time: 05:22:02
  LDP Discovery Sources:
    IPv4: (1)
      Targeted Hello (10.1.1.6 -> 10.1.1.2, active/passive)
    IPv6: (0)
  Addresses bound to this peer:
    IPv4: (9)
      10.1.1.2       2.2.2.99       10.1.2.2       10.2.3.2
      10.2.4.2       10.2.22.2      10.2.222.2     10.30.110.132
      11.2.9.2
    IPv6: (0)
  Peer holdtime: 180 sec; KA interval: 60 sec; Peer state: Estab
  NSR: Disabled
  Clients: LDP over SR Policy
  Capabilities:
    Sent:
      0x508  (MP: Point-to-Multipoint (P2MP))
      0x509  (MP: Multipoint-to-Multipoint (MP2MP))
      0x50a  (MP: Make-Before-Break (MBB))
      0x50b  (Typed Wildcard FEC)
    Received:
      0x508  (MP: Point-to-Multipoint (P2MP))
      0x509  (MP: Multipoint-to-Multipoint (MP2MP))
      0x50a  (MP: Make-Before-Break (MBB))
      0x50b  (Typed Wildcard FEC)
```