Segment Routing Configuration Guide for Cisco NCS 560 Series Routers, IOS XR Release 6.6.x

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CHAPTER 1

About Segment Routing

This chapter introduces the concept of segment routing and provides a workflow for configuring segment routing.

Scope

Segment routing is a method of forwarding packets on the network based on the source routing paradigm. The source chooses a path and encodes it in the packet header as an ordered list of segments. Segments are an identifier for any type of instruction. For example, topology segments identify the next hop toward a destination. Each segment is identified by the segment ID (SID) consisting of a flat unsigned 20-bit integer.

Segments

Interior gateway protocol (IGP) distributes two types of segments: prefix segments and adjacency segments. Each router (node) and each link (adjacency) has an associated segment identifier (SID).

- A prefix SID is associated with an IP prefix. The prefix SID is manually configured from the segment routing global block (SRGB) range of labels, and is distributed by IS-IS or OSPF. The prefix segment steers the traffic along the shortest path to its destination. A node SID is a special type of prefix SID that identifies a specific node. It is configured under the loopback interface with the loopback address of the node as the prefix.

  A prefix segment is a global segment, so a prefix SID is globally unique within the segment routing domain.

- An adjacency segment is identified by a label called an adjacency SID, which represents a specific adjacency, such as egress interface, to a neighboring router. An adjacency SID can be allocated dynamically from the dynamic label range or configured manually from the segment routing local block (SRLB) range of labels. The adjacency SID is distributed by IS-IS or OSPF. The adjacency segment steers the traffic to a specific adjacency.

  An adjacency segment is a local segment, so the adjacency SID is locally unique relative to a specific router.

By combining prefix (node) and adjacency segment IDs in an ordered list, any path within a network can be constructed. At each hop, the top segment is used to identify the next hop. Segments are stacked in order at the top of the packet header. When the top segment contains the identity of another node, the receiving node uses equal cost multipaths (ECMP) to move the packet to the next hop. When the identity is that of the receiving node, the node pops the top segment and performs the task required by the next segment.

Dataplane

Segment routing can be directly applied to the Multiprotocol Label Switching (MPLS) architecture with no change in the forwarding plane. A segment is encoded as an MPLS label. An ordered list of segments is encoded as a stack of labels. The segment to process is on the top of the stack. The related label is popped from the stack, after the completion of a segment.

Services

Segment Routing integrates with the rich multi-service capabilities of MPLS, including Layer 3 VPN (L3VPN), Virtual Private Wire Service (VPWS), Virtual Private LAN Service (VPLS), and Ethernet VPN (EVPN).

Segment Routing for Traffic Engineering

Segment routing for traffic engineering (SR-TE) takes place through a policy between a source and destination pair. Segment routing for traffic engineering uses the concept of source routing, where the source calculates the path and encodes it in the packet header as a segment. Each segment is an end-to-end path from the source to the destination, and instructs the routers in the provider core network to follow the specified path instead of the shortest path calculated by the IGP. The destination is unaware of the presence of the policy.

Need

With segment routing for traffic engineering (SR-TE), the network no longer needs to maintain a per-application and per-flow state. Instead, it simply obeys the forwarding instructions provided in the packet.

SR-TE utilizes network bandwidth more effectively than traditional MPLS-TE networks by using ECMP at every segment level. It uses a single intelligent source and relieves remaining routers from the task of calculating the required path through the network.

Benefits

- **Ready for SDN**: Segment routing was built for SDN and is the foundation for Application Engineered Routing (AER). SR prepares networks for business models, where applications can direct network behavior. SR provides the right balance between distributed intelligence and centralized optimization and programming.
- **Minimal configuration**: Segment routing for TE requires minimal configuration on the source router.
- **Load balancing**: Unlike in RSVP-TE, load balancing for segment routing can take place in the presence of equal cost multiple paths (ECMPs).
- **Supports Fast Reroute (FRR)**: Fast reroute enables the activation of a pre-configured backup path within 50 milliseconds of path failure.

- **Plug-and-Play deployment**: Segment routing policies are interoperable with existing MPLS control and data planes and can be implemented in an existing deployment.

Workflow for Deploying Segment Routing

Follow this workflow to deploy segment routing.

1. Configure the Segment Routing Global Block (SRGB)
2. Enable Segment Routing and Node SID for the IGP
3. Configure Segment Routing for BGP
4. Configure the SR-TE Policy
5. Configure the SR-PCE
6. Configure TI-LFA and Microloop Avoidance
7. Configure the Segment Routing Mapping Server

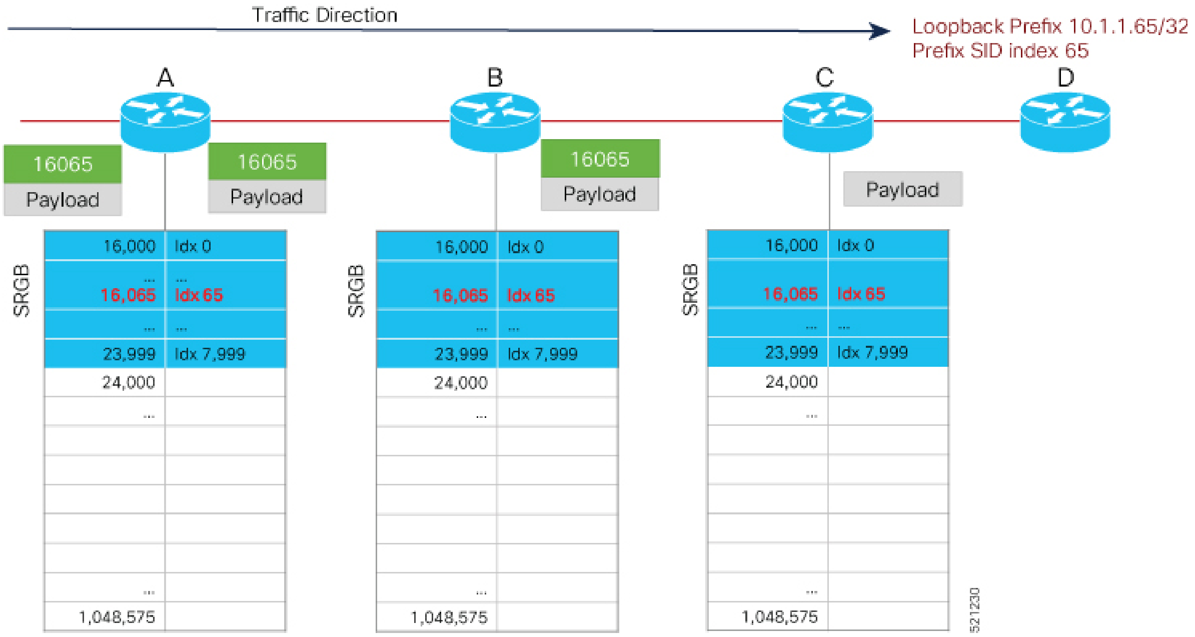
CHAPTER 2

Configure Segment Routing Global Block and Segment Routing Local Block

Local label allocation is managed by the label switching database (LSD). The Segment Routing Global Block (SRGB) and Segment Routing Local Block (SRLB) are label values preserved for segment routing in the LSD.

About the Segment Routing Global Block

The Segment Routing Global Block (SRGB) is a range of labels reserved for Segment Routing global segments. A prefix-SID is advertised as a domain-wide unique index. The prefix-SID index points to a unique label within the SRGB range. The index is zero-based, meaning that the first index is 0. The MPLS label assigned to a prefix is derived from the Prefix-SID index plus the SRGB base. For example, considering an SRGB range of 16,000 to 23,999, a prefix 10.1.1.65/32 with prefix-SID index of **65** is assigned the label value of **16065**.



To keep the configuration simple and straightforward, we strongly recommended that you use a homogenous SRGB (meaning, the same SRGB range across all nodes). Using a heterogenous SRGB (meaning, a different SRGB range of the same size across nodes) is also supported but is not recommended.

Behaviors and Limitations

- The default SRGB in IOS XR has a size of 8000 starting from label value 16000. The default range is 16000 to 23,999. With this size, and assuming one loopback prefix per router, an operator can assign prefix SIDs to a network with 8000 routers.
- There are instances when you might need to define a different SRGB range. For example:
  - Non-IOS XR nodes with a SRGB range that is different than the default IOS XR SRGB range.
  - The default SRGB range is not large enough to accommodate all required prefix SIDs.
- A non-default SRGB can be configured following these guidelines:
  - The SRGB starting value can be configured anywhere in the dynamic label range space (16,000 to 1,048,575).
  - In Cisco IOS XR release earlier than 6.6.3, the SRGB can have a maximum configurable size of 262,143.
  - In Cisco IOS XR release 6.6.3 and later, the SRGB can be configured to any size value that fits within the dynamic label range space.
- Allocating an SRGB label range does not mean that all the labels in this range are programmed in the forwarding table. The label range is just reserved for SR and not available for other purposes. Furthermore, a platform may limit the number of local labels that can be programmed.
- We recommend that the non-default SRGB be configured under the **segment-routing** global configuration mode. By default, all IGP instances and BGP use this SRGB.

- You can also configure a non-default SRGB under the IGP, but it is not recommended.

SRGB Label Conflicts

When you define a non-default SRGB range, there might be a label conflict (for example, if labels are already allocated, statically or dynamically, in the new SRGB range). The following system log message indicates a label conflict:

```
%ROUTING-ISIS-4-SRGB_ALLOC_FAIL : SRGB allocation failed: 'SRGB reservation not
successful for [16000,80000], SRGB (16000 80000, SRGB_ALLOC_CONFIG_PENDING, 0x2)
(So far 16 attempts). Make sure label range is free'
```

To remove this conflict, you must reload the router to release the currently allocated labels and to allocate the new SRGB.

After the system reloads, LSD does not accept any dynamic label allocation before IS-IS/OSPF/BGP have registered with LSD. Upon IS-IS/OSPF/BGP registration, LSD allocates the requested SRGB (either the default range or the customized range).

After IS-IS/OSPF/BGP have registered and their SRGB is allocated, LSD starts serving dynamic label requests from other clients.

Note To avoid a potential router reload due to label conflicts, and assuming that the default SRGB size is large enough, we recommend that you use the default IOS XR SRGB range.

Note Allocating a non-default SRGB in the upper part of the MPLS label space increases the chance that the labels are available and a reload can be avoided.

Caution Modifying a SRGB configuration is disruptive for traffic and may require a reboot if the new SRGB is not available entirely.

About the Segment Routing Local Block

A local segment is automatically assigned an MPLS label from the dynamic label range. In most cases, such as TI-LFA backup paths and SR-TE explicit paths defined with IP addresses, this dynamic label allocation is sufficient. However, in some scenarios, it could be beneficial to allocate manually local segment label values to maintain label persistency. For example, an SR-TE policy with a manual binding SID that is performing traffic steering based on incoming label traffic with the binding SID.

The Segment Routing Local Block (SRLB) is a range of label values preserved for the manual allocation of local segments, such as adjacency segment identifiers (adj-SIDs) , Layer 2 adj-SIDs, binding SIDs (BSIDs). These labels are locally significant and are only valid on the nodes that allocate the labels.

Behaviors and Limitations

- The default SRLB has a size of 1000 starting from label value 15000; therefore, the default SRLB range goes from 15000 to 15,999.
- A non-default SRLB can be configured following these guidelines:
  - The SRLB starting value can be configured anywhere in the dynamic label range space (16,000 to 1,048,575).
  - In Cisco IOS XR release earlier than 6.6.3, the SRLB can have a maximum configurable size of 262,143.
  - In Cisco IOS XR release 6.6.3 and later, the SRLB can be configured to any size value that fits within the dynamic label range space.

SRLB Label Conflicts

When you define a non-default SRLB range, there might be a label conflict (for example, if labels are already allocated, statically or dynamically, in the new SRLB range). In this case, the new SRLB range will be accepted, but not applied (pending state). The previous SRLB range (active) will continue to be in use.

To remove this conflict, you must reload the router to release the currently allocated labels and to allocate the new SRLB.

Caution You can use the **clear segment-routing local-block discrepancy all** command to clear label conflicts. However, using this command is disruptive for traffic since it forces all other MPLS applications with conflicting labels to allocate new labels.

Note To avoid a potential router reload due to label conflicts, and assuming that the default SRGB size is large enough, we recommend that you use the default IOS XR SRLB range.

Note Allocating a non-default SRLB in the upper part of the MPLS label space increases the chance that the labels are available and a reload can be avoided.

Understanding Segment Routing Label Allocation

In IOS XR, local label allocation is managed by the Label Switching Database (LSD). MPLS applications must register as a client with the LSD to allocate labels. Most MPLS applications (for example: LDP, RSVP, L2VPN, BGP [LU, VPN], IS-IS and OSPF [Adj-SID], SR-TE [Binding-SID]) use labels allocated dynamically by LSD.

With Segment Routing-capable IOS XR software releases, the LSD *preserves* the default SRLB label range (15,000 to 15,999) and default SRGB label range (16,000 to 23,999), even if Segment Routing is not enabled.

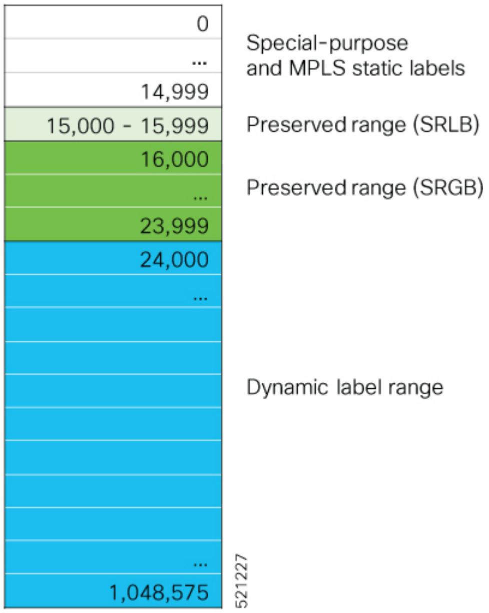
This preservation of the default SRLB/SRGB label range makes future Segment Routing activation possible without a reboot. No labels are allocated from this preserved range. When you enable Segment Routing with the default SRLB/SRGB in the future, these label ranges will be available and ready for use.

The LSD allocates dynamic labels starting from 24,000.

Note If an MPLS label range is configured and it overlaps with the default SRLB/SRGB label ranges (for example, **mpls label range 15000 1048575**), then the default SRLB/SRGB preservation is disabled.

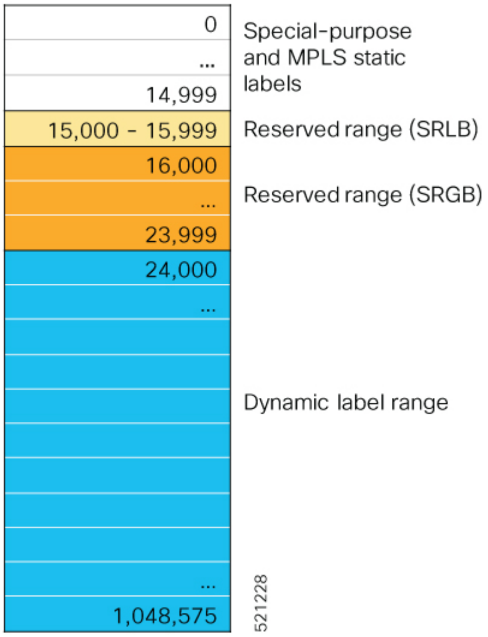
Example 1: LSD Label Allocation When SR is not Configured

- Special use: 0-15
- MPLS static: 16 to 14,999
- SRLB (preserved): 15,000 to 15,999
- SRGB (preserved): 16,000 to 23,999
- Dynamic: 24,000 to max



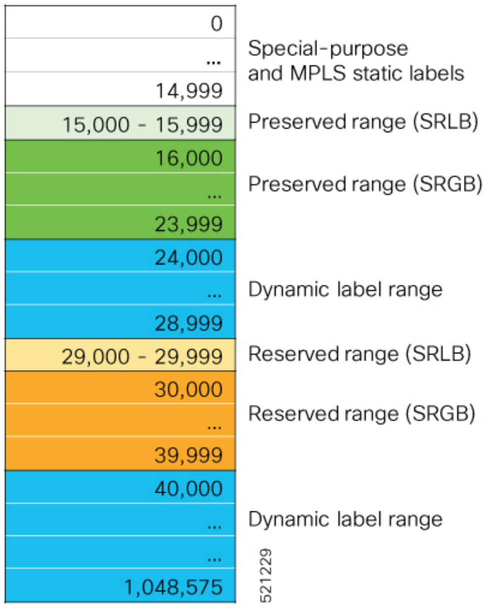
Example 2: LSD Label Allocation When SR is Configured with Default SRGB and Default SRLB

- Special use: 0-15
- MPLS static: 16 to 14,999
- SRLB (reserved): 15,000 to 15,999
- SRGB (reserved): 16,000 to 23,999
- Dynamic: 24,000 to max



Example 3: LSD Label Allocation When SR is Configured with Non-default SRGB and Non-default SRLB

- Special use: 0-15
- MPLS static: 16 to 14,999
- SRLB (preserved): 15,000 to 15,999
- SRGB (preserved): 16,000 to 23,999
- Dynamic: 24000 to 28,999
- SRLB (reserved): 29,000 to 29,999
- SRGB (reserved): 30,000 to 39,999
- Dynamic: 40,000 to max



Setup a Non-Default Segment Routing Global Block Range

This task explains how to configure a non-default SRGB range.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.

Step 2	**segment-routing global-block** *starting_value ending_value*
	Example:
	`RP/0/RP0/CPU0:router(config)#`
	`segment-routing global-block 16000 80000`
		Enter the lowest value that you want the SRGB range to include as the starting value. Enter the highest value that you want the SRGB range to include as the ending value.

Step 3	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session.

	Command or Action	Purpose
		• **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

Use the **show mpls label table** [**label** *label-value*] command to verify the SRGB configuration:

```
Router# show mpls label table label 16000 detail
Table Label   Owner                           State  Rewrite
----- ------- ------------------------------- ------ -------
0     16000   ISIS(A):1                       InUse  No
  (Lbl-blk SRGB, vers:0, (start_label=16000, size=64001)
```

What to do next

Configure prefix SIDs and enable segment routing.

Setup a Non-Default Segment Routing Local Block Range

This task explains how to configure a non-default SRLB range.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.

Step 2	**segment-routing local-block** *starting_value ending_value*
	Example:
	`RP/0/RP0/CPU0:router(config)#`
	`segment-routing local-block 30000 30999`
		Enter the lowest value that you want the SRLB range to include as the starting value. Enter the highest value that you want the SRLB range to include as the ending value.

Step 3	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session.

	Command or Action	Purpose
		• **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

Use the **show mpls label table** [**label** *label-value*] [**detail**] command to verify the SRLB configuration:

```
Router# show mpls label table label 30000 detail

Table Label   Owner                           State  Rewrite
----- ------- ------------------------------- ------ -------
0     30000   LSD(A)                          InUse  No
  (Lbl-blk SRLB, vers:0, (start_label=30000, size=1000, app_notify=0)

Router# show segment-routing local-block inconsistencies

No inconsistencies
```

The following example shows an SRLB label conflict in the range of 30000 and 30999. Note that the default SRLB is active and the configured SRLB is pending:

```
Router(config)# segment-routing local-block 30000 30999

%ROUTING-MPLS_LSD-3-ERR_SRLB_RANGE : SRLB allocation failed: 'SRLB reservation not successfull

for [30000,30999]. Use with caution 'clear segment-routing local-block discrepancy all'
command
to force srlb allocation'
```

Caution You can use the **clear segment-routing local-block discrepancy all** command to clear label conflicts. However, using this command is disruptive for traffic since it forces all other MPLS applications with conflicting labels to allocate new labels.

```
Router# show mpls label table label 30000 detail

Table Label   Owner                           State  Rewrite
----- ------- ------------------------------- ------ -------
0     30000   LSD(A)                          InUse  No
  (Lbl-blk SRLB, vers:0, (start_label=30000, size=1000, app_notify=0)

Router# show segment-routing local-block inconsistencies
SRLB inconsistencies range: Start/End: 30000/30999

Router# show mpls lsd private | i SRLB

SRLB Lbl Mgr:
   Current Active SRLB block      = [15000, 15999]
   Configured Pending SRLB block  = [30000, 30999]
```

Reload the router to release the currently allocated labels and to allocate the new SRLB:

```
Router# reload

Proceed with reload? [confirm]yes
```

After the system is brought back up, verify that there are no label conflicts with the SRLB configuration:

```
Router# show mpls lsd private | i SRLB

SRLB Lbl Mgr:
   Current Active SRLB block      = [30000, 30999]
   Configured Pending SRLB block  = [0, 0]

Router# show segment-routing local-block inconsistencies

No inconsistencies
```

What to do next

Configure adjacency SIDs and enable segment routing.

CHAPTER 3

Configure Segment Routing for IS-IS Protocol

Integrated Intermediate System-to-Intermediate System (IS-IS), Internet Protocol Version 4 (IPv4), is a standards-based Interior Gateway Protocol (IGP). The Cisco IOS XR software implements the IP routing capabilities described in International Organization for Standardization (ISO)/International Engineering Consortium (IEC) 10589 and RFC 1995, and adds the standard extensions for single topology and multitopology IS-IS for IP Version 6 (IPv6).

This module provides the configuration information used to enable segment routing for IS-IS.

Enabling Segment Routing for IS-IS Protocol

Segment routing on the IS-IS control plane supports the following:

- IPv4 and IPv6 control plane
- Level 1, level 2, and multi-level routing
- Prefix SIDs for host prefixes on loopback interfaces
- Adjacency SIDs for adjacencies
- MPLS penultimate hop popping (PHP) and explicit-null signaling

This task explains how to enable segment routing for IS-IS.

Before you begin

Your network must support the MPLS Cisco IOS XR software feature before you enable segment routing for IS-IS on your router.

Note You must enter the commands in the following task list on every IS-IS router in the traffic-engineered portion of your network.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router isis** *instance-id* **Example:** `RP/0/RP0/CPU0:router(config)#` **`router isis isp`**	Enables IS-IS routing for the specified routing instance, and places the router in router configuration mode. **Note** You can change the level of routing to be performed by a particular routing instance by using the **is-type** router configuration command.
Step 3	**address-family** { **ipv4** | **ipv6** } [**unicast**] **Example:** `RP/0/RP0/CPU0:router(config-isis)#` **`address-family ipv4 unicast`**	Specifies the IPv4 or IPv6 address family, and enters router address family configuration mode.
Step 4	**metric-style wide** [**level** { **1** | **2** }] **Example:** `RP/0/RP0/CPU0:router(config-isis-af)#` **`metric-style wide level 1`**	Configures a router to generate and accept only wide link metrics in the Level 1 area.
Step 5	**router-id loopback** *loopback interface used for prefix-sid* **Example:** `RP/0/RP0/CPU0:router(config-isis-af)#router-id loopback0`	Configures router ID for each address-family (IPv4/IPv6). IS-IS advertises the router ID in TLVs 134 (for IPv4 address family) and 140 (for IPv6 address family). Required when traffic engineering is used.
Step 6	**segment-routing mpls** **Example:** `RP/0/RP0/CPU0:router(config-isis-af)#` **`segment-routing mpls`**	Segment routing is enabled by the following actions: • MPLS forwarding is enabled on all interfaces where IS-IS is active. • All known prefix-SIDs in the forwarding plain are programmed, with the prefix-SIDs advertised by remote routers or learned through local or remote mapping server. • The prefix-SIDs locally configured are advertised.
Step 7	**exit**	

	Command or Action	Purpose

	Example:
	`RP/0/RP0/CPU0:router(config-isis-af)# exit`
	`RP/0/RP0/CPU0:router(config-isis)# exit`	

Step 8	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

What to do next

Configure the prefix SID.

Configuring a Prefix-SID on the IS-IS Enabled Loopback Interface

A prefix segment identifier (SID) is associated with an IP prefix. The prefix SID is manually configured from the segment routing global block (SRGB) range of labels. A prefix SID is configured under the loopback interface with the loopback address of the node as the prefix. The prefix segment steers the traffic along the shortest path to its destination.

A prefix SID can be a node SID or an Anycast SID. A node SID is a type of prefix SID that identifies a specific node. An Anycast SID is a type of prefix SID that identifies a set of nodes, and is configured with n-flag clear. The set of nodes (Anycast group) is configured to advertise a shared prefix address and prefix SID. Anycast routing enables the steering of traffic toward multiple advertising nodes. Packets addressed to an Anycast address are forwarded to the topologically nearest nodes.

The prefix SID is globally unique within the segment routing domain.

This task explains how to configure prefix segment identifier (SID) index or absolute value on the IS-IS enabled Loopback interface.

Before you begin

Ensure that segment routing is enabled on the corresponding address family.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router isis** *instance-id* **Example:** `RP/0/RP0/CPU0:router(config)# router isis 1`	Enables IS-IS routing for the specified routing instance, and places the router in router configuration mode. - You can change the level of routing to be performed by a particular routing instance by using the **is-type** router configuration command.
Step 3	**interface Loopback** *instance* **Example:** `RP/0/RP0/CPU0:router(config-isis)# interface Loopback0`	Specifies the loopback interface and instance.
Step 4	**address-family** { **ipv4** | **ipv6** } [**unicast**] **Example:** The following is an example for ipv4 address family: `RP/0/RP0/CPU0:router(config-isis-if)# address-family ipv4 unicast`	Specifies the IPv4 or IPv6 address family, and enters router address family configuration mode.

Step 5	**prefix-sid** [**algorithm** *algorithm-number*] {**index** *SID-index* | **absolute** *SID-value*} [**n-flag-clear**] [**explicit-null**]
	Example:
	`RP/0/RP0/CPU0:router(config-isis-if-af)# prefix-sid index 1001`
	`RP/0/RP0/CPU0:router(config-isis-if-af)# prefix-sid absolute 17001`
		Configures the prefix-SID index or absolute value for the interface.
		Specify **algorithm** *algorithm-number* to configure SR Flexible Algorithm. See Enabling Segment Routing Flexible Algorithm, on page 155.
		Specify **index** *SID-index* for each node to create a prefix SID based on the lower boundary of the SRGB + the index.
		Specify **absolute** *SID-value* for each node to create a specific prefix SID within the SRGB.
		By default, the n-flag is set on the prefix-SID, indicating that it is a node SID. For specific prefix-SID (for example, Anycast prefix-SID), enter the `n-flag-clear` keyword. IS-IS does not set the `N` flag in the prefix-SID sub Type Length Value (TLV).

	Command or Action	Purpose
		To disable penultimate-hop-popping (PHP) and add explicit-Null label, enter `explicit-null` keyword. IS-IS sets the `E` flag in the prefix-SID sub TLV.
Step 6	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

Verify the prefix-SID configuration:

```
RP/0/RP0/CPU0:router# show isis database verbose

IS-IS 1 (Level-2) Link State Database
LSPID                 LSP Seq Num  LSP Checksum  LSP Holdtime  ATT/P/OL
router.00-00        * 0x0000039b   0xfc27        1079            0/0/0
  Area Address: 49.0001
  NLPID:        0xcc
  NLPID:        0x8e
  MT:           Standard (IPv4 Unicast)
  MT:           IPv6 Unicast                                     0/0/0
  Hostname:     router
  IP Address:   10.0.0.1
  IPv6 Address: 2001:0db8:1234::0a00:0001
  Router Cap:   10.0.0.1, D:0, S:0
    Segment Routing: I:1 V:1, SRGB Base: 16000 Range: 8000
    SR Algorithm:
      Algorithm: 0

<...>
  Metric: 0          IP-Extended 10.0.0.1/32
    Prefix-SID Index: 1001, Algorithm:0, R:0 N:1 P:0 E:0 V:0 L:0

<...>
```

What to do next

Configure the SR-TE policy.

Configuring an Adjacency SID

An adjacency SID (Adj-SID) is associated with an adjacency to a neighboring node. The adjacency SID steers the traffic to a specific adjacency. Adjacency SIDs have local significance and are only valid on the node that allocates them.

An adjacency SID can be allocated dynamically from the dynamic label range or configured manually from the segment routing local block (SRLB) range of labels.

Adjacency SIDs that are dynamically allocated do not require any special configuration, however there are some limitations:

- A dynamically allocated Adj-SID value is not known until it has been allocated, and a controller will not know the Adj-SID value until the information is flooded by the IGP.
- Dynamically allocated Adj-SIDs are not persistent and can be reallocated after a reload or a process restart.
- Each link is allocated a unique Adj-SID, so the same Adj-SID cannot be shared by multiple links.

Manually allocated Adj-SIDs are persistent over reloads and restarts. They can be provisioned for multiple adjacencies to the same neighbor or to different neighbors. You can specify that the Adj-SID is protected. If the Adj-SID is protected on the primary interface and a backup path is available, a backup path is installed. By default, manual Adj-SIDs are not protected.

Adjacency SIDs are advertised using the existing IS-IS Adj-SID sub-TLV. The S and P flags are defined for manually allocated Adj-SIDs.

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|F|B|V|L|S|P|   |
+-+-+-+-+-+-+-+-+
```

Table 1: Adjacency Segment Identifier (Adj-SID) Flags Sub-TLV Fields

Field	Description
S (Set)	This flag is set if the same Adj-SID value has been provisioned on multiple interfaces.
P (Persistent)	This flag is set if the Adj-SID is persistent (manually allocated).

Manually allocated Adj-SIDs are supported on point-to-point (P2P) interfaces.

This task explains how to configure an Adj-SID on an interface.

Before you begin

Ensure that segment routing is enabled on the corresponding address family.

Use the **show mpls label table detail** command to verify the SRLB range.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router isis** *instance-id* **Example:** `RP/0/RP0/CPU0:router(config)# router isis 1`	Enables IS-IS routing for the specified routing instance, and places the router in router configuration mode. • You can change the level of routing to be performed by a particular routing instance by using the **is-type** router configuration command.
Step 3	**interface** *type interface-path-id* **Example:** `RP/0/RP0/CPU0:router(config-isis)# interface GigabitEthernet0/0/0/7`	Specifies the interface and enters interface configuration mode.
Step 4	**point-to-point** **Example:** `RP/0/RP0/CPU0:router(config-isis-if)# point-to-point`	Specifies the interface is a point-to-point interface.
Step 5	**address-family** { **ipv4** | **ipv6** } [**unicast**] **Example:** The following is an example for ipv4 address family: `RP/0/RP0/CPU0:router(config-isis-if)# address-family ipv4 unicast`	Specifies the IPv4 or IPv6 address family, and enters router address family configuration mode.

Step 6	**adjacency-sid** {**index** *adj-SID-index* | **absolute** *adj-SID-value* } [**protected**]
	Example:
	`RP/0/RP0/CPU0:router(config-isis-if-af)# adjacency-sid index 10`
	`RP/0/RP0/CPU0:router(config-isis-if-af)# adjacency-sid absolute 15010`
		Configures the Adj-SID index or absolute value for the interface.
		Specify **index** *adj-SID-index* for each link to create an Ajd-SID based on the lower boundary of the SRLB + the index.
		Specify **absolute** *adj-SID-value* for each link to create a specific Ajd-SID within the SRLB.
		Specify if the Adj-SID is **protected**. For each primary path, if the Adj-SID is protected on the primary interface and a backup path is available, a backup path is installed. By default, manual Adj-SIDs are not protected.

	Command or Action	Purpose
Step 7	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

Verify the Adj-SID configuration:

```
RP/0/RP0/CPU0:router# show isis segment-routing label adjacency persistent
Mon Jun 12 02:44:07.085 PDT

IS-IS 1 Manual Adjacency SID Table

15010 AF IPv4
      GigabitEthernet0/0/0/3: IPv4, Protected 1/65/N, Active
      GigabitEthernet0/0/0/7: IPv4, Protected 2/66/N, Active

15100 AF IPv6
      GigabitEthernet0/0/0/3: IPv6, Not protected 255/255/N, Active
```

Verify the labels are added to the MPLS Forwarding Information Base (LFIB):

```
RP/0/RP0/CPU0:router# show mpls forwarding labels 15010
Mon Jun 12 02:50:12.172 PDT
Local  Outgoing    Prefix             Outgoing     Next Hop        Bytes
Label  Label       or ID              Interface                    Switched
------ ----------- ------------------ ------------ --------------- ------------
15010  Pop         SRLB (idx 10)      Gi0/0/0/3    10.0.3.3        0
       Pop         SRLB (idx 10)      Gi0/0/0/7    10.1.0.5        0
       16004       SRLB (idx 10)      Gi0/0/0/7    10.1.0.5        0            (!)
       16004       SRLB (idx 10)      Gi0/0/0/3    10.0.3.3        0            (!)
```

What to do next

Configure the SR-TE policy.

Manually Configure a Layer 2 Adjacency SID

Typically, an adjacency SID (Adj-SID) is associated with a Layer 3 adjacency to a neighboring node, to steer the traffic to a specific adjacency. If you have Layer 3 bundle interfaces, where multiple physical interfaces form a bundle interface, the individual Layer 2 bundle members are not visible to IGP; only the bundle interface is visible.

You can configure a Layer 2 Adj-SID for the individual Layer 2 bundle interfaces. This configuration allows you to track the availability of individual bundle member links and to verify the segment routing forwarding over the individual bundle member links, for Operational Administration and Maintenance (OAM) purposes.

A Layer 2 Adj-SID can be allocated dynamically or configured manually.

- IGP dynamically allocates Layer 2 Adj-SIDs from the dynamic label range for each Layer 2 bundle member. A dynamic Layer 2 Adj-SID is not persistent and can be reallocated as the Layer 3 bundle link goes up and down.
- Manually configured Layer 2 Adj-SIDs are persistent if the Layer 3 bundle link goes up and down. Layer 2 Adj-SIDs are allocated from the Segment Routing Local Block (SRLB) range of labels. However, if the configured value of Layer 2 Adj-SID does not fall within the available SRLB, a Layer 2 Adj-SID will not be programmed into forwarding information base (FIB).

Restrictions

- Adj-SID forwarding requires a next-hop, which can be either an IPv4 address or an IPv6 address, but not both. Therefore, manually configured Layer 2 Adj-SIDs are configured per address-family.
- Manually configured Layer 2 Adj-SID can be associated with only one Layer 2 bundle member link.
- A SID value used for Layer 2 Adj-SID cannot be shared with Layer 3 Adj-SID.
- SR-TE using Layer 2 Adj-SID is not supported.

This task explains how to configure a Layer 2 Adj-SID on an interface.

Before you begin

Ensure that segment routing is enabled on the corresponding address family.

Use the **show mpls label table detail** command to verify the SRLB range.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**segment-routing** **Example:** `RP/0/RP0/CPU0:Router(config)# **segment-routing**`	Enters segment routing configuration mode.
Step 3	**adjacency-sid** **Example:**	Enters adjacency SID configuration mode.

	Command or Action	Purpose

	`RP/0/RP0/CPU0:Router(config-sr)#`
	`adjacency-sid`	

Step 4	**interface** *type interface-path-id*
	Example:
	`RP/0/RP0/CPU0:Router(config-sr-adj)#`
	`interface GigabitEthernet0/0/0/3`
		Specifies the interface and enters interface configuration mode.

Step 5	**address-family** { **ipv4** | **ipv6** } [**unicast**]
	Example:
	`RP/0/RP0/CPU0:Router(config-sr-adj-intf)#`
	`address-family ipv4 unicast`
		Specifies the IPv4 or IPv6 address family, and enters router address family configuration mode.

Step 6	**l2-adjacency sid** {**index** *adj-SID-index* | **absolute** *adj-SID-value* } [**next-hop** { *ipv4_address* | *ipv6_address* }]
	Example:
	`RP/0/RP0/CPU0:Router(config-sr-adj-intf-af)#`
	`l2-adjacency sid absolute 15015 next-hop 10.1.1.4`
		Configures the Adj-SID index or absolute value for the interface.
		Specify **index** *adj-SID-index* for each link to create an Ajd-SID based on the lower boundary of the SRLB + the index.
		Specify **absolute** *adj-SID-value* for each link to create a specific Ajd-SID within the SRLB.
		For point-to-point interfaces, you are not required to specify a next-hop. However, if you do specify the next-hop, the Layer 2 Adj-SID will be used only if the specified next-hop matches the neighbor address.
		For LAN interfaces, you must configure the next-hop IPv4 or IPv6 address. If you do not configure the next-hop, the Layer 2 Adj-SID will not be used for LAN interface.

Step 7	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.
Step 8	**end**	

<table>
<tr><th></th><th>Command or Action</th><th>Purpose</th></tr>
<tr><td><b>Step 9</b></td><td><b>router isis</b> <i>instance-id</i>
<b>Example:</b>
RP/0/RP0/CPU0:Router(config)# <b>router isis isp</b></td><td>Enables IS-IS routing for the specified routing instance, and places the router in router configuration mode.</td></tr>
<tr><td><b>Step 10</b></td><td><b>address-family</b> { <b>ipv4</b> | <b>ipv6</b> } [<b>unicast</b>]
<b>Example:</b>
RP/0/RP0/CPU0:Router(config-isis)# <b>address-family ipv4 unicast</b></td><td>Specifies the IPv4 or IPv6 address family, and enters router address family configuration mode.</td></tr>
<tr><td><b>Step 11</b></td><td><b>segment-routing bundle-member-adj-sid</b>
<b>Example:</b>
RP/0/RP0/CPU0:Router(config-isis-af)# <b>segment-routing bundle-member-adj-sid</b></td><td>Programs the dynamic Layer 2 Adj-SIDs, and advertises both manual and dynamic Layer 2 Adj-SIDs.
<b>Note</b> This command is not required to program manual L2 Adj-SID, but is required to program the dynamic Layer 2 Adj-SIDs and to advertise both manual and dynamic Layer 2 Adj-SIDs.</td></tr>
</table>

Verify the configuration:

```
Router# show mpls forwarding detail | i "Pop|Outgoing Interface|Physical Interface"
Tue Jun 20 06:53:51.876 PDT
. . .
15001  Pop         SRLB (idx 1)      BE1          10.1.1.4        0
     Outgoing Interface: Bundle-Ether1 (ifhandle 0x000000b0)
     Physical Interface: GigabitEthernet0/0/0/3 (ifhandle 0x000000b0)


Router# show running-config segment-routing
Tue Jun 20 07:14:25.815 PDT
segment-routing
 adjacency-sid
  interface GigabitEthernet0/0/0/3
   address-family ipv4 unicast
    l2-adjacency-sid absolute 15015
   !
  !
 !
!
```

Configuring Bandwidth-Based Local UCMP

Bandwidth-based local Unequal Cost Multipath (UCMP) allows you to enable UCMP functionality locally between Equal Cost Multipath (ECMP) paths based on the bandwidth of the local links.

Bandwidth-based local UCMP is performed for prefixes, segment routing Adjacency SIDs, and Segment Routing label cross-connects installed by IS-IS, and is supported on any physical or virtual interface that has a valid bandwidth.

For example, if the capacity of a bundle interface changes due to the link or line card up/down event, traffic continues to use the affected bundle interface regardless of the available provisioned bundle members. If some bundle members were not available due to the failure, this behavior could cause the traffic to overload the bundle interface. To address the bundle capacity changes, bandwidth-based local UCMP uses the bandwidth of the local links to load balance traffic when bundle capacity changes.

Before you begin

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router isis** *instance-id* **Example:** `RP/0/RP0/CPU0:router(config)# router isis 1`	Enables IS-IS routing for the specified routing instance, and places the router in router configuration mode. You can change the level of routing to be performed by a particular routing instance by using the **is-type** router configuration command.
Step 3	**address-family** { **ipv4** | **ipv6** } [**unicast**] **Example:** The following is an example for ipv4 address family: `RP/0/RP0/CPU0:router(config-isis)# address-family ipv4 unicast`	Specifies the IPv4 or IPv6 address family, and enters IS-IS address family configuration mode.
Step 4	**apply-weight ecmp-only bandwidth** **Example:** `RP/0/RP0/CPU0:router(config-isis-af)# apply-weight ecmp-only bandwidth`	Enables UCMP functionality locally between ECMP paths based on the bandwidth of the local links.
Step 5	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session.

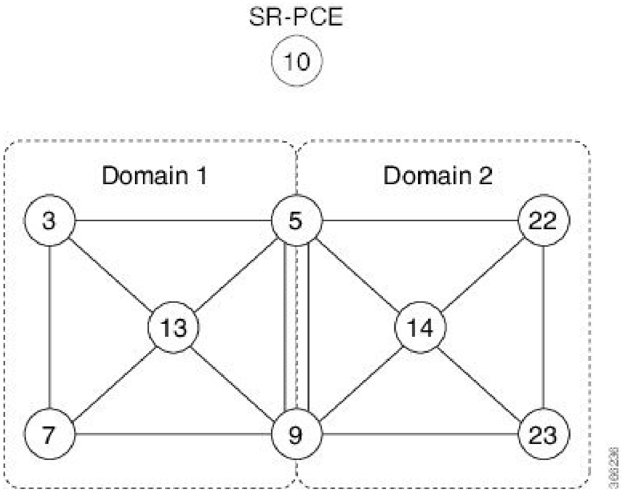
	Command or Action	Purpose
		• **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

IS-IS Multi-Domain Prefix SID and Domain Stitching: Example

IS-IS Multi-Domain Prefix SID and Domain Stitching allows you to configure multiple IS-IS instances on the same loopback interface for domain border nodes. You specify a loopback interface and prefix SID under multiple IS-IS instances to make the prefix and prefix SID reachable in different domains.

This example uses the following topology. Node 5 and 9 are border nodes between two IS-IS domains (Domain1 and Domain2). Node 10 is configured as the Segment Routing Path Computation Element (SR-PCE).

Figure 1: Multi-Domain Topology



Configure IS-IS Multi-Domain Prefix SID

Specify a loopback interface and prefix SID under multiple IS-IS instances on each border node:

```
Example: Border Node 5
router isis Domain1
 interface Loopback0
  address-family ipv4 unicast
   prefix-sid absolute 16005

router isis Domain2
 interface Loopback0
  address-family ipv4 unicast
   prefix-sid absolute 16005
```

```
Example: Border Node 9
router isis Domain1
 interface Loopback0
  address-family ipv4 unicast
   prefix-sid absolute 16009

router isis Domain2
 interface Loopback0
  address-family ipv4 unicast
   prefix-sid absolute 16009
```

Border nodes 5 and 9 each run two IS-IS instances (Domain1 and Domain2) and advertise their Loopback0 prefix and prefix SID in both domains.

Nodes in both domains can reach the border nodes by using the same prefix and prefix SID. For example, Node 3 and Node 22 can reach Node 5 using prefix SID 16005.

Configure Common Router ID

On each border node, configure a common TE router ID under each IS-IS instance:

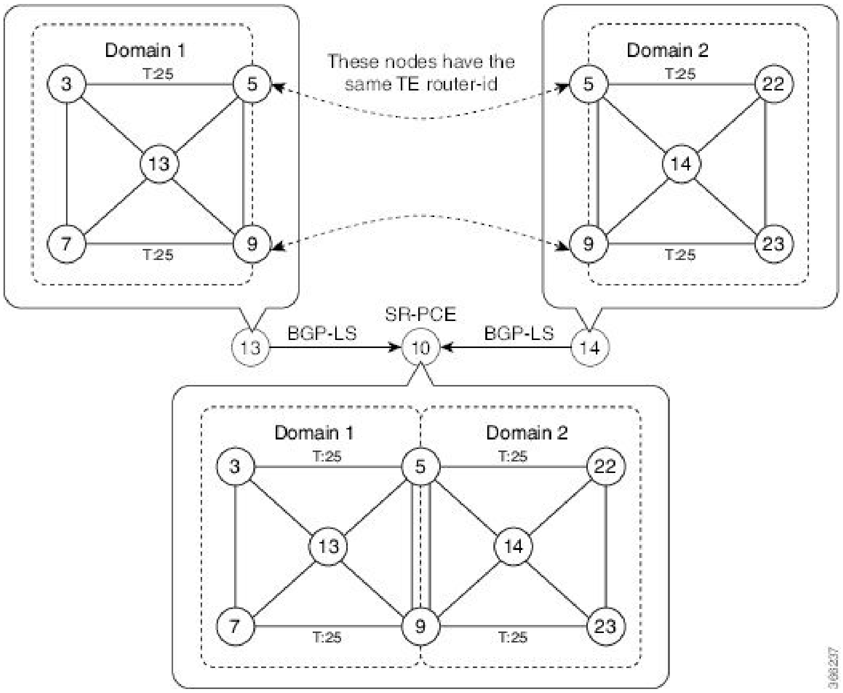
```
Example: Border Node 5
router isis Domain1
 address-family ipv4 unicast
  router-id loopback0

router isis Domain2
 address-family ipv4 unicast
  router-id loopback0
```

```
Example: Border Node 9
router isis Domain1
 address-family ipv4 unicast
  router-id loopback0

router isis Domain2
 address-family ipv4 unicast
  router-id loopback0
```

Distribute IS-IS Link-State Data



Configure BGP Link-state (BGP-LS) on Node 13 and Node 14 to report their local domain to Node 10:

```
Example: Node 13
router isis Domain1
 distribute link-state instance-id instance-id
```

```
Example: Node 14
router isis Domain2
 distribute link-state instance-id instance-id
```

Link-state ID starts from 32. One ID is required per IGP domain. Different domain IDs are essential to identify that the SR-TE TED belongs to a particular IGP domain.

Nodes 13 and 14 each reports its local domain in BGP-LS to Node 10.

Node 10 identifies the border nodes (Nodes 5 and 9) by their common advertised TE router ID, then combines (stitches) the domains on these border nodes for end-to-end path computations.

CHAPTER 4

Configure Segment Routing for OSPF Protocol

Open Shortest Path First (OSPF) is an Interior Gateway Protocol (IGP) developed by the OSPF working group of the Internet Engineering Task Force (IETF). Designed expressly for IP networks, OSPF supports IP subnetting and tagging of externally derived routing information. OSPF also allows packet authentication and uses IP multicast when sending and receiving packets.

This module provides the configuration information to enable segment routing for OSPF.

Note For additional information on implementing OSPF on your , see the *Implementing OSPF* module in the .

Enabling Segment Routing for OSPF Protocol

Segment routing on the OSPF control plane supports the following:

- OSPFv2 control plane
- Multi-area
- IPv4 prefix SIDs for host prefixes on loopback interfaces
- Adjacency SIDs for adjacencies
- MPLS penultimate hop popping (PHP) and explicit-null signaling

This section describes how to enable segment routing MPLS and MPLS forwarding in OSPF. Segment routing can be configured at the instance, area, or interface level.

Before you begin

Your network must support the MPLS Cisco IOS XR software feature before you enable segment routing for OSPF on your router.

Note You must enter the commands in the following task list on every OSPF router in the traffic-engineered portion of your network.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router ospf** *process-name* **Example:** `RP/0/RP0/CPU0:router(config)# router ospf 1`	Enables OSPF routing for the specified routing process and places the router in router configuration mode.
Step 3	**segment-routing mpls** **Example:** `RP/0/RP0/CPU0:router(config-ospf)# segment-routing mpls`	Enables segment routing using the MPLS data plane on the routing process and all areas and interfaces in the routing process. Enables segment routing fowarding on all interfaces in the routing process and installs the SIDs received by OSPF in the forwarding table.
Step 4	**area** *area* **Example:** `RP/0/RP0/CPU0:router(config-ospf)# area 0`	Enters area configuration mode.
Step 5	**segment-routing mpls** **Example:** `RP/0/RP0/CPU0:router(config-ospf-ar)# segment-routing mpls`	(Optional) Enables segment routing using the MPLS data plane on the area and all interfaces in the area. Enables segment routing fowarding on all interfaces in the area and installs the SIDs received by OSPF in the forwarding table.

Step 6	**exit**
	Example:
	`RP/0/RP0/CPU0:router(config-ospf-ar)# exit`
	`RP/0/RP0/CPU0:router(config-ospf)# exit`	

Step 7	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions:

	Command or Action	Purpose
		• **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

What to do next

Configure the prefix SID.

Configuring a Prefix-SID on the OSPF-Enabled Loopback Interface

A prefix segment identifier (SID) is associated with an IP prefix. The prefix SID is manually configured from the segment routing global block (SRGB) range of labels. A prefix SID is configured under the loopback interface with the loopback address of the node as the prefix. The prefix segment steers the traffic along the shortest path to its destination.

A prefix SID can be a node SID or an Anycast SID. A node SID is a type of prefix SID that identifies a specific node. An Anycast SID is a type of prefix SID that identifies a set of nodes, and is configured with n-flag clear. The set of nodes (Anycast group) is configured to advertise a shared prefix address and prefix SID. Anycast routing enables the steering of traffic toward multiple advertising nodes. Packets addressed to an Anycast address are forwarded to the topologically nearest nodes.

The prefix SID is globally unique within the segment routing domain.

This task describes how to configure prefix segment identifier (SID) index or absolute value on the OSPF-enabled Loopback interface.

Before you begin

Ensure that segment routing is enabled on an instance, area, or interface.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.

	Command or Action	Purpose
Step 2	**router ospf** *process-name* **Example:** `RP/0/RP0/CPU0:router(config)# router ospf 1`	Enables OSPF routing for the specified routing process, and places the router in router configuration mode.
Step 3	**area** *value* **Example:** `RP/0/RP0/CPU0:router(config-ospf)# area 0`	Enters area configuration mode.
Step 4	**interface Loopback** *interface-instance* **Example:** `RP/0/RP0/CPU0:router(config-ospf-ar)# interface loopback 0`	Specifies the loopback interface and instance.

Step 5	**prefix-sid**{**index** *SID-index* | **absolute** *SID-value* } [**n-flag-clear**] [**explicit-null**]
	Example:
	`RP/0/RP0/CPU0:router(config-ospf-ar)# prefix-sid index 1001`
	`RP/0/RP0/CPU0:router(config-ospf-ar)# prefix-sid absolute 17001`
		Configures the prefix-SID index or absolute value for the interface.
		Specify **index** *SID-index* for each node to create a prefix SID based on the lower boundary of the SRGB + the index.
		Specify **absolute** *SID-value* for each node to create a specific prefix SID within the SRGB.
		By default, the n-flag is set on the prefix-SID, indicating that it is a node SID. For specific prefix-SID (for example, Anycast prefix-SID), enter the `n-flag-clear` keyword. OSPF does not set the `N` flag in the prefix-SID sub Type Length Value (TLV).
		To disable penultimate-hop-popping (PHP) and add an explicit-Null label, enter the `explicit-null` keyword. OSPF sets the `E` flag in the prefix-SID sub TLV.

Step 6	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes.

	Command or Action	Purpose
		- **Cancel** —Remains in the configuration session, without committing the configuration changes.

Verify the prefix-SID configuration:

```
RP/0/RP0/CPU0:router# show ospf database opaque-area 7.0.0.1 self-originate
 OSPF Router with ID (10.0.0.1) (Process ID 1)
                Type-10 Opaque Link Area Link States (Area 0)
<...>
    Extended Prefix TLV: Length: 20
      Route-type: 1
      AF        : 0
      Flags     : 0x40
      Prefix    : 10.0.0.1/32

      SID sub-TLV: Length: 8
        Flags     : 0x0
        MTID      : 0
        Algo      : 0
        SID Index : 1001
```

Configuring an Adjacency SID

An adjacency SID (Adj-SID) is associated with an adjacency to a neighboring node. The adjacency SID steers the traffic to a specific adjacency. Adjacency SIDs have local significance and are only valid on the node that allocates them.

An adjacency SID can be allocated dynamically from the dynamic label range or configured manually from the segment routing local block (SRLB) range of labels.

Adjacency SIDs that are dynamically allocated do not require any special configuration, however there are some limitations:

- A dynamically allocated Adj-SID value is not known until it has been allocated, and a controller will not know the Adj-SID value until the information is flooded by the IGP.
- Dynamically allocated Adj-SIDs are not persistent and can be reallocated after a reload or a process restart.
- Each link is allocated a unique Adj-SID, so the same Adj-SID cannot be shared by multiple links.

Manually allocated Adj-SIDs are persistent over reloads and restarts. They can be provisioned for multiple adjacencies to the same neighbor or to different neighbors. You can specify that the Adj-SID is protected. If the Adj-SID is protected on the primary interface and a backup path is available, a backup path is installed. By default, manual Adj-SIDs are not protected.

Adjacency SIDs are advertised using the existing OSPF Adj-SID sub-TLV. The P-flag is defined for manually allocated Adj-SIDs.

```
 0 1 2 3 4 5 6 7
```

```
+-+-+-+-+-+-+-+-+
|B|V|L|G|P|     |
+-+-+-+-+-+-+-+-+
```

Table 2: Adjacency Segment Identifier (Adj-SID) Flags Sub-TLV Fields

Field	Description
P (Persistent)	This flag is set if the Adj-SID is persistent (manually allocated).

This task explains how to configure an Adj-SID on an interface.

Before you begin

Ensure that segment routing is enabled on the corresponding address family.

Use the **show mpls label table detail** command to verify the SRLB range.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router ospf** *process-name* **Example:** `RP/0/RP0/CPU0:router(config)# router ospf 1`	Enables OSPF routing for the specified routing instance, and places the router in router configuration mode.
Step 3	**area** *area* **Example:** `RP/0/RP0/CPU0:router(config-ospf)# area 0`	Enters area configuration mode.
Step 4	**interface** *type interface-path-id* **Example:** `RP/0/RP0/CPU0:router(config-ospf-ar)# interface HundredGigE0/0/0/1`	Specifies the interface and enters interface configuration mode.
Step 5	**adjacency-sid** {**index** *adj-SID-index* | **absolute** *adj-SID-value*} [**protected**] **Example:** `RP/0/RP0/CPU0:router(config-config-ospf-ar-if)# adjacency-sid index 10`	Configures the Adj-SID index or absolute value for the interface. Specify **index** *adj-SID-index* for each link to create an Ajd-SID based on the lower boundary of the SRLB + the index. Specify **absolute** *adj-SID-value* for each link to create a specific Ajd-SID within the SRLB.

	Command or Action	Purpose
	`RP/0/RP0/CPU0:router(config-config-ospf-ar-if)# adjacency-sid absolute 15010`	Specify if the Adj-SID is **protected**. For each primary path, if the Adj-SID is protected on the primary interface and a backup path is available, a backup path is installed. By default, manual Adj-SIDs are not protected.
Step 6	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

What to do next

Configure the SR-TE policy.

Protected Adjacency SID Backup Timer

OSPF advertises a protected adjacency SID for an adjacency when a backup path is available. Primary and backup paths are programmed into the label switching database (LSD) as rewrites.

When an adjacency goes down, OSPF stops advertising the protected adjacency SID immediately, and the backup path is promoted and installed as LSD rewrite. After a specified amount of time, the LSD rewrite is deleted. If the installed path fails again, the protection ends there and traffic through the original protected adjacency SID is permanently lost.

The Protected Adjacency SID Backup Timer provides a configurable maintenance time period. During this time period, OSPF updates the LSD rewrite with primary and backup (if available) paths to the neighbor upon topology changes.

Configuration

Use the **segment-routing protected-adjacency-sid-delay** command in OSPF configuration mode. The range is from 30 to 3600 seconds; the default is 900 seconds (15 min).

```
Router(config)# router ospf 1
Router(config-ospf)# segment-routing protected-adjacency-sid-delay 360
```

Running Configuration

```
router ospf 1
 segment-routing protected-adjacency-sid-delay 360
 area 1
  interface HundredGigE0/0/0/1
   fast-reroute per-prefix
   fast-reroute per-prefix ti-lfa enable
  !
 !
!
```

CHAPTER 5

Configure Segment Routing for BGP

Border Gateway Protocol (BGP) is an Exterior Gateway Protocol (EGP) that allows you to create loop-free inter-domain routing between autonomous systems. An autonomous system is a set of routers under a single technical administration. Routers in an autonomous system can use multiple Interior Gateway Protocols (IGPs) to exchange routing information inside the autonomous system and an EGP to route packets outside the autonomous system.

This module provides the configuration information used to enable Segment Routing for BGP.

Note For additional information on implementing BGP on your router , see the *Implementing BGP* module in the *Routing Configuration Guide for Cisco NCS 560 Series Routers*.

Segment Routing for BGP

In a traditional BGP-based data center (DC) fabric, packets are forwarded hop-by-hop to each node in the autonomous system. Traffic is directed only along the external BGP (eBGP) multipath ECMP. No traffic engineering is possible.

In an MPLS-based DC fabric, the eBGP sessions between the nodes exchange BGP labeled unicast (BGP-LU) network layer reachability information (NLRI). An MPLS-based DC fabric allows any leaf (top-of-rack or border router) in the fabric to communicate with any other leaf using a single label, which results in higher packet forwarding performance and lower encapsulation overhead than traditional BGP-based DC fabric. However, since each label value might be different for each hop, an MPLS-based DC fabric is more difficult to troubleshoot and more complex to configure.

BGP has been extended to carry segment routing prefix-SID index. BGP-LU helps each node learn BGP prefix SIDs of other leaf nodes and can use ECMP between source and destination. Segment routing for BGP simplifies the configuration, operation, and troubleshooting of the fabric. With segment routing for BGP, you can enable traffic steering capabilities in the data center using a BGP prefix SID.

Configure BGP Prefix Segment Identifiers

Segments associated with a BGP prefix are known as BGP prefix SIDs. The BGP prefix SID is global within a segment routing or BGP domain. It identifies an instruction to forward the packet over the ECMP-aware best-path computed by BGP to the related prefix. The BGP prefix SID is manually configured from the segment routing global block (SRGB) range of labels.

Each BGP speaker must be configured with an SRGB using the **segment-routing global-block** command. See the About the Segment Routing Global Block section for information about the SRGB.

Note Because the values assigned from the range have domain-wide significance, we recommend that all routers within the domain be configured with the same range of values.

To assign a BGP prefix SID, first create a routing policy using the **set label-index** *index* attribute, then associate the index to the node.

Example

The following example shows how to configure the SRGB, create a BGP route policy using a $SID parameter and **set label-index** attribute, and then associate the prefix-SID index to the node.

```
RP/0/RP0/CPU0:router(config)# segment-routing global-block 16000 23999

RP/0/RP0/CPU0:router(config)# route-policy SID($SID)
RP/0/RP0/CPU0:router(config-rpl)# set label-index $SID
RP/0/RP0/CPU0:router(config-rpl)# end policy

RP/0/RP0/CPU0:router(config)# router bgp 1
RP/0/RP0/CPU0:router(config-bgp)# bgp router-id 10.1.1.1
RP/0/RP0/CPU0:router(config-bgp)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-bgp-af)# network 10.1.1.3/32 route-policy SID(3)
RP/0/RP0/CPU0:router(config-bgp-af)# allocate-label all
RP/0/RP0/CPU0:router(config-bgp-af)# commit
RP/0/RP0/CPU0:router(config-bgp-af)# end


RP/0/RP0/CPU0:router# show bgp 10.1.1.3/32
BGP routing table entry for 10.1.1.3/32
Versions:
  Process           bRIB/RIB  SendTblVer
  Speaker                 74          74
    Local Label: 16003
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
    99.3.21.3 from 99.3.21.3 (10.1.1.3)
      Received Label 3
      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: 3
```

Segment Routing Egress Peer Engineering

Segment routing egress peer engineering (EPE) uses a controller to instruct an ingress provider edge, or a content source (node) within the segment routing domain, to use a specific egress provider edge (node) and a specific external interface to reach a destination. BGP peer SIDs are used to express source-routed inter-domain paths.

Below are the BGP-EPE peering SID types:

- PeerNode SID—To an eBGP peer. Pops the label and forwards the traffic on any interface to the peer.
- PeerAdjacency SID—To an eBGP peer via interface. Pops the label and forwards the traffic on the related interface.

The controller learns the BGP peer SIDs and the external topology of the egress border router through BGP-LS EPE routes. The controller can program an ingress node to steer traffic to a destination through the egress node and peer node using BGP labeled unicast (BGP-LU).

EPE functionality is only required at the EPE egress border router and the EPE controller.

Configure Segment Routing Egress Peer Engineering

This task explains how to configure segment routing EPE on the EPE egress node.

Procedure

	Command or Action	Purpose
Step 1	**router bgp** *as-number* **Example:** `RP/0/RP0/CPU0:router(config)# router bgp 1`	Specifies the BGP AS number and enters the BGP configuration mode, allowing you to configure the BGP routing process.
Step 2	**neighbor** *ip-address* **Example:** `RP/0/RP0/CPU0:router(config-bgp)# neighbor 192.168.1.3`	Places the router in neighbor configuration mode for BGP routing and configures the neighbor IP address as a BGP peer.
Step 3	**remote-as** *as-number* **Example:** `RP/0/RP0/CPU0:router(config-bgp-nbr)# remote-as 3`	Creates a neighbor and assigns a remote autonomous system number to it.

	Command or Action	Purpose
Step 4	**egress-engineering** **Example:** `RP/0/RP0/CPU0:router(config-bgp-nbr)# egress-engineering`	Configures the egress node with EPE for the eBGP peer.

Step 5	**exit**
	Example:
	`RP/0/RP0/CPU0:router(config-bgp-nbr)# exit`
	`RP/0/RP0/CPU0:router(config-bgp)# exit`
	`RP/0/RP0/CPU0:router(config)#`	

Step 6	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

Example

Running Config:

```
router bgp 1
 neighbor 192.168.1.3
  remote-as 3
  egress-engineering
  !
 !
!
```

Configure BGP Link-State

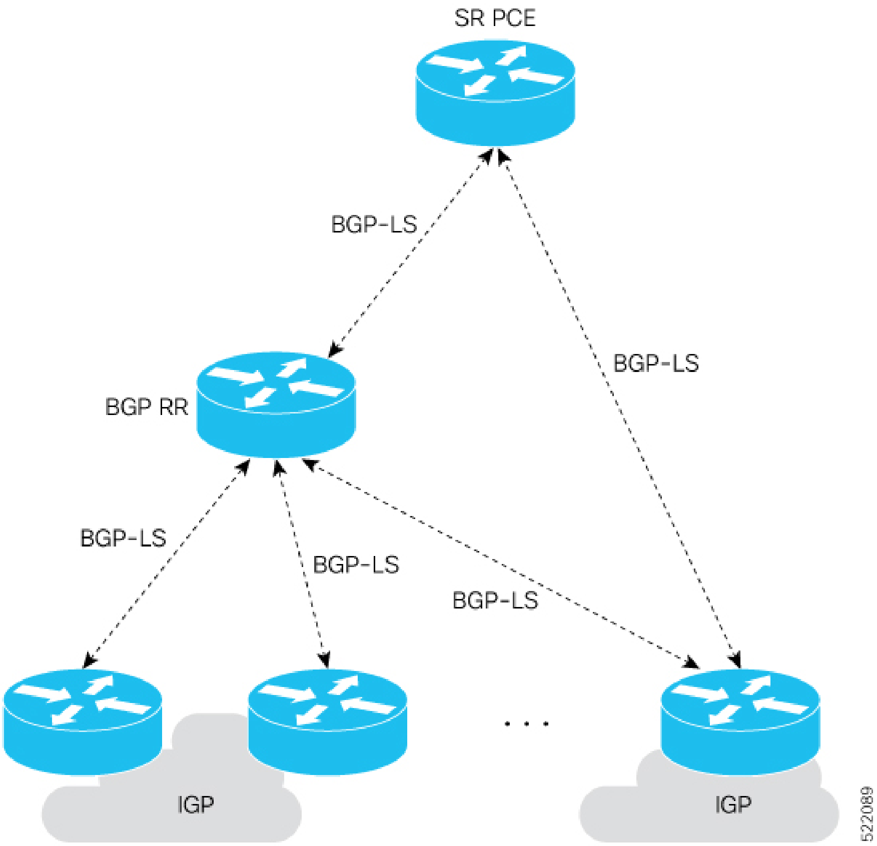
BGP Link-State (LS) is an Address Family Identifier (AFI) and Sub-address Family Identifier (SAFI) originally defined to carry interior gateway protocol (IGP) link-state information through BGP. The BGP Network Layer Reachability Information (NLRI) encoding format for BGP-LS and a new BGP Path Attribute called the

BGP-LS attribute are defined in RFC7752. The identifying key of each Link-State object, namely a node, link, or prefix, is encoded in the NLRI and the properties of the object are encoded in the BGP-LS attribute.

The BGP-LS Extensions for Segment Routing are documented in RFC9085.

BGP-LS applications like an SR Path Computation Engine (SR-PCE) can learn the SR capabilities of the nodes in the topology and the mapping of SR segments to those nodes. This can enable the SR-PCE to perform path computations based on SR-TE and to steer traffic on paths different from the underlying IGP-based distributed best-path computation.

The following figure shows a typical deployment scenario. In each IGP area, one or more nodes (BGP speakers) are configured with BGP-LS. These BGP speakers form an iBGP mesh by connecting to one or more route-reflectors. This way, all BGP speakers (specifically the route-reflectors) obtain Link-State information from all IGP areas (and from other ASes from eBGP peers).



Usage Guidelines and Limitations

- BGP-LS supports IS-IS and OSPFv2.
- The identifier field of BGP-LS (referred to as the Instance-ID) identifies the IGP routing domain where the NLRI belongs. The NLRIs representing link-state objects (nodes, links, or prefixes) from the same IGP routing instance must use the same Instance-ID value.
- When there is only a single protocol instance in the network where BGP-LS is operational, we recommend configuring the Instance-ID value to **0**.
- Assign consistent BGP-LS Instance-ID values on all BGP-LS Producers within a given IGP domain.

- NLRIs with different Instance-ID values are considered to be from different IGP routing instances.
- Unique Instance-ID values must be assigned to routing protocol instances operating in different IGP domains. This allows the BGP-LS Consumer (for example, SR-PCE) to build an accurate segregated multi-domain topology based on the Instance-ID values, even when the topology is advertised via BGP-LS by multiple BGP-LS Producers in the network.
- If the BGP-LS Instance-ID configuration guidelines are not followed, a BGP-LS Consumer may see duplicate link-state objects for the same node, link, or prefix when there are multiple BGP-LS Producers deployed. This may also result in the BGP-LS Consumers getting an inaccurate network-wide topology.
- The following table defines the supported extensions to the BGP-LS address family for carrying IGP topology information (including SR information) via BGP. For more information on the BGP-LS TLVs, refer to Border Gateway Protocol - Link State (BGP-LS) Parameters.

Table 3: IOS XR Supported BGP-LS Node Descriptor, Link Descriptor, Prefix Descriptor, and Attribute TLVs

TLV Code Point	Description	Produced by IS-IS	Produced by OSPFv2	Produced by BGP
256	Local Node Descriptors	X	X	—
257	Remote Node Descriptors	X	X	—
258	Link Local/Remote Identifiers	X	X	—
259	IPv4 interface address	X	X	—
260	IPv4 neighbor address	X		
261	IPv6 interface address	X	—	—
262	IPv6 neighbor address	X	—	—
263	Multi-Topology ID	X	—	—
264	OSPF Route Type	—	X	—
265	IP Reachability Information	X	X	—
266	Node MSD TLV	X	X	—
267	Link MSD TLV	X	X	—
512	Autonomous System	—	—	X
513	BGP-LS Identifier	—	—	X
514	OSPF Area-ID	—	X	—
515	IGP Router-ID	X	X	—
516	BGP Router-ID TLV	—	—	X
517	BGP Confederation Member TLV	—	—	X
1024	Node Flag Bits	X	X	—
1026	Node Name	X	X	—
1027	IS-IS Area Identifier	X	—	—

TLV Code Point	Description	Produced by IS-IS	Produced by OSPFv2	Produced by BGP
1028	IPv4 Router-ID of Local Node	X	X	—
1029	IPv6 Router-ID of Local Node	X	—	—
1030	IPv4 Router-ID of Remote Node	X	X	—
1031	IPv6 Router-ID of Remote Node	X	—	—
1034	SR Capabilities TLV	X	X	—
1035	SR Algorithm TLV	X	X	—
1036	SR Local Block TLV	X	X	—
1039	Flex Algo Definition (FAD) TLV	X	X	—
1044	Flex Algorithm Prefix Metric (FAPM) TLV	X	X	—
1088	Administrative group (color)	X	X	—
1089	Maximum link bandwidth	X	X	—
1090	Max. reservable link bandwidth	X	X	—
1091	Unreserved bandwidth	X	X	—
1092	TE Default Metric	X	X	—
1093	Link Protection Type	X	X	—
1094	MPLS Protocol Mask	X	X	—
1095	IGP Metric	X	X	—
1096	Shared Risk Link Group	X	X	—
1099	Adjacency SID TLV	X	X	—
1100	LAN Adjacency SID TLV	X	X	—
1101	PeerNode SID TLV	—	—	X
1102	PeerAdj SID TLV	—	—	X
1103	PeerSet SID TLV	—	—	X
1114	Unidirectional Link Delay TLV	X	X	—
1115	Min/Max Unidirectional Link Delay TLV	X	X	—
1116	Unidirectional Delay Variation TLV	X	X	—
1117	Unidirectional Link Loss	X	X	—
1118	Unidirectional Residual Bandwidth	X	X	—
1119	Unidirectional Available Bandwidth	X	X	—
1120	Unidirectional Utilized Bandwidth	X	X	—
1122	Application-Specific Link Attribute TLV	X	X	—

TLV Code Point	Description	Produced by IS-IS	Produced by OSPFv2	Produced by BGP
1152	IGP Flags	X	X	—
1153	IGP Route Tag	X	X	—
1154	IGP Extended Route Tag	X	—	—
1155	Prefix Metric	X	X	—
1156	OSPF Forwarding Address	—	X	—
1158	Prefix-SID	X	X	—
1159	Range	X	X	—
1161	SID/Label TLV	X	X	—
1170	Prefix Attribute Flags	X	X	—
1171	Source Router Identifier	X	—	—
1172	L2 Bundle Member Attributes TLV	X	—	—
1173	Extended Administrative Group	X	X	—

Exchange Link State Information with BGP Neighbor

The following example shows how to exchange link-state information with a BGP neighbor:

```
Router# configure
Router(config)# router bgp 1
Router(config-bgp)# neighbor 10.0.0.2
Router(config-bgp-nbr)# remote-as 1
Router(config-bgp-nbr)# address-family link-state link-state
Router(config-bgp-nbr-af)# exit
```

IGP Link-State Database Distribution

A given BGP node may have connections to multiple, independent routing domains. IGP link-state database distribution into BGP-LS is supported for both OSPF and IS-IS protocols in order to distribute this information on to controllers or applications that desire to build paths spanning or including these multiple domains.

To distribute IS-IS link-state data using BGP-LS, use the **distribute link-state** command in router configuration mode.

```
Router# configure
Router(config)# router isis isp
Router(config-isis)# distribute link-state instance-id 32
```

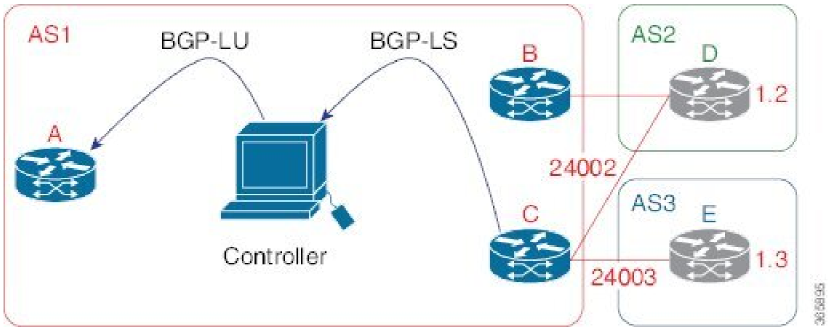
To distribute OSPFv2 link-state data using BGP-LS, use the **distribute link-state** command in router configuration mode.

```
Router# configure
Router(config)# router ospf 100
Router(config-ospf)# distribute link-state instance-id 32
```

Use Case: Configuring SR-EPE and BGP-LS

In the following figure, segment routing is enabled on autonomous system AS1 with ingress node A and egress nodes B and C. In this example, we configure EPE on egress node C.

Figure 2: Topology



Procedure

Step 1 Configure node C with EPE for eBGP peers D and E.

Example:

```
RP/0/RP0/CPU0:router_C(config)# router bgp 1
RP/0/RP0/CPU0:router_C(config-bgp)# neighbor 192.168.1.3
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# remote-as 3
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# description to E
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# egress-engineering
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# address-family ipv4 unicast
RP/0/RP0/CPU0:router_C(config-bgp-nbr-af)# route-policy bgp_in in
RP/0/RP0/CPU0:router_C(config-bgp-nbr-af)# route-policy bgp_out out
RP/0/RP0/CPU0:router_C(config-bgp-nbr-af)# exit
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# exit
RP/0/RP0/CPU0:router_C(config-bgp)# neighbor 192.168.1.2
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# remote-as 2
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# description to D
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# egress-engineering
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# address-family ipv4 unicast
RP/0/RP0/CPU0:router_C(config-bgp-nbr-af)# route-policy bgp_in in
RP/0/RP0/CPU0:router_C(config-bgp-nbr-af)# route-policy bgp_out out
RP/0/RP0/CPU0:router_C(config-bgp-nbr-af)# exit
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# exit
```

Step 2 Configure node C to advertise peer node SIDs to the controller using BGP-LS.

Example:

```
RP/0/RP0/CPU0:router_C(config-bgp)# neighbor 172.29.50.71
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# remote-as 1
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# description to EPE_controller
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# address-family link-state link-state
RP/0/RP0/CPU0:router_C(config-bgp-nbr)# exit
RP/0/RP0/CPU0:router_C(config-bgp)# exit
```

Step 3 Commit the configuration.

Example:

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

Step 4 Verify the configuration.

Example:

```
RP/0/RP0/CPU0:router_C# show bgp egress-engineering

 Egress Engineering Peer Set: 192.168.1.2/32 (10b87210)
     Nexthop: 192.168.1.2
     Version: 2, rn_version: 2
       Flags: 0x00000002
   Local ASN: 1
  Remote ASN: 2
   Local RID: 10.1.1.3
  Remote RID: 10.1.1.4
   First Hop: 192.168.1.2
        NHID: 3
       Label: 24002, Refcount: 3
     rpc_set: 10b9d408

 Egress Engineering Peer Set: 192.168.1.3/32 (10be61d4)
     Nexthop: 192.168.1.3
     Version: 3, rn_version: 3
       Flags: 0x00000002
   Local ASN: 1
  Remote ASN: 3
   Local RID: 10.1.1.3
  Remote RID: 10.1.1.5
   First Hop: 192.168.1.3
        NHID: 4
       Label: 24003, Refcount: 3
     rpc_set: 10be6250
```

The output shows that node C has allocated peer SIDs for each eBGP peer.

Example:

```
RP/0/RP0/CPU0:router_C# show mpls forwarding labels 24002 24003
Local  Outgoing    Prefix             Outgoing     Next Hop        Bytes
Label  Label       or ID              Interface                    Switched
------ ----------- ------------------ ------------ --------------- ------------
24002  Pop         No ID              Te0/0/0/1    192.168.1.2     0
24003  Pop         No ID              Te0/0/0/2    192.168.1.3     0
```

The output shows that node C installed peer node SIDs in the Forwarding Information Base (FIB).

Configure BGP Proxy Prefix SID

To support segment routing, Border Gateway Protocol (BGP) requires the ability to advertise a segment identifier (SID) for a BGP prefix. A BGP-Prefix-SID is the segment identifier of the BGP prefix segment in a segment routing network. BGP prefix SID attribute is a BGP extension to signal BGP prefix-SIDs. However, there may be routers which do not support BGP extension for segment routing. Hence, those routers also do not support BGP prefix SID attribute and an alternate approach is required.

BGP proxy prefix SID feature allows you to attach BGP prefix SID attributes for remote prefixes learnt from BGP labeled unicast (LU) neighbours which are not SR-capable and propagate them as SR prefixes. This allows an LSP towards non SR endpoints to use segment routing global block in a SR domain. Since BGP proxy prefix SID uses global label values it minimizes the use of limited resources such as ECMP-FEC and provides more scalability for the networks.

BGP proxy prefix SID feature is implemented using the segment routing mapping server (SRMS). SRMS allows the user to configure SID mapping entries to specify the prefix-SIDs for the prefixes. The mapping server advertises the local SID-mapping policy to the mapping clients. BGP acts as a client of the SRMS and uses the mapping policy to calculate the prefix-SIDs.

Configuration Example:

This example shows how to configure the BGP proxy prefix SID feature for the segment routing mapping server.

```
RP/0/RSP0/CPU0:router(config)# segment-routing
RP/0/RSP0/CPU0:router(config-sr)# mapping-server
RP/0/RSP0/CPU0:router(config-sr-ms)# prefix-sid-map
RP/0/RSP0/CPU0:router(config-sr-ms-map)# address-family ipv4
RP/0/RSP0/CPU0:router(config-sr-ms-map-af)# 10.1.1.1/32 10 range 200
RP/0/RSP0/CPU0:router(config-sr-ms-map-af)# 192.168.64.1/32 400 range 300
```

This example shows how to configure the BGP proxy prefix SID feature for the segment-routing mapping client.

```
RP/0/RSP0/CPU0:router(config)# router bgp 1
RP/0/RSP0/CPU0:router(config-bgp)# address-family ip4 unicast
RP/0/RSP0/CPU0:router(config-bgp-af)# segment-routing prefix-sid-map
```

Verification

These examples show how to verify the BGP proxy prefix SID feature.

```
RP/0/RSP0/CPU0:router# show segment-routing mapping-server prefix-sid-map ipv4 detail
Prefix
10.1.1.1/32
    SID Index:      10
    Range:          200
    Last Prefix:    10.1.1.200/32
    Last SID Index: 209
    Flags:
Number of mapping entries: 1


RP/0/RSP0/CPU0:router# show bgp ipv4 labeled-unicast 192.168.64.1/32

BGP routing table entry for 192.168.64.1/32
Versions:
  Process           bRIB/RIB  SendTblVer
  Speaker                117         117
  Local Label: 16400
Last Modified: Oct 25 01:02:28.562 for 00:11:45Paths: (2 available, best #1)
 Advertised to peers (in unique update groups):
   201.1.1.1
 Path #1: Received by speaker 0  Advertised to peers (in unique update groups):
    201.1.1.1
  Local
   20.0.101.1 from 20.0.101.1 (20.0.101.1)      Received Label 61
   Origin IGP, localpref 100, valid, internal, best, group-best, multipath, labeled-unicast

   Received Path ID 0, Local Path ID 0, version 117
  Prefix SID Attribute Size: 7
  Label Index: 1

 RP/0/RSP0/CPU0:router# show route ipv4 unicast 192.68.64.1/32 detail

Routing entry for 192.168.64.1/32
  Known via "bgp 65000", distance 200, metric 0, [ei]-bgp, labeled SR, type internal
  Installed Oct 25 01:02:28.583 for 00:20:09
  Routing Descriptor Blocks
    20.0.101.1, from 20.0.101.1, BGP multi path
      Route metric is 0
      Label: 0x3d (61)
      Tunnel ID: None
      Binding Label: None
      Extended communities count: 0
      NHID:0x0(Ref:0)
   Route version is 0x6 (6)
  Local Label: 0x3e81 (16400)
  IP Precedence: Not Set
  QoS Group ID: Not Set
  Flow-tag: Not Set
  Fwd-class: Not Set
  Route Priority: RIB_PRIORITY_RECURSIVE (12) SVD Type RIB_SVD_TYPE_LOCAL
  Download Priority 4, Download Version 242
  No advertising protos.


RP/0/RSP0/CPU0:router# show cef ipv4 192.168.64.1/32 detail
192.168.64.1/32, version 476, labeled SR, drop adjacency, internal 0x5000001 0x80 (ptr
0x71c42b40) [1], 0x0 (0x71c11590), 0x808 (0x722b91e0)
 Updated Oct 31 23:23:48.733
 Prefix Len 32, traffic index 0, precedence n/a, priority 4
 Extensions: context-label:16400
  gateway array (0x71ae7e78) reference count 3, flags 0x7a, source rib (7), 0 backups
                [2 type 5 flags 0x88401 (0x722eb450) ext 0x0 (0x0)]
  LW-LDI[type=5, refc=3, ptr=0x71c11590, sh-ldi=0x722eb450]
  gateway array update type-time 3 Oct 31 23:49:11.720
 LDI Update time Oct 31 23:23:48.733
 LW-LDI-TS Oct 31 23:23:48.733
   via 20.0.101.1/32, 0 dependencies, recursive, bgp-ext [flags 0x6020]
    path-idx 0 NHID 0x0 [0x7129a294 0x0]
    recursion-via-/32
    unresolved
     local label 16400
     labels imposed {ExpNullv6}



RP/0/RSP0/CPU0:router# show bgp labels
BGP router identifier 2.1.1.1, local AS number 65000
BGP generic scan interval 60 secs
Non-stop routing is enabled
BGP table state: Active
Table ID: 0xe0000000   RD version: 245
BGP main routing table version 245
BGP NSR Initial initsync version 16 (Reached)
BGP NSR/ISSU Sync-Group versions 245/0
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
*>i10.1.1.1/32        10.1.1.1        3               16010
*> 2.1.1.1/32         0.0.0.0         nolabel         3
*> 192.68.64.1/32     20.0.101.1      2               16400
*> 192.68.64.2/32     20.0.101.1      2               16401
```

CHAPTER 6

Configure SR-TE Policies

This module provides information about segment routing for traffic engineering (SR-TE) policies, how to configure SR-TE policies, and how to steer traffic into an SR-TE policy.

SR-TE Policy Overview

Segment routing for traffic engineering (SR-TE) uses a “policy” to steer traffic through the network. An SR-TE policy path is expressed as a list of segments that specifies the path, called a segment ID (SID) list. Each segment 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 SR-TE policy, the SID list is pushed on the packet by the head-end. The rest of the network executes the instructions embedded in the SID list.

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

- Head-end – Where the SR-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 SR-TE policy

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

An SR-TE policy uses one or more candidate paths. A candidate path is a single segment list (SID-list) or a set of weighted SID-lists (for weighted equal cost multi-path [WECMP]). A candidate path is either dynamic or explicit. See *SR-TE Policy Path Types* section for more information.

Auto-Route Announce for SR-TE

Auto-route announce for SR-TE cannot handle LDP-over-SR-TE if the SR-TE terminates at an LDP mid-node.

Let us consider the following topology:

R1---R2---R3---R4---R5---R6

If there is an SR-TE route from R1 to R4, and an LDP prefix is learnt from R6, then auto-route announce will fail.

Autoroute Include

You can configure SR-TE policies with Autoroute Include to steer specific IGP (IS-IS, OSPF) prefixes, or all prefixes, over non-shortest paths and to divert the traffic for those prefixes on to the SR-TE policy.

The **autoroute include all** option applies Autoroute Announce functionality for all destinations or prefixes.

The **autoroute include ipv4** *address* option applies Autoroute Destination functionality for the specified destinations or prefixes. This option is supported for IS-IS only; it is not supported for OSPF.

The Autoroute SR-TE policy adds the prefixes into the IGP, which determines if the prefixes on the endpoint or downstream of the endpoint are eligible to use the SR-TE policy. If a prefix is eligible, then the IGP checks if the prefix is listed in the Autoroute Include configuration. If the prefix is included, then the IGP downloads the prefix route with the SR-TE policy as the outgoing path.

Usage Guidelines and Limitations

- Autoroute Include supports three metric types:
  - Default (no metric): The path over the SR-TE policy inherits the shortest path metric.
  - Absolute (constant) metric: The shortest path metric to the policy endpoint is replaced with the configured absolute metric. The metric to any prefix that is Autoroute Included is modified to the absolute metric. Use the **autoroute metric constant** *constant-metric* command, where *constant-metric* is from 1 to 2147483647.
  - Relative metric: The shortest path metric to the policy endpoint is modified with the relative value configured (plus or minus). Use the **autoroute metric relative** *relative-metric* command, where *relative-metric* is from -10 to +10.

Note To prevent load-balancing over IGP paths, you can specify a metric that is lower than the value that IGP takes into account for autorouted destinations (for example, **autoroute metric relative -1**).

Configuration Examples

The following example shows how to configure autoroute include for all prefixes:

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)#policy P1
Router(config-sr-te-policy)# color 20 end-point ipv4 10.1.1.2
Router(config-sr-te-policy)# autoroute include all
Router(config-sr-te-policy)# candidate-paths
Router(config-sr-te-policy-path)# preference 100
Router(config-sr-te-pp-index)# explicit segment-list Plist-1
```

The following example shows how to configure autoroute include for the specified IPv4 prefixes:

Note This option is supported for IS-IS only; it is not supported for OSPF.

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)#policy P1
Router(config-sr-te-policy)# color 20 end-point ipv4 10.1.1.2
Router(config-sr-te-policy)# autoroute include ipv4 10.1.1.21/32
Router(config-sr-te-policy)# autoroute include ipv4 10.1.1.23/32
Router(config-sr-te-policy)# autoroute metric constant 1
Router(config-sr-te-policy)# candidate-paths
Router(config-sr-te-policy-path)# preference 100
Router(config-sr-te-pp-index)# explicit segment-list Plist-1
```

Color-Only Automated Steering

Color-only steering is a traffic steering mechanism where a policy is created with given color, regardless of the endpoint.

You can create an SR-TE policy for a specific color that uses a NULL end-point (0.0.0.0 for IPv4 NULL, and ::0 for IPv6 NULL end-point). This means that you can have a single policy that can steer traffic that is based on that color and a NULL endpoint for routes with a particular color extended community, but different destinations (next-hop).

Note Every SR-TE policy with a NULL end-point must have an explicit path-option. The policy cannot have a dynamic path-option (where the path is computed by the head-end or PCE) since there is no destination for the policy.

You can also specify a color-only (CO) flag in the color extended community for overlay routes. The CO flag allows the selection of an SR-policy with a matching color, regardless of endpoint Sub-address Family Identifier (SAFI) (IPv4 or IPv6). See Setting CO Flag, on page 110.

Configure Color-Only Steering

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# policy P1
Router(config-sr-te-policy)# color 1 end-point ipv4 0.0.0.0

Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# policy P2
Router(config-sr-te-policy)# color 2 end-point ipv6 ::0
```

```
Router# show running-configuration
segment-routing
 traffic-eng
  policy P1
   color 1 end-point ipv4 0.0.0.0
  !
  policy P2
   color 2 end-point ipv6 ::
  !
 !
!
end
```

Address-Family Agnostic Automated Steering

Address-family agnostic steering uses an SR-TE policy to steer both labeled and unlabeled IPv4 and IPv6 traffic. This feature requires support of IPv6 encapsulation (IPv6 caps) over IPV4 endpoint policy.

IPv6 caps for IPv4 NULL end-point is enabled automatically when the policy is created in Segment Routing Path Computation Element (SR-PCE). The binding SID (BSID) state notification for each policy contains an "ipv6_caps" flag that notifies SR-PCE clients (PCC) of the status of IPv6 caps (enabled or disabled).

An SR-TE policy with a given color and IPv4 NULL end-point could have more than one candidate path. If any of the candidate paths has IPv6 caps enabled, then all of the remaining candidate paths need IPv6 caps enabled. If IPv6 caps is not enabled on all candidate paths of same color and end-point, traffic drops can occur.

You can disable IPv6 caps for a particular color and IPv4 NULL end-point using the **ipv6 disable** command on the local policy. This command disables IPv6 caps on all candidate paths that share the same color and IPv4 NULL end-point.

Disable IPv6 Encapsulation

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# policy P1
Router(config-sr-te-policy)# color 1 end-point ipv4 0.0.0.0
Router(config-sr-te-policy)# ipv6 disable
```

LDP over Segment Routing Policy

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)
```

Static Route over Segment Routing Policy

This feature allows you to specify a Segment Routing (SR) policy as an interface type when configuring static routes for MPLS data planes.

For information on configuring static routes, see the "Implementing Static Routes" chapter in the *Routing Configuration Guide for Cisco NCS 560 Series Routers*.

Configuration Example

The following example depicts a configuration of a static route for an IPv4 destination over an SR policy according to following parameters:

- Target SR policy:
  - Color = 200
  - End-point = 10.1.1.4
  - Auto-generated SR policy name = srte_c_200_ep_10.1.1.4

> **Note** Use the auto-generated SR-TE policy name to attach the SR policy to the static route. Auto-generated SR policy names use the following naming convention: **srte_c_***color_val***_ep_***endpoint-address*.
>
> Use the show segment-routing traffic-eng policy color <color_val> endpoint ipv4 <ip_addr> command to display the auto-generated policy name.

- Admin distance = 40
- Load metric = 150
- Install the route in RIB regardless of reachability

```
Router(config)# router static
Router(config-static)# address-family ipv4 unicast
Router(config-static-afi)# 10.1.1.4/32 sr-policy srte_c_200_ep_10.1.1.4 40 permanent metric
 150
```

Running Configuration

```
router static
 address-family ipv4 unicast
  10.1.1.4/32 sr-policy srte_c_200_ep_10.1.1.4 40 permanent metric 150
 !
!
```

Verification

```
RP/0/RP0/CPU0:RTR-1# show run segment-routing traffic-eng policy sample-policy-foo
Tue Feb 16 17:40:16.759 PST
segment-routing
 traffic-eng
  policy sample-policy-foo
   color 200 end-point ipv4 10.1.1.4
   candidate-paths
    preference 100
     dynamic
      metric
```

```
       type te
      !
     !
    !
   !
  !
 !
!

RP/0/RP0/CPU0:RTR-1# show segment-routing traffic-eng policy color 200 endpoint ipv4 10.1.1.4
Tue Feb 16 17:17:45.724 PST

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

Color: 200, End-point: 10.1.1.4
  Name: srte_c_200_ep_10.1.1.4
  Status:
    Admin: up  Operational: up for 5d04h (since Feb 11 12:22:59.054)
  Candidate-paths:
    Preference: 100 (configuration) (active)
      Name: sample-policy-foo
      Requested BSID: dynamic
        Protection Type: protected-preferred
        Maximum SID Depth: 10
      Dynamic (valid)
        Metric Type: TE,   Path Accumulated Metric: 14
          16005 [Prefix-SID, 10.1.1.5]
          16004 [Prefix-SID, 10.1.1.4]
  Attributes:
    Binding SID: 24014
    Forward Class: Not Configured
    Steering labeled-services disabled: no
    Steering BGP disabled: no
    IPv6 caps enable: yes
    Invalidation drop enabled: no

RP/0/RP0/CPU0:RTR-1# show static sr-policy srte_c_200_ep_10.1.1.4
Tue Feb 16 17:50:19.932 PST

Interface                VRF                 State     Paths
srte_c_200_ep_10.1.1.4   default             Up        10.1.1.4/32
Reference Count(in path with both intf<-->NH):0
Last IM notification was Up at Feb 16 17:09:08.325

     Global ifh          : 0x0000007c
     IM state            : up
     RSI registration    : Yes
     Table IDs           : 0xe0000000

     Address Info:
      10.1.1.1/32
      Route tag: 0x00000000 Flags: 0x00000000 Prefix SID: False [Active]

IP-STATIC-IDB-CLASS
 Total entries : 1
 Interface     : sr-srte_c_200_ep_10.1.1.4
| Event Name               | Time Stamp           | S, M
| idb-create               | Feb 16 17:09:08.352  | 0, 0


RP/0/RP0/CPU0:RTR-1# show route 10.1.1.4/32
Tue Feb 16 17:09:21.164 PST

Routing entry for 10.1.1.4/32
```

```
  Known via "static", distance 40, metric 0 (connected)
  Installed Feb 16 17:09:08.325 for 00:00:13
  Routing Descriptor Blocks
    directly connected, via srte_c_200_ep_10.1.1.4, permanent
      Route metric is 0, Wt is 150
  No advertising protos.

RP/0/RP0/CPU0:RTR-1# show route 10.1.1.4/32 detail
Tue Feb 16 17:09:36.718 PST

Routing entry for 10.1.1.4/32
  Known via "static", distance 40, metric 0 (connected)
  Installed Feb 16 17:09:08.325 for 00:00:28
  Routing Descriptor Blocks
    directly connected, via srte_c_200_ep_10.1.1.4, permanent
      Route metric is 0, Wt is 150
      Label: None
      Tunnel ID: None
      Binding Label: None
      Extended communities count: 0
      NHID:0x0(Ref:0)
  Route version is 0x4a (74)
  Local Label: 0x3e84 (16004)
  IP Precedence: Not Set
  QoS Group ID: Not Set
  Flow-tag: Not Set
  Fwd-class: Not Set
  Route Priority: RIB_PRIORITY_RECURSIVE (9) SVD Type RIB_SVD_TYPE_LOCAL
  Download Priority 3, Download Version 258
  No advertising protos.

RP/0/RP0/CPU0:RTR-1# show cef 10.1.1.4/32 detail
Tue Feb 16 17:10:06.956 PST
10.1.1.4/32, version 258, attached, internal 0x1000441 0x30 (ptr 0xd3f0d30) [1], 0x0
(0xe46f960), 0xa20 (0xe9694e0)
 Updated Feb 16 17:09:08.328
 Prefix Len 32, traffic index 0, precedence n/a, priority 3
  gateway array (0xe2d9a08) reference count 2, flags 0x8068, source rib (7), 0 backups
                [3 type 4 flags 0x108401 (0xe9aeb98) ext 0x0 (0x0)]
  LW-LDI[type=1, refc=1, ptr=0xe46f960, sh-ldi=0xe9aeb98]
  gateway array update type-time 1 Feb 16 17:07:59.946
 LDI Update time Feb 16 17:07:59.946
 LW-LDI-TS Feb 16 17:07:59.946
   via srte_c_200_ep_10.1.1.4, 5 dependencies, weight 0, class 0 [flags 0xc]
    path-idx 0 NHID 0x0 [0xf3b1a30 0x0]
    local adjacency
     local label 16004      labels imposed {None}

    Load distribution: 0 (refcount 3)

    Hash  OK  Interface                 Address
    0     Y   srte_c_200_ep_10.1.1.4    point2point

RP/0/RP0/CPU0:RTR-1# show mpls forwarding labels 16004 detail
Tue Feb 16 17:27:59.831 PST
Local  Outgoing    Prefix             Outgoing     Next Hop        Bytes
Label  Label       or ID              Interface                    Switched
------ ----------- ------------------ ------------ --------------- ------------
16004  Unlabelled  SR Pfx (idx 4)     srte_c_200_e point2point     990
     Updated: Feb 16 17:07:59.945
     Path Flags: 0xc [  ]
     Version: 258, Priority: 3
```

```
Label Stack (Top -> Bottom): { Unlabelled Unlabelled }
NHID: 0x0, Encap-ID: N/A, Path idx: 0, Backup path idx: 0, Weight: 0
MAC/Encaps: 0/0, MTU: 0
Outgoing Interface: srte_c_200_ep_10.1.1.4 (ifhandle 0x0000007c)
Packets Switched: 20
```

Instantiation of an SR Policy

An SR policy is instantiated, or implemented, at the head-end router.

The following sections provide details on the SR policy instantiation methods:

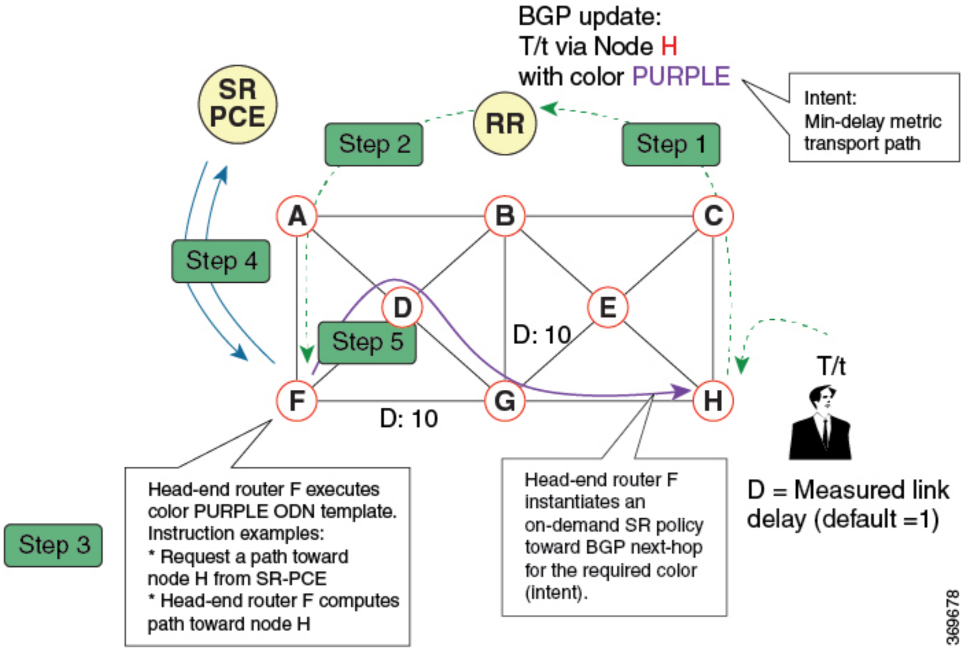
- On-Demand SR Policy – SR On-Demand Next-Hop , on page 63
- Manually Provisioned SR Policy, on page 92
- PCE-Initiated SR Policy, on page 92

On-Demand SR Policy – SR On-Demand Next-Hop

Segment Routing On-Demand Next Hop (SR-ODN) allows a service head-end router to automatically instantiate an SR policy to a BGP next-hop when required (on-demand). Its key benefits include:

- **SLA-aware BGP service** – Provides per-destination steering behaviors where a prefix, a set of prefixes, or all prefixes from a service can be associated with a desired underlay SLA. The functionality applies equally to single-domain and multi-domain networks.
- **Simplicity** – No prior SR Policy configuration needs to be configured and maintained. Instead, operator simply configures a small set of common intent-based optimization templates throughout the network.
- **Scalability** – Device resources at the head-end router are used only when required, based on service or SLA connectivity needs.

The following example shows how SR-ODN works:


BGP update:
T/t via Node H
with color PURPLE
Intent:
Min-delay metric
transport path
SR
PCE
RR
Step 2
Step 1
Step 4
Step 5
A
B
C
D
E
D: 10
F
G
H
D: 10
T/t
Step 3
Head-end router F executes color PURPLE ODN template. Instruction examples:
* Request a path toward node H from SR-PCE
* Head-end router F computes path toward node H
Head-end router F instantiates an on-demand SR policy toward BGP next-hop for the required color (intent).
D = Measured link delay (default =1)
369678

1. An egress PE (node H) advertises a BGP route for prefix T/t. This advertisement includes an SLA intent encoded with a BGP color extended community. In this example, the operator assigns color purple (example value = 100) to prefixes that should traverse the network over the delay-optimized path.

2. The route reflector receives the advertised route and advertises it to other PE nodes.

3. Ingress PEs in the network (such as node F) are pre-configured with an ODN template for color purple that provides the node with the steps to follow in case a route with the intended color appears, for example:

   - Contact SR-PCE and request computation for a path toward node H that does not share any nodes with another LSP in the same disjointness group.

   - At the head-end router, compute a path towards node H that minimizes cumulative delay.

4. In this example, the head-end router contacts the SR-PCE and requests computation for a path toward node H that minimizes cumulative delay.

5. After SR-PCE provides the compute path, an intent-driven SR policy is instantiated at the head-end router. Other prefixes with the same intent (color) and destined to the same egress PE can share the same on-demand SR policy. When the last prefix associated with a given [intent, egress PE] pair is withdrawn, the on-demand SR policy is deleted, and resources are freed from the head-end router.

An on-demand SR policy is created dynamically for BGP global or VPN (service) routes. The following services are supported with SR-ODN:

- IPv4 BGP global routes

- IPv6 BGP global routes (6PE)

- VPNv4

- VPNv6 (6vPE)

- EVPN-VPWS (single-homing)

Configuring SR-ODN: Examples

Configuring SR-ODN: Layer-3 Services Examples

The following examples show end-to-end configurations used in implementing SR-ODN on the head-end router.

Configuring ODN Color Templates: Example

Configure ODN color templates on routers acting as SR-TE head-end nodes. The following example shows various ODN color templates:

- color 10: minimization objective = te-metric
- color 20: minimization objective = igp-metric
- color 21: minimization objective = igp-metric; constraints = affinity
- color 22: minimization objective = te-metric; path computation at SR-PCE; constraints = affinity
- color 30: minimization objective = delay-metric
- color 128: constraints = flex-algo

```
segment-routing
 traffic-eng
  on-demand color 10
   dynamic
    metric
     type te
    !
   !
  !
  on-demand color 20
   dynamic
    metric
     type igp
    !
   !
  !
  on-demand color 21
   dynamic
    metric
     type igp
    !
    affinity exclude-any
     name CROSS
    !
   !
  !
  on-demand color 22
   dynamic
    pcep
    !
    metric
     type te
    !
    affinity exclude-any
     name CROSS
    !
   !
  !
  on-demand color 30
   dynamic
    metric
     type latency
    !
   !
  !
  on-demand color 128
   dynamic
    sid-algorithm 128
   !
  !
!
end
```

Configuring BGP Color Extended Community Set: Example

The following example shows how to configure BGP color extended communities that are later applied to BGP service routes via route-policies.

Note In most common scenarios, egress PE routers that advertise BGP service routes apply (set) BGP color extended communities. However, color can also be set at the ingress PE router.

```
extcommunity-set opaque color10-te
  10
end-set
!
extcommunity-set opaque color20-igp
  20
end-set
!
extcommunity-set opaque color21-igp-excl-cross
  21
end-set
!
extcommunity-set opaque color30-delay
  30
end-set
!
extcommunity-set opaque color128-fa128
  128
end-set
!
```

Configuring RPL to Set BGP Color (Layer-3 Services): Examples

The following example shows various representative RPL definitions that set BGP color community.

The first 4 RPL examples include the set color action only. The last RPL example performs the set color action for selected destinations based on a prefix-set.

```
route-policy SET_COLOR_LOW_LATENCY_TE
  set extcommunity color color10-te
  pass
end-policy
!
route-policy SET_COLOR_HI_BW
  set extcommunity color color20-igp
  pass
end-policy
```

```
!
route-policy SET_COLOR_LOW_LATENCY
  set extcommunity color color30-delay
  pass
end-policy
!
route-policy SET_COLOR_FA_128
  set extcommunity color color128-fa128
  pass
end-policy
!

prefix-set sample-set
  88.1.0.0/24
end-set
!
route-policy SET_COLOR_GLOBAL
  if destination in sample-set then
    set extcommunity color color10-te
  else
    pass
  endif
end-policy
```

Applying RPL to BGP Services (Layer-3 Services): Example

The following example shows various RPLs that set BGP color community being applied to BGP Layer-3 VPN services (VPNv4/VPNv6) and BGP global.

- The L3VPN examples show the RPL applied at the VRF export attach-point.
- The BGP global example shows the RPL applied at the BGP neighbor-out attach-point.

```
vrf vrf_cust1
 address-family ipv4 unicast
  export route-policy SET_COLOR_LOW_LATENCY_TE
 !
 address-family ipv6 unicast
  export route-policy SET_COLOR_LOW_LATENCY_TE
 !
!
vrf vrf_cust2
 address-family ipv4 unicast
  export route-policy SET_COLOR_HI_BW
 !
 address-family ipv6 unicast
  export route-policy SET_COLOR_HI_BW
 !
!
vrf vrf_cust3
 address-family ipv4 unicast
  export route-policy SET_COLOR_LOW_LATENCY
 !
 address-family ipv6 unicast
  export route-policy SET_COLOR_LOW_LATENCY
 !
!

vrf vrf_cust4
 address-family ipv4 unicast
  export route-policy SET_COLOR_FA_128
 !
 address-family ipv6 unicast
```

```
  export route-policy SET_COLOR_FA_128
 !
!
router bgp 100
 neighbor-group BR-TO-RR
  address-family ipv4 unicast
   route-policy SET_COLOR_GLOBAL out
  !
 !
!
end
```

Verifying BGP VRF Information

Use the **show bgp vrf** command to display BGP prefix information for VRF instances. The following output shows the BGP VRF table including a prefix (88.1.1.0/24) with color 10 advertised by router 10.1.1.8.

```
RP/0/RP0/CPU0:R4# show bgp vrf vrf_cust1

BGP VRF vrf_cust1, state: Active
BGP Route Distinguisher: 10.1.1.4:101
VRF ID: 0x60000007
BGP router identifier 10.1.1.4, local AS number 100
Non-stop routing is enabled
BGP table state: Active
Table ID: 0xe0000007   RD version: 282
BGP main routing table version 287
BGP NSR Initial initsync version 31 (Reached)
BGP NSR/ISSU Sync-Group versions 0/0

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
Route Distinguisher: 10.1.1.4:101 (default for vrf vrf_cust1)
*> 44.1.1.0/24        40.4.101.11                            0 400 {1} i
*>i55.1.1.0/24        10.1.1.5                      100      0 500 {1} i
*>i88.1.1.0/24        10.1.1.8 C:10                 100      0 800 {1} i
*>i99.1.1.0/24        10.1.1.9                      100      0 800 {1} i

Processed 4 prefixes, 4 paths
```

The following output displays the details for prefix 88.1.1.0/24. Note the presence of BGP extended color community 10, and that the prefix is associated with an SR policy with color 10 and BSID value of 24036.

```
RP/0/RP0/CPU0:R4# show bgp vrf vrf_cust1 88.1.1.0/24

BGP routing table entry for 88.1.1.0/24, Route Distinguisher: 10.1.1.4:101
Versions:
  Process           bRIB/RIB  SendTblVer
  Speaker                282         282
Last Modified: May 20 09:23:34.112 for 00:06:03
Paths: (1 available, best #1)
  Advertised to CE peers (in unique update groups):
    40.4.101.11
  Path #1: Received by speaker 0
  Advertised to CE peers (in unique update groups):
    40.4.101.11
  800 {1}
    10.1.1.8 C:10 (bsid:24036) (metric 20) from 10.1.1.55 (10.1.1.8)
      Received Label 24012
      Origin IGP, localpref 100, valid, internal, best, group-best, import-candidate,
imported
```

```
      Received Path ID 0, Local Path ID 1, version 273
      Extended community: Color:10 RT:100:1
      Originator: 10.1.1.8, Cluster list: 10.1.1.55
      SR policy color 10, up, registered, bsid 24036, if-handle 0x08000024

     Source AFI: VPNv4 Unicast, Source VRF: default, Source Route Distinguisher: 10.1.1.8:101
```

Verifying Forwarding (CEF) Table

Use the **show cef vrf** command to display the contents of the CEF table for the VRF instance. Note that prefix 88.1.1.0/24 points to the BSID label corresponding to an SR policy. Other non-colored prefixes, such as 55.1.1.0/24, point to BGP next-hop.

```
RP/0/RP0/CPU0:R4# show cef vrf vrf_cust1

Prefix              Next Hop            Interface
------------------- ------------------- ------------------
0.0.0.0/0           drop                default handler
0.0.0.0/32          broadcast
40.4.101.0/24       attached            TenGigE0/0/0/0.101
40.4.101.0/32       broadcast           TenGigE0/0/0/0.101
40.4.101.4/32       receive             TenGigE0/0/0/0.101
40.4.101.11/32      40.4.101.11/32      TenGigE0/0/0/0.101
40.4.101.255/32     broadcast           TenGigE0/0/0/0.101
44.1.1.0/24         40.4.101.11/32      <recursive>
55.1.1.0/24         10.1.1.5/32         <recursive>
88.1.1.0/24         24036 (via-label)   <recursive>
99.1.1.0/24         10.1.1.9/32         <recursive>
224.0.0.0/4         0.0.0.0/32
224.0.0.0/24        receive
255.255.255.255/32  broadcast
```

The following output displays CEF details for prefix 88.1.1.0/24. Note that the prefix is associated with an SR policy with BSID value of 24036.

```
RP/0/RP0/CPU0:R4# show cef vrf vrf_cust1 88.1.1.0/24

88.1.1.0/24, version 51, internal 0x5000001 0x0 (ptr 0x98c60ddc) [1], 0x0 (0x0), 0x208
(0x98425268)
 Updated May 20 09:23:34.216
 Prefix Len 24, traffic index 0, precedence n/a, priority 3
   via local-label 24036, 5 dependencies, recursive [flags 0x6000]
    path-idx 0 NHID 0x0 [0x97091ec0 0x0]
    recursion-via-label
    next hop VRF - 'default', table - 0xe0000000
    next hop via 24036/0/21
     next hop srte_c_10_ep labels imposed {ImplNull 24012}
```

Verifying SR Policy

Use the **show segment-routing traffic-eng policy** command to display SR policy information.

The following outputs show the details of an on-demand SR policy that was triggered by prefixes with color 10 advertised by node 10.1.1.8.

```
RP/0/RP0/CPU0:R4# show segment-routing traffic-eng policy color 10 tabular

 Color             Endpoint  Admin   Oper              Binding
                             State  State                  SID
------ -------------------- ------ ------ --------------------
```

```
    10              10.1.1.8    up     up                 24036
```

The following outputs show the details of the on-demand SR policy for BSID 24036.

Note There are 2 candidate paths associated with this SR policy: the path that is computed by the head-end router (with preference 200), and the path that is computed by the SR-PCE (with preference 100). The candidate path with the highest preference is the active candidate path (highlighted below) and is installed in forwarding.

```
RP/0/RP0/CPU0:R4# show segment-routing traffic-eng policy binding-sid 24036

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

Color: 10, End-point: 10.1.1.8
  Name: srte_c_10_ep_10.1.1.8
  Status:
    Admin: up  Operational: up for 4d14h (since Jul  3 20:28:57.840)
  Candidate-paths:
    Preference: 200 (BGP ODN) (active)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: bgp_c_10_ep_10.1.1.8_discr_200
        PLSP-ID: 12
      Dynamic (valid)
        Metric Type: TE,   Path Accumulated Metric: 30
            16009 [Prefix-SID, 10.1.1.9]
            16008 [Prefix-SID, 10.1.1.8]
    Preference: 100 (BGP ODN)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: bgp_c_10_ep_10.1.1.8_discr_100
        PLSP-ID: 11
      Dynamic (pce 10.1.1.57) (valid)
        Metric Type: TE,   Path Accumulated Metric: 30
            16009 [Prefix-SID, 10.1.1.9]
            16008 [Prefix-SID, 10.1.1.8]
  Attributes:
    Binding SID: 24036
    Forward Class: 0
    Steering BGP disabled: no
    IPv6 caps enable: yes
```

Verifying SR Policy Forwarding

Use the **show segment-routing traffic-eng forwarding policy** command to display the SR policy forwarding information.

The following outputs show the forwarding details for an on-demand SR policy that was triggered by prefixes with color 10 advertised by node 10.1.1.8.

```
RP/0/RP0/CPU0:R4# show segment-routing traffic-eng forwarding policy binding-sid 24036
tabular

Color Endpoint        Segment      Outgoing Outgoing     Next Hop     Bytes        Pure
                      List         Label    Interface                 Switched     Backup
----- --------------- ------------ -------- ------------ ------------ ------------ ------
10    10.1.1.8        dynamic      16009    Gi0/0/0/4    10.4.5.5     0
                                   16001    Gi0/0/0/5    11.4.8.8     0            Yes
```

```
RP/0/RP0/CPU0:R4# show segment-routing traffic-eng forwarding policy binding-sid 24036
detail
Mon Jul  8 11:56:46.887 PST

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

Color: 10, End-point: 10.1.1.8
  Name: srte_c_10_ep_10.1.1.8
  Binding SID: 24036
  Segment Lists:
    SL[0]:
      Name: dynamic
      Paths:
        Path[0]:
          Outgoing Label: 16009
          Outgoing Interface: GigabitEthernet0/0/0/4
          Next Hop: 10.4.5.5
          Switched Packets/Bytes: 0/0
          FRR Pure Backup: No
          Label Stack (Top -> Bottom): { 16009, 16008 }
          Path-id: 1 (Protected), Backup-path-id: 2, Weight: 64
        Path[1]:
          Outgoing Label: 16001
          Outgoing Interface: GigabitEthernet0/0/0/5
          Next Hop: 11.4.8.8
          Switched Packets/Bytes: 0/0
          FRR Pure Backup: Yes
          Label Stack (Top -> Bottom): { 16001, 16009, 16008 }
          Path-id: 2 (Pure-Backup), Weight: 64
  Policy Packets/Bytes Switched: 0/0
  Local label: 80013
```

Configuring SR-ODN for EVPN-VPWS: Use Case

This use case shows how to set up a pair of ELINE services using EVPN-VPWS between two sites. Services are carried over SR policies that must not share any common links along their paths (link-disjoint). The SR policies are triggered on-demand based on ODN principles. An SR-PCE computes the disjoint paths.

This use case uses the following topology with 2 sites: Site 1 with nodes A and B, and Site 2 with nodes C and D.

Figure 3: Topology for Use Case: SR-ODN for EVPN-VPWS

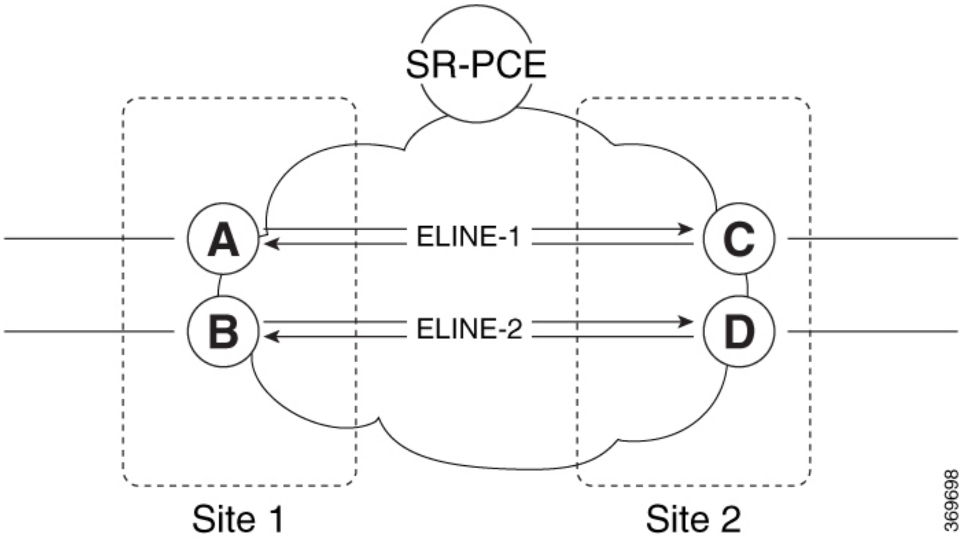


Table 4: Use Case Parameters

IP Addresses of Loopback0 (Lo0) Interfaces	SR-PCE Lo0: 10.1.1.207	
	Site 1: • Node A Lo0: 10.1.1.5 • Node B Lo0: 10.1.1.6	Site 2: • Node C Lo0: 10.1.1.2 • Node D Lo0: 10.1.1.4
EVPN-VPWS Service Parameters	ELINE-1: • EVPN-VPWS EVI 100 • Node A: AC-ID = 11 • Node C: AC-ID = 21	ELINE-2: • EVPN-VPWS EVI 101 • Node B: AC-ID = 12 • Node D: AC-ID = 22
ODN BGP Color Extended Communities	Site 1 routers (Nodes A and B): • set color 10000 • match color 11000	Site 2 routers (Nodes C and D): • set color 11000 • match color 10000
Note These colors are associated with the EVPN route-type 1 routes of the EVPN-VPWS services.		
PCEP LSP Disjoint-Path Association Group ID	Site 1 to Site 2 LSPs (from Node A to Node C/from Node B to Node D): • group-id = 775	Site 2 to Site 1 LSPs (from Node C to Node A/from Node D to Node B): • group-id = 776

The use case provides configuration and verification outputs for all devices.

Configuration	Verification
Configuration: SR-PCE, on page 73	Verification: SR-PCE, on page 77
Configuration: Site 1 Node A, on page 73	Verification: Site 1 Node A, on page 81
Configuration: Site 1 Node B, on page 74	Verification: Site 1 Node B, on page 84
Configuration: Site 2 Node C, on page 75	Verification: Site 2 Node C, on page 87
Configuration: Site 2 Node D, on page 76	Verification: Site 2 Node D, on page 89

Configuration: SR-PCE

For cases when PCC nodes support, or signal, PCEP association-group object to indicate the pair of LSPs in a disjoint set, there is no extra configuration required at the SR-PCE to trigger disjoint-path computation.

Note SR-PCE also supports disjoint-path computation for cases when PCC nodes do not support PCEP association-group object. See Configure the Disjoint Policy (Optional), on page 128 for more information.

Configuration: Site 1 Node A

This section depicts relevant configuration of Node A at Site 1. It includes service configuration, BGP color extended community, and RPL. It also includes the corresponding ODN template required to achieve the disjointness SLA.

Nodes in Site 1 are configured to set color 10000 on originating EVPN routes, while matching color 11000 on incoming EVPN routes from routers located at Site 2.

Since both nodes in Site 1 request path computation from SR-PCE using the same disjoint-path group-id (775), the PCE will attempt to compute disjointness for the pair of LSPs originating from Site 1 toward Site 2.

```
/* EVPN-VPWS configuration */

interface GigabitEthernet0/0/0/3.2500 l2transport
 encapsulation dot1q 2500
 rewrite ingress tag pop 1 symmetric
!
l2vpn
 xconnect group evpn_vpws_group
  p2p evpn_vpws_100
   interface GigabitEthernet0/0/0/3.2500
   neighbor evpn evi 100 target 21 source 11
   !
  !
 !
!

/* BGP color community and RPL configuration */

extcommunity-set opaque color-10000
  10000
end-set
!
route-policy SET_COLOR_EVPN_VPWS
```

```
  if evpn-route-type is 1 and rd in (ios-regex '.*..*..*..*:(100)') then
    set extcommunity color color-10000
  endif
  pass
end-policy
!
router bgp 65000
 neighbor 10.1.1.253
  address-family l2vpn evpn
   route-policy SET_COLOR_EVPN_VPWS out
  !
 !
!

/* ODN template configuration */

segment-routing
 traffic-eng
  on-demand color 11000
   dynamic
    pcep
    !
    metric
     type igp
    !
    disjoint-path group-id 775 type link
   !
  !
 !
!
```

Configuration: Site 1 Node B

This section depicts relevant configuration of Node B at Site 1.

```
/* EVPN-VPWS configuration */

interface TenGigE0/3/0/0/8.2500 l2transport
 encapsulation dot1q 2500
 rewrite ingress tag pop 1 symmetric
!
l2vpn
 xconnect group evpn_vpws_group
  p2p evpn_vpws_101
   interface TenGigE0/3/0/0/8.2500
   neighbor evpn evi 101 target 22 source 12
   !
  !
 !
!

/* BGP color community and RPL configuration */

extcommunity-set opaque color-10000
  10000
end-set
!
route-policy SET_COLOR_EVPN_VPWS
  if evpn-route-type is 1 and rd in (ios-regex '.*..*..*..*:(101)') then
    set extcommunity color color-10000
  endif
  pass
end-policy
!
```

```
router bgp 65000
 neighbor 10.1.1.253
  address-family l2vpn evpn
   route-policy SET_COLOR_EVPN_VPWS out
  !
 !
!

/* ODN template configuration */

segment-routing
 traffic-eng
  on-demand color 11000
   dynamic
    pcep
    !
    metric
     type igp
    !
    disjoint-path group-id 775 type link
   !
  !
 !
!
```

Configuration: Site 2 Node C

This section depicts relevant configuration of Node C at Site 2. It includes service configuration, BGP color extended community, and RPL. It also includes the corresponding ODN template required to achieve the disjointness SLA.

Nodes in Site 2 are configured to set color 11000 on originating EVPN routes, while matching color 10000 on incoming EVPN routes from routers located at Site 1.

Since both nodes on Site 2 request path computation from SR-PCE using the same disjoint-path group-id (776), the PCE will attempt to compute disjointness for the pair of LSPs originating from Site 2 toward Site 1.

```
/* EVPN-VPWS configuration */

interface GigabitEthernet0/0/0/3.2500 l2transport
 encapsulation dot1q 2500
 rewrite ingress tag pop 1 symmetric
!
l2vpn
 xconnect group evpn_vpws_group
  p2p evpn_vpws_100
   interface GigabitEthernet0/0/0/3.2500
   neighbor evpn evi 100 target 11 source 21
   !
  !
 !
!

/* BGP color community and RPL configuration */

extcommunity-set opaque color-11000
  11000
end-set
!
route-policy SET_COLOR_EVPN_VPWS
  if evpn-route-type is 1 and rd in (ios-regex '.*..*..*..*:(100)') then
    set extcommunity color color-11000
  endif
  pass
end-policy
!
router bgp 65000
 neighbor 10.1.1.253
  address-family l2vpn evpn
   route-policy SET_COLOR_EVPN_VPWS out
  !
 !
!

/* ODN template configuration */

segment-routing
 traffic-eng
  on-demand color 10000
   dynamic
    pcep
    !
    metric
     type igp
    !
    disjoint-path group-id 776 type link
   !
  !
 !
!
```

Configuration: Site 2 Node D

This section depicts relevant configuration of Node D at Site 2.

```
/* EVPN-VPWS configuration */

interface GigabitEthernet0/0/0/1.2500 l2transport
 encapsulation dot1q 2500
 rewrite ingress tag pop 1 symmetric
!
l2vpn
 xconnect group evpn_vpws_group
  p2p evpn_vpws_101
   interface GigabitEthernet0/0/0/1.2500
   neighbor evpn evi 101 target 12 source 22
   !
  !
 !
!

/* BGP color community and RPL configuration */

extcommunity-set opaque color-11000
  11000
end-set
!
route-policy SET_COLOR_EVPN_VPWS
  if evpn-route-type is 1 and rd in (ios-regex '.*..*..*..*:(101)') then
    set extcommunity color color-11000
  endif
  pass
end-policy
!
router bgp 65000
 neighbor 10.1.1.253
```

```
  address-family l2vpn evpn
   route-policy SET_COLOR_EVPN_VPWS out
  !
 !
!

/* ODN template configuration */

segment-routing
 traffic-eng
  on-demand color 10000
   dynamic
    pcep
    !
    metric
     type igp
    !
    disjoint-path group-id 776 type link
   !
  !
 !
!
```

Verification: SR-PCE

Use the **show pce ipv4 peer** command to display the SR-PCE's PCEP peers and session status. SR-PCE performs path computation for the 4 nodes depicted in the use-case.

```
RP/0/0/CPU0:SR-PCE# show pce ipv4 peer
Mon Jul 15 19:41:43.622 UTC

PCE's peer database:
--------------------
Peer address: 10.1.1.2
  State: Up
  Capabilities: Stateful, Segment-Routing, Update, Instantiation

Peer address: 10.1.1.4
  State: Up
  Capabilities: Stateful, Segment-Routing, Update, Instantiation

Peer address: 10.1.1.5
  State: Up
  Capabilities: Stateful, Segment-Routing, Update, Instantiation

Peer address: 10.1.1.6
  State: Up
  Capabilities: Stateful, Segment-Routing, Update, Instantiation
```

Use the **show pce association group-id** command to display information for the pair of LSPs assigned to a given association group-id value.

Based on the goals of this use case, SR-PCE computes link-disjoint paths for the SR policies associated with a pair of ELINE services between site 1 and site 2. In particular, disjoint LSPs from site 1 to site 2 are identified by association group-id 775. The output includes high-level information for LSPs associated to this group-id:

- At Node A (10.1.1.5): LSP symbolic name = bgp_c_11000_ep_10.1.1.2_discr_100
- At Node B (10.1.1.6): LSP symbolic name = bgp_c_11000_ep_10.1.1.4_discr_100

In this case, the SR-PCE was able to achieve the desired disjointness level; therefore the Status is shown as "Satisfied".

```
RP/0/0/CPU0:SR-PCE# show pce association group-id 775
Thu Jul 11 03:52:20.770 UTC

PCE's association database:
----------------------
Association: Type Link-Disjoint, Group 775, Not Strict
 Associated LSPs:
  LSP[0]:
   PCC 10.1.1.6, tunnel name bgp_c_11000_ep_10.1.1.4_discr_100,  PLSP ID 18, tunnel ID 17,
 LSP ID 3, Configured on PCC
  LSP[1]:
   PCC 10.1.1.5, tunnel name bgp_c_11000_ep_10.1.1.2_discr_100,  PLSP ID 18, tunnel ID 18,
 LSP ID 3, Configured on PCC
 Status: Satisfied
```

Use the **show pce lsp** command to display detailed information of an LSP present in the PCE's LSP database. This output shows details for the LSP at Node A (10.1.1.5) that is used to carry traffic of EVPN VPWS EVI 100 towards node C (10.1.1.2).

```
RP/0/0/CPU0:SR-PCE# show pce lsp pcc ipv4 10.1.1.5 name bgp_c_11000_ep_10.1.1.2_discr_100
Thu Jul 11 03:58:45.903 UTC

PCE's tunnel database:
----------------------
PCC 10.1.1.5:

Tunnel Name: bgp_c_11000_ep_10.1.1.2_discr_100
Color: 11000
Interface Name: srte_c_11000_ep_10.1.1.2
 LSPs:
  LSP[0]:
   source 10.1.1.5, destination 10.1.1.2, tunnel ID 18, LSP ID 3
   State: Admin up, Operation up
   Setup type: Segment Routing
   Binding SID: 80037
   Maximum SID Depth: 10
   Absolute Metric Margin: 0
   Relative Metric Margin: 0%
   Preference: 100
   Bandwidth: signaled 0 kbps, applied 0 kbps
   PCEP information:
     PLSP-ID 0x12, flags: D:1 S:0 R:0 A:1 O:1 C:0
   LSP Role: Exclude LSP
   State-sync PCE: None
   PCC: 10.1.1.5
   LSP is subdelegated to: None
   Reported path:
     Metric type: IGP, Accumulated Metric 40
      SID[0]: Adj, Label 80003, Address: local 11.5.8.5 remote 11.5.8.8
      SID[1]: Node, Label 16007, Address 10.1.1.7
      SID[2]: Node, Label 16002, Address 10.1.1.2
   Computed path: (Local PCE)
     Computed Time: Thu Jul 11 03:49:48 UTC 2019 (00:08:58 ago)
     Metric type: IGP, Accumulated Metric 40
      SID[0]: Adj, Label 80003, Address: local 11.5.8.5 remote 11.5.8.8
      SID[1]: Node, Label 16007, Address 10.1.1.7
      SID[2]: Node, Label 16002, Address 10.1.1.2
   Recorded path:
     None
   Disjoint Group Information:
     Type Link-Disjoint, Group 775
```

This output shows details for the LSP at Node B (10.1.1.6) that is used to carry traffic of EVPN VPWS EVI 101 towards node D (10.1.1.4).

```
RP/0/0/CPU0:SR-PCE# show pce lsp pcc ipv4 10.1.1.6 name bgp_c_11000_ep_10.1.1.4_discr_100
Thu Jul 11 03:58:56.812 UTC

PCE's tunnel database:
----------------------
PCC 10.1.1.6:

Tunnel Name: bgp_c_11000_ep_10.1.1.4_discr_100
Color: 11000
Interface Name: srte_c_11000_ep_10.1.1.4
 LSPs:
  LSP[0]:
   source 10.1.1.6, destination 10.1.1.4, tunnel ID 17, LSP ID 3
   State: Admin up, Operation up
   Setup type: Segment Routing
   Binding SID: 80061
   Maximum SID Depth: 10
   Absolute Metric Margin: 0
   Relative Metric Margin: 0%
   Preference: 100
   Bandwidth: signaled 0 kbps, applied 0 kbps
   PCEP information:
     PLSP-ID 0x12, flags: D:1 S:0 R:0 A:1 O:1 C:0
   LSP Role: Disjoint LSP
   State-sync PCE: None
   PCC: 10.1.1.6
   LSP is subdelegated to: None
   Reported path:
     Metric type: IGP, Accumulated Metric 40
      SID[0]: Node, Label 16001, Address 10.1.1.1
      SID[1]: Node, Label 16004, Address 10.1.1.4
   Computed path: (Local PCE)
     Computed Time: Thu Jul 11 03:49:48 UTC 2019 (00:09:08 ago)
     Metric type: IGP, Accumulated Metric 40
      SID[0]: Node, Label 16001, Address 10.1.1.1
      SID[1]: Node, Label 16004, Address 10.1.1.4
   Recorded path:
     None
   Disjoint Group Information:
     Type Link-Disjoint, Group 775
```

Based on the goals of this use case, SR-PCE computes link-disjoint paths for the SR policies associated with a pair of ELINE services between site 1 and site 2. In particular, disjoint LSPs from site 2 to site 1 are identified by association group-id 776. The output includes high-level information for LSPs associated to this group-id:

- At Node C (10.1.1.2): LSP symbolic name = bgp_c_10000_ep_10.1.1.5_discr_100
- At Node D (10.1.1.4): LSP symbolic name = bgp_c_10000_ep_10.1.1.6_discr_100

In this case, the SR-PCE was able to achieve the desired disjointness level; therefore, the Status is shown as "Satisfied".

```
RP/0/0/CPU0:SR-PCE# show pce association group-id 776
Thu Jul 11 03:52:24.370 UTC

PCE's association database:
----------------------
Association: Type Link-Disjoint, Group 776, Not Strict
 Associated LSPs:
  LSP[0]:
   PCC 10.1.1.4, tunnel name bgp_c_10000_ep_10.1.1.6_discr_100,  PLSP ID 16, tunnel ID 14,
 LSP ID 1, Configured on PCC
  LSP[1]:
   PCC 10.1.1.2, tunnel name bgp_c_10000_ep_10.1.1.5_discr_100,  PLSP ID 6, tunnel ID 21,
LSP ID 3, Configured on PCC
 Status: Satisfied
```

Use the **show pce lsp** command to display detailed information of an LSP present in the PCE's LSP database. This output shows details for the LSP at Node C (10.1.1.2) that is used to carry traffic of EVPN VPWS EVI 100 towards node A (10.1.1.5).

```
RP/0/0/CPU0:SR-PCE# show pce lsp pcc ipv4 10.1.1.2 name bgp_c_10000_ep_10.1.1.5_discr_100
Thu Jul 11 03:55:21.706 UTC

PCE's tunnel database:
----------------------
PCC 10.1.1.2:

Tunnel Name: bgp_c_10000_ep_10.1.1.5_discr_100
Color: 10000
Interface Name: srte_c_10000_ep_10.1.1.5
 LSPs:
  LSP[0]:
   source 10.1.1.2, destination 10.1.1.5, tunnel ID 21, LSP ID 3
   State: Admin up, Operation up
   Setup type: Segment Routing
   Binding SID: 80052
   Maximum SID Depth: 10
   Absolute Metric Margin: 0
   Relative Metric Margin: 0%
   Preference: 100
   Bandwidth: signaled 0 kbps, applied 0 kbps
   PCEP information:
     PLSP-ID 0x6, flags: D:1 S:0 R:0 A:1 O:1 C:0
   LSP Role: Exclude LSP
   State-sync PCE: None
   PCC: 10.1.1.2
   LSP is subdelegated to: None
   Reported path:
     Metric type: IGP, Accumulated Metric 40
      SID[0]: Node, Label 16007, Address 10.1.1.7
      SID[1]: Node, Label 16008, Address 10.1.1.8
      SID[2]: Adj, Label 80005, Address: local 11.5.8.8 remote 11.5.8.5
   Computed path: (Local PCE)
     Computed Time: Thu Jul 11 03:50:03 UTC 2019 (00:05:18 ago)
     Metric type: IGP, Accumulated Metric 40
      SID[0]: Node, Label 16007, Address 10.1.1.7
      SID[1]: Node, Label 16008, Address 10.1.1.8
      SID[2]: Adj, Label 80005, Address: local 11.5.8.8 remote 11.5.8.5
   Recorded path:
     None
   Disjoint Group Information:
     Type Link-Disjoint, Group 776
```

This output shows details for the LSP at Node D (10.1.1.4) used to carry traffic of EVPN VPWS EVI 101 towards node B (10.1.1.6).

```
RP/0/0/CPU0:SR-PCE# show pce lsp pcc ipv4 10.1.1.4 name bgp_c_10000_ep_10.1.1.6_discr_100
Thu Jul 11 03:55:23.296 UTC

PCE's tunnel database:
----------------------
PCC 10.1.1.4:

Tunnel Name: bgp_c_10000_ep_10.1.1.6_discr_100
Color: 10000
Interface Name: srte_c_10000_ep_10.1.1.6
```

```
 LSPs:
  LSP[0]:
   source 10.1.1.4, destination 10.1.1.6, tunnel ID 14, LSP ID 1
   State: Admin up, Operation up
   Setup type: Segment Routing
   Binding SID: 80047
   Maximum SID Depth: 10
   Absolute Metric Margin: 0
   Relative Metric Margin: 0%
   Preference: 100
   Bandwidth: signaled 0 kbps, applied 0 kbps
   PCEP information:
     PLSP-ID 0x10, flags: D:1 S:0 R:0 A:1 O:1 C:0
   LSP Role: Disjoint LSP
   State-sync PCE: None
   PCC: 10.1.1.4
   LSP is subdelegated to: None
   Reported path:
     Metric type: IGP, Accumulated Metric 40
      SID[0]: Node, Label 16001, Address 10.1.1.1
      SID[1]: Node, Label 16006, Address 10.1.1.6
   Computed path: (Local PCE)
     Computed Time: Thu Jul 11 03:50:03 UTC 2019 (00:05:20 ago)
     Metric type: IGP, Accumulated Metric 40
      SID[0]: Node, Label 16001, Address 10.1.1.1
      SID[1]: Node, Label 16006, Address 10.1.1.6
   Recorded path:
     None
   Disjoint Group Information:
     Type Link-Disjoint, Group 776
```

Verification: Site 1 Node A

This section depicts verification steps at Node A.

Use the **show bgp l2vpn evpn** command to display BGP prefix information for EVPN-VPWS EVI 100 (rd 10.1.1.5:100). The output includes an EVPN route-type 1 route with color 11000 originated at Node C (10.1.1.2).

```
RP/0/RSP0/CPU0:Node-A# show bgp l2vpn evpn rd 10.1.1.5:100
Wed Jul 10 18:57:57.704 PST
BGP router identifier 10.1.1.5, local AS number 65000
BGP generic scan interval 60 secs
Non-stop routing is enabled
BGP table state: Active
Table ID: 0x0   RD version: 0
BGP main routing table version 360
BGP NSR Initial initsync version 1 (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
Route Distinguisher: 10.1.1.5:100 (default for vrf VPWS:100)
*> [1][0000.0000.0000.0000.0000][11]/120
                      0.0.0.0                                0 i
*>i[1][0000.0000.0000.0000.0000][21]/120
                      10.1.1.2 C:11000               100      0 i
```

The following output displays the details for the incoming EVPN RT1. Note the presence of BGP extended color community 11000, and that the prefix is associated with an SR policy with color 11000 and BSID value of 80044.

```
RP/0/RSP0/CPU0:Node-A# show bgp l2vpn evpn rd 10.1.1.5:100
[1][0000.0000.0000.0000.0000][21]/120
Wed Jul 10 18:57:58.107 PST
BGP routing table entry for [1][0000.0000.0000.0000.0000][21]/120, Route Distinguisher:
10.1.1.5:100
Versions:
  Process           bRIB/RIB  SendTblVer
  Speaker                360         360
Last Modified: Jul 10 18:36:18.369 for 00:21:40
Paths: (1 available, best #1)
  Not advertised to any peer
  Path #1: Received by speaker 0
  Not advertised to any peer
  Local
    10.1.1.2 C:11000 (bsid:80044) (metric 40) from 10.1.1.253 (10.1.1.2)
      Received Label 80056
      Origin IGP, localpref 100, valid, internal, best, group-best, import-candidate,
imported, rib-install
      Received Path ID 0, Local Path ID 1, version 358
      Extended community: Color:11000 RT:65000:100
      Originator: 10.1.1.2, Cluster list: 10.1.1.253
      SR policy color 11000, up, registered, bsid 80044, if-handle 0x00001b20

      Source AFI: L2VPN EVPN, Source VRF: default, Source Route Distinguisher: 10.1.1.2:100
```

Use the **show l2vpn xconnect** command to display the state associated with EVPN-VPWS EVI 100 service.

```
RP/0/RSP0/CPU0:Node-A# show l2vpn xconnect group evpn_vpws_group
Wed Jul 10 18:58:02.333 PST
Legend: ST = State, UP = Up, DN = Down, AD = Admin Down, UR = Unresolved,
        SB = Standby, SR = Standby Ready, (PP) = Partially Programmed

XConnect                   Segment 1                       Segment 2
Group      Name       ST   Description            ST       Description            ST
------------------------   -----------------------------   -----------------------------
evpn_vpws_group
           evpn_vpws_100
                      UP   Gi0/0/0/3.2500         UP       EVPN 100,21,10.1.1.2    UP
----------------------------------------------------------------------------------------
```

The following output shows the details for the service. Note that the service is associated with the on-demand SR policy with color 11000 and end-point 10.1.1.2 (node C).

```
RP/0/RSP0/CPU0:Node-A# show l2vpn xconnect group evpn_vpws_group xc-name evpn_vpws_100
detail
Wed Jul 10 18:58:02.755 PST

Group evpn_vpws_group, XC evpn_vpws_100, state is up; Interworking none
  AC: GigabitEthernet0/0/0/3.2500, state is up
    Type VLAN; Num Ranges: 1
    Rewrite Tags: []
    VLAN ranges: [2500, 2500]
    MTU 1500; XC ID 0x120000c; interworking none
    Statistics:
      packets: received 0, sent 0
      bytes: received 0, sent 0
      drops: illegal VLAN 0, illegal length 0
  EVPN: neighbor 10.1.1.2, PW ID: evi 100, ac-id 21, state is up ( established )
    XC ID 0xa0000007
    Encapsulation MPLS
    Source address 10.1.1.5
    Encap type Ethernet, control word enabled
    Sequencing not set
    Preferred path Active : SR TE srte_c_11000_ep_10.1.1.2, On-Demand, fallback enabled
    Tunnel : Up
    Load Balance Hashing: src-dst-mac

      EVPN         Local                          Remote
      ------------ ------------------------------ -----------------------------
      Label        80040                          80056
      MTU          1500                           1500
      Control word enabled                        enabled
      AC ID        11                             21
      EVPN type    Ethernet                       Ethernet

      ------------ ------------------------------ -----------------------------
    Create time: 10/07/2019 18:31:30 (1d17h ago)
    Last time status changed: 10/07/2019 19:42:00 (1d16h ago)
    Last time PW went down: 10/07/2019 19:40:55 (1d16h ago)
    Statistics:
      packets: received 0, sent 0
      bytes: received 0, sent 0
```

Use the **show segment-routing traffic-eng policy** command with **tabular** option to display SR policy summary information.

The following output shows the on-demand SR policy with BSID 80044 that was triggered by EVPN RT1 prefix with color 11000 advertised by node C (10.1.1.2).

```
RP/0/RSP0/CPU0:Node-A# show segment-routing traffic-eng policy color 11000 tabular
Wed Jul 10 18:58:00.732 PST

 Color             Endpoint  Admin   Oper              Binding
                             State  State                  SID
------ -------------------- ------ ------ --------------------
 11000              10.1.1.2     up     up                 80044
```

The following output shows the details for the on-demand SR policy. Note that the SR policy's active candidate path (preference 100) is computed by SR-PCE (10.1.1.207).

Based on the goals of this use case, SR-PCE computes link-disjoint paths for the SR policies associated with a pair of ELINE services between site 1 and site 2. Specifically, from site 1 to site 2, LSP at Node A (srte_c_11000_ep_10.1.1.2) is link-disjoint from LSP at Node B (srte_c_11000_ep_10.1.1.4).

```
RP/0/RSP0/CPU0:Node-A# show segment-routing traffic-eng policy color 11000
Wed Jul 10 19:15:47.217 PST

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

Color: 11000, End-point: 10.1.1.2
  Name: srte_c_11000_ep_10.1.1.2
  Status:
    Admin: up  Operational: up for 00:39:31 (since Jul 10 18:36:00.471)
  Candidate-paths:
    Preference: 200 (BGP ODN) (shutdown)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: bgp_c_11000_ep_10.1.1.2_discr_200
        PLSP-ID: 19
      Dynamic (invalid)
    Preference: 100 (BGP ODN) (active)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: bgp_c_11000_ep_10.1.1.2_discr_100
        PLSP-ID: 18
      Dynamic (pce 10.1.1.207) (valid)
        Metric Type: IGP,   Path Accumulated Metric: 40
          80003 [Adjacency-SID, 11.5.8.5 - 11.5.8.8]
          16007 [Prefix-SID, 10.1.1.7]
          16002 [Prefix-SID, 10.1.1.2]
  Attributes:
    Binding SID: 80044
    Forward Class: 0
    Steering BGP disabled: no
    IPv6 caps enable: yes
```

Verification: Site 1 Node B

This section depicts verification steps at Node B.

Use the **show bgp l2vpn evpn** command to display BGP prefix information for EVPN-VPWS EVI 101 (rd 10.1.1.6:101). The output includes an EVPN route-type 1 route with color 11000 originated at Node D (10.1.1.4).

```
RP/0/RSP0/CPU0:Node-B# show bgp l2vpn evpn rd 10.1.1.6:101
Wed Jul 10 19:08:54.964 PST
BGP router identifier 10.1.1.6, local AS number 65000
BGP generic scan interval 60 secs
Non-stop routing is enabled
BGP table state: Active
Table ID: 0x0   RD version: 0
BGP main routing table version 322
BGP NSR Initial initsync version 7 (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
Route Distinguisher: 10.1.1.6:101 (default for vrf VPWS:101)
*> [1][0000.0000.0000.0000.0000][12]/120
                      0.0.0.0                                0 i
*>i[1][0000.0000.0000.0000.0000][22]/120
                      10.1.1.4 C:11000              100      0 i

Processed 2 prefixes, 2 paths
```

The following output displays the details for the incoming EVPN RT1. Note the presence of BGP extended color community 11000, and that the prefix is associated with an SR policy with color 11000 and BSID value of 80061.

```
RP/0/RSP0/CPU0:Node-B# show bgp l2vpn evpn rd 10.1.1.6:101
[1][0000.0000.0000.0000.0000][22]/120
Wed Jul 10 19:08:55.039 PST
BGP routing table entry for [1][0000.0000.0000.0000.0000][22]/120, Route Distinguisher:
10.1.1.6:101
Versions:
  Process           bRIB/RIB  SendTblVer
  Speaker                322         322
```

```
Last Modified: Jul 10 18:42:10.408 for 00:26:44
Paths: (1 available, best #1)
  Not advertised to any peer
  Path #1: Received by speaker 0
  Not advertised to any peer
  Local
    10.1.1.4 C:11000 (bsid:80061) (metric 40) from 10.1.1.253 (10.1.1.4)
      Received Label 80045
      Origin IGP, localpref 100, valid, internal, best, group-best, import-candidate,
imported, rib-install
      Received Path ID 0, Local Path ID 1, version 319
      Extended community: Color:11000 RT:65000:101
      Originator: 10.1.1.4, Cluster list: 10.1.1.253
      SR policy color 11000, up, registered, bsid 80061, if-handle 0x00000560

      Source AFI: L2VPN EVPN, Source VRF: default, Source Route Distinguisher: 10.1.1.4:101
```

Use the **show l2vpn xconnect** command to display the state associated with EVPN-VPWS EVI 101 service.

```
RP/0/RSP0/CPU0:Node-B# show l2vpn xconnect group evpn_vpws_group
Wed Jul 10 19:08:56.388 PST
Legend: ST = State, UP = Up, DN = Down, AD = Admin Down, UR = Unresolved,
        SB = Standby, SR = Standby Ready, (PP) = Partially Programmed

XConnect                   Segment 1                       Segment 2
Group      Name       ST   Description            ST       Description            ST
------------------------   -----------------------------   -----------------------------
evpn_vpws_group
           evpn_vpws_101
                      UP   Te0/3/0/0/8.2500       UP       EVPN 101,22,10.1.1.4    UP
----------------------------------------------------------------------------------------
```

The following output shows the details for the service. Note that the service is associated with the on-demand SR policy with color 11000 and end-point 10.1.1.4 (node D).

```
RP/0/RSP0/CPU0:Node-B# show l2vpn xconnect group evpn_vpws_group xc-name evpn_vpws_101
Wed Jul 10 19:08:56.511 PST

Group evpn_vpws_group, XC evpn_vpws_101, state is up; Interworking none
  AC: TenGigE0/3/0/0/8.2500, state is up
    Type VLAN; Num Ranges: 1
    Rewrite Tags: []
    VLAN ranges: [2500, 2500]
    MTU 1500; XC ID 0x2a0000e; interworking none
    Statistics:
      packets: received 0, sent 0
      bytes: received 0, sent 0
      drops: illegal VLAN 0, illegal length 0
  EVPN: neighbor 10.1.1.4, PW ID: evi 101, ac-id 22, state is up ( established )
    XC ID 0xa0000009
    Encapsulation MPLS
    Source address 10.1.1.6
    Encap type Ethernet, control word enabled
    Sequencing not set
    Preferred path Active : SR TE srte_c_11000_ep_10.1.1.4, On-Demand, fallback enabled
    Tunnel : Up
    Load Balance Hashing: src-dst-mac

      EVPN         Local                          Remote
      ------------ ------------------------------ -----------------------------
      Label        80060                          80045
      MTU          1500                           1500
      Control word enabled                        enabled
      AC ID        12                             22
      EVPN type    Ethernet                       Ethernet

      ------------ ------------------------------ -----------------------------
    Create time: 10/07/2019 18:32:49 (00:36:06 ago)
    Last time status changed: 10/07/2019 18:42:07 (00:26:49 ago)
    Statistics:
      packets: received 0, sent 0
      bytes: received 0, sent 0
```

Use the **show segment-routing traffic-eng policy** command with **tabular** option to display SR policy summary information.

The following output shows the on-demand SR policy with BSID 80061 that was triggered by EVPN RT1 prefix with color 11000 advertised by node D (10.1.1.4).

```
RP/0/RSP0/CPU0:Node-B# show segment-routing traffic-eng policy color 11000 tabular
Wed Jul 10 19:08:56.146 PST

 Color             Endpoint  Admin   Oper              Binding
                             State  State                  SID
------ -------------------- ------ ------ --------------------
 11000              10.1.1.4     up     up               80061
```

The following output shows the details for the on-demand SR policy. Note that the SR policy's active candidate path (preference 100) is computed by SR-PCE (10.1.1.207).

Based on the goals of this use case, SR-PCE computes link-disjoint paths for the SR policies associated with a pair of ELINE services between site 1 and site 2. Specifically, from site 1 to site 2, LSP at Node B (srte_c_11000_ep_10.1.1.4) is link-disjoint from LSP at Node A (srte_c_11000_ep_10.1.1.2).

```
RP/0/RSP0/CPU0:Node-B# show segment-routing traffic-eng policy color 11000
Wed Jul 10 19:08:56.207 PST

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

Color: 11000, End-point: 10.1.1.4
  Name: srte_c_11000_ep_10.1.1.4
  Status:
    Admin: up  Operational: up for 00:26:47 (since Jul 10 18:40:05.868)
  Candidate-paths:
    Preference: 200 (BGP ODN) (shutdown)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: bgp_c_11000_ep_10.1.1.4_discr_200
        PLSP-ID: 19
      Dynamic (invalid)
    Preference: 100 (BGP ODN) (active)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: bgp_c_11000_ep_10.1.1.4_discr_100
        PLSP-ID: 18
      Dynamic (pce 10.1.1.207) (valid)
        Metric Type: IGP,   Path Accumulated Metric: 40
          16001 [Prefix-SID, 10.1.1.1]
          16004 [Prefix-SID, 10.1.1.4]
  Attributes:
    Binding SID: 80061
    Forward Class: 0
    Steering BGP disabled: no
    IPv6 caps enable: yes
```

Verification: Site 2 Node C

This section depicts verification steps at Node C.

Use the **show bgp l2vpn evpn** command to display BGP prefix information for EVPN-VPWS EVI 100 (rd 10.1.1.2:100). The output includes an EVPN route-type 1 route with color 10000 originated at Node A (10.1.1.5).

```
RP/0/RSP0/CPU0:Node-C# show bgp l2vpn evpn rd 10.1.1.2:100
BGP router identifier 10.1.1.2, local AS number 65000
BGP generic scan interval 60 secs
Non-stop routing is enabled
BGP table state: Active
Table ID: 0x0   RD version: 0
BGP main routing table version 21
BGP NSR Initial initsync version 1 (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
Route Distinguisher: 10.1.1.2:100 (default for vrf VPWS:100)
*>i[1][0000.0000.0000.0000.0000][11]/120
                      10.1.1.5 C:10000               100      0 i
*> [1][0000.0000.0000.0000.0000][21]/120
                      0.0.0.0                                0 i
```

The following output displays the details for the incoming EVPN RT1. Note the presence of BGP extended color community 10000, and that the prefix is associated with an SR policy with color 10000 and BSID value of 80058.

```
RP/0/RSP0/CPU0:Node-C# show bgp l2vpn evpn rd 10.1.1.2:100
[1][0000.0000.0000.0000.0000][11]/120
BGP routing table entry for [1][0000.0000.0000.0000.0000][11]/120, Route Distinguisher:
10.1.1.2:100
Versions:
  Process           bRIB/RIB  SendTblVer
  Speaker                   20          20
Last Modified: Jul 10 18:36:20.503 for 00:45:21
Paths: (1 available, best #1)
  Not advertised to any peer
  Path #1: Received by speaker 0
  Not advertised to any peer
  Local
    10.1.1.5 C:10000 (bsid:80058) (metric 40) from 10.1.1.253 (10.1.1.5)
      Received Label 80040
      Origin IGP, localpref 100, valid, internal, best, group-best, import-candidate,
imported, rib-install
      Received Path ID 0, Local Path ID 1, version 18
      Extended community: Color:10000 RT:65000:100
      Originator: 10.1.1.5, Cluster list: 10.1.1.253
      SR policy color 10000, up, registered, bsid 80058, if-handle 0x000006a0

      Source AFI: L2VPN EVPN, Source VRF: default, Source Route Distinguisher: 10.1.1.5:100
```

Use the **show l2vpn xconnect** command to display the state associated with EVPN-VPWS EVI 100 service.

```
RP/0/RSP0/CPU0:Node-C# show l2vpn xconnect group evpn_vpws_group
Legend: ST = State, UP = Up, DN = Down, AD = Admin Down, UR = Unresolved,
        SB = Standby, SR = Standby Ready, (PP) = Partially Programmed

XConnect                   Segment 1                       Segment 2
Group      Name       ST   Description            ST       Description            ST
------------------------   -----------------------------   -----------------------------
evpn_vpws_group
           evpn_vpws_100
                      UP   Gi0/0/0/3.2500         UP       EVPN 100,11,10.1.1.5    UP
----------------------------------------------------------------------------------------
```

The following output shows the details for the service. Note that the service is associated with the on-demand SR policy with color 10000 and end-point 10.1.1.5 (node A).

```
RP/0/RSP0/CPU0:Node-C# show l2vpn xconnect group evpn_vpws_group xc-name evpn_vpws_100

Group evpn_vpws_group, XC evpn_vpws_100, state is up; Interworking none
  AC: GigabitEthernet0/0/0/3.2500, state is up
    Type VLAN; Num Ranges: 1
    Rewrite Tags: []
    VLAN ranges: [2500, 2500]
    MTU 1500; XC ID 0x1200008; interworking none
    Statistics:
      packets: received 0, sent 0
      bytes: received 0, sent 0
      drops: illegal VLAN 0, illegal length 0
  EVPN: neighbor 10.1.1.5, PW ID: evi 100, ac-id 11, state is up ( established )
    XC ID 0xa0000003
    Encapsulation MPLS
    Source address 10.1.1.2
    Encap type Ethernet, control word enabled
    Sequencing not set
    Preferred path Active : SR TE srte_c_10000_ep_10.1.1.5, On-Demand, fallback enabled
    Tunnel : Up
    Load Balance Hashing: src-dst-mac

      EVPN         Local                          Remote
      ------------ ------------------------------ -----------------------------
      Label        80056                          80040
      MTU          1500                           1500
      Control word enabled                        enabled
      AC ID        21                             11
      EVPN type    Ethernet                       Ethernet

      ------------ ------------------------------ -----------------------------
    Create time: 10/07/2019 18:36:16 (1d19h ago)
    Last time status changed: 10/07/2019 19:41:59 (1d18h ago)
    Last time PW went down: 10/07/2019 19:40:54 (1d18h ago)
    Statistics:
      packets: received 0, sent 0
      bytes: received 0, sent 0
```

Use the **show segment-routing traffic-eng policy** command with **tabular** option to display SR policy summary information.

The following output shows the on-demand SR policy with BSID 80058 that was triggered by EVPN RT1 prefix with color 10000 advertised by node A (10.1.1.5).

```
RP/0/RSP0/CPU0:Node-C# show segment-routing traffic-eng policy color 10000 tabular
```

```
 Color             Endpoint  Admin   Oper             Binding
                             State  State                 SID
------ -------------------- ------ ------ --------------------
 10000             10.1.1.5     up     up               80058
```

The following output shows the details for the on-demand SR policy. Note that the SR policy's active candidate path (preference 100) is computed by SR-PCE (10.1.1.207).

Based on the goals of this use case, SR-PCE computes link-disjoint paths for the SR policies associated with a pair of ELINE services between site 1 and site 2. Specifically, from site 2 to site 1, LSP at Node C (srte_c_10000_ep_10.1.1.5) is link-disjoint from LSP at Node D (srte_c_10000_ep_10.1.1.6).

```
RP/0/RSP0/CPU0:Node-C# show segment-routing traffic-eng policy color 10000

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

Color: 10000, End-point: 10.1.1.5
  Name: srte_c_10000_ep_10.1.1.5
  Status:
    Admin: up  Operational: up for 00:12:35 (since Jul 10 19:49:21.890)
  Candidate-paths:
    Preference: 200 (BGP ODN) (shutdown)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: bgp_c_10000_ep_10.1.1.5_discr_200
        PLSP-ID: 7
      Dynamic (invalid)
    Preference: 100 (BGP ODN) (active)
      Requested BSID: dynamic
      PCC info:
        Symbolic name: bgp_c_10000_ep_10.1.1.5_discr_100
        PLSP-ID: 6
      Dynamic (pce 10.1.1.207) (valid)
        Metric Type: IGP,   Path Accumulated Metric: 40
          16007 [Prefix-SID, 10.1.1.7]
          16008 [Prefix-SID, 10.1.1.8]
          80005 [Adjacency-SID, 11.5.8.8 - 11.5.8.5]
  Attributes:
    Binding SID: 80058
    Forward Class: 0
    Steering BGP disabled: no
    IPv6 caps enable: yes
```

Verification: Site 2 Node D

This section depicts verification steps at Node D.

Use the **show bgp l2vpn evpn** command to display BGP prefix information for EVPN-VPWS EVI 101 (rd 10.1.1.4:101). The output includes an EVPN route-type 1 route with color 10000 originated at Node B (10.1.1.6).

```
RP/0/RSP0/CPU0:Node-D# show bgp l2vpn evpn rd 10.1.1.4:101
BGP router identifier 10.1.1.4, local AS number 65000
BGP generic scan interval 60 secs
Non-stop routing is enabled
BGP table state: Active
Table ID: 0x0   RD version: 0
BGP main routing table version 570
BGP NSR Initial initsync version 1 (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
Route Distinguisher: 10.1.1.4:101 (default for vrf VPWS:101)
*>i[1][0000.0000.0000.0000.0000][12]/120
                      10.1.1.6 C:10000              100      0 i
*> [1][0000.0000.0000.0000.0000][22]/120
                      0.0.0.0                                0 i

Processed 2 prefixes, 2 paths
```

The following output displays the details for the incoming EVPN RT1. Note the presence of BGP extended color community 10000, and that the prefix is associated with an SR policy with color 10000 and BSID value of 80047.

```
RP/0/RSP0/CPU0:Node-D# show bgp l2vpn evpn rd 10.1.1.4:101
[1][0000.0000.0000.0000.0000][12]/120
BGP routing table entry for [1][0000.0000.0000.0000.0000][12]/120, Route Distinguisher:
10.1.1.4:101
Versions:
  Process           bRIB/RIB  SendTblVer
  Speaker                569         569
Last Modified: Jul 10 18:42:12.455 for 00:45:38
Paths: (1 available, best #1)
  Not advertised to any peer
  Path #1: Received by speaker 0
  Not advertised to any peer
  Local
    10.1.1.6 C:10000 (bsid:80047) (metric 40) from 10.1.1.253 (10.1.1.6)
      Received Label 80060
      Origin IGP, localpref 100, valid, internal, best, group-best, import-candidate,
imported, rib-install
      Received Path ID 0, Local Path ID 1, version 568
      Extended community: Color:10000 RT:65000:101
      Originator: 10.1.1.6, Cluster list: 10.1.1.253
      SR policy color 10000, up, registered, bsid 80047, if-handle 0x00001720

      Source AFI: L2VPN EVPN, Source VRF: default, Source Route Distinguisher: 10.1.1.6:101
```

Use the **show l2vpn xconnect** command to display the state associated with EVPN-VPWS EVI 101 service.

```
RP/0/RSP0/CPU0:Node-D# show l2vpn xconnect group evpn_vpws_group
Legend: ST = State, UP = Up, DN = Down, AD = Admin Down, UR = Unresolved,
        SB = Standby, SR = Standby Ready, (PP) = Partially Programmed

XConnect                   Segment 1                       Segment 2
Group      Name       ST   Description            ST       Description            ST
------------------------   -----------------------------   -----------------------------
evpn_vpws_group
           evpn_vpws_101
                      UP   Gi0/0/0/1.2500         UP       EVPN 101,12,10.1.1.6    UP
----------------------------------------------------------------------------------------
```

The following output shows the details for the service. Note that the service is associated with the on-demand SR policy with color 10000 and end-point 10.1.1.6 (node B).

```
RP/0/RSP0/CPU0:Node-D# show l2vpn xconnect group evpn_vpws_group xc-name evpn_vpws_101

Group evpn_vpws_group, XC evpn_vpws_101, state is up; Interworking none
```

```
  AC: GigabitEthernet0/0/0/1.2500, state is up
    Type VLAN; Num Ranges: 1
    Rewrite Tags: []
    VLAN ranges: [2500, 2500]
    MTU 1500; XC ID 0x120000c; interworking none
    Statistics:
      packets: received 0, sent 0
      bytes: received 0, sent 0
      drops: illegal VLAN 0, illegal length 0
  EVPN: neighbor 10.1.1.6, PW ID: evi 101, ac-id 12, state is up ( established )
    XC ID 0xa000000d
    Encapsulation MPLS
    Source address 10.1.1.4
    Encap type Ethernet, control word enabled
    Sequencing not set
    Preferred path Active : SR TE srte_c_10000_ep_10.1.1.6, On-Demand, fallback enabled
    Tunnel : Up
    Load Balance Hashing: src-dst-mac

      EVPN         Local                          Remote
      ------------ ------------------------------ -----------------------------
      Label        80045                          80060
      MTU          1500                           1500
      Control word enabled                        enabled
      AC ID        22                             12
      EVPN type    Ethernet                       Ethernet

      ------------ ------------------------------ -----------------------------
    Create time: 10/07/2019 18:42:07 (00:45:49 ago)
    Last time status changed: 10/07/2019 18:42:09 (00:45:47 ago)
    Statistics:
      packets: received 0, sent 0
      bytes: received 0, sent 0
```

Use the **show segment-routing traffic-eng policy** command with **tabular** option to display SR policy summary information.

The following output shows the on-demand SR policy with BSID 80047 that was triggered by EVPN RT1 prefix with color 10000 advertised by node B (10.1.1.6).

```
RP/0/RSP0/CPU0:Node-D# show segment-routing traffic-eng policy color 10000 tabular

 Color              Endpoint   Admin   Oper              Binding
                               State  State                  SID
------ -------------------- ------ ------ --------------------
 10000               10.1.1.6      up     up                 80047
```

The following output shows the details for the on-demand SR policy. Note that the SR policy's active candidate path (preference 100) is computed by SR-PCE (10.1.1.207).

Based on the goals of this use case, SR-PCE computes link-disjoint paths for the SR policies associated with a pair of ELINE services between site 1 and site 2. Specifically, from site 2 to site 1, LSP at Node D (srte_c_10000_ep_10.1.1.6) is link-disjoint from LSP at Node C (srte_c_10000_ep_10.1.1.5).

```
RP/0/RSP0/CPU0:Node-D# show segment-routing traffic-eng policy color 10000

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

Color: 10000, End-point: 10.1.1.6
  Name: srte_c_10000_ep_10.1.1.6
  Status:
```

```
  Admin: up  Operational: up for 01:23:04 (since Jul 10 18:42:07.350)
Candidate-paths:
  Preference: 200 (BGP ODN) (shutdown)
    Requested BSID: dynamic
    PCC info:
      Symbolic name: bgp_c_10000_ep_10.1.1.6_discr_200
      PLSP-ID: 17
    Dynamic (invalid)
  Preference: 100 (BGP ODN) (active)
    Requested BSID: dynamic
    PCC info:
      Symbolic name: bgp_c_10000_ep_10.1.1.6_discr_100
      PLSP-ID: 16
    Dynamic (pce 10.1.1.207) (valid)
      Metric Type: IGP,  Path Accumulated Metric: 40
        16001 [Prefix-SID, 10.1.1.1]
        16006 [Prefix-SID, 10.1.1.6]
Attributes:
  Binding SID: 80047
  Forward Class: 0
  Steering BGP disabled: no
  IPv6 caps enable: yes
```

Manually Provisioned SR Policy

Manually provisioned SR policies are configured on the head-end router. These policies can use dynamic paths or explicit paths. See the SR-TE Policy Path Types, on page 92 section for information on manually provisioning an SR policy using dynamic or explicit paths.

PCE-Initiated SR Policy

An SR-TE policy can be configured on the path computation element (PCE) to reduce link congestion or to minimize the number of network touch points.

The PCE collects network information, such as traffic demand and link utilization. When the PCE determines that a link is congested, it identifies one or more flows that are causing the congestion. The PCE finds a suitable path and deploys an SR-TE policy to divert those flows, without moving the congestion to another part of the network. When there is no more link congestion, the policy is removed.

To minimize the number of network touch points, an application, such as a Network Services Orchestrator (NSO), can request the PCE to create an SR-TE policy. PCE deploys the SR-TE policy using PCC-PCE communication protocol (PCEP).

For more information, see the PCE-Initiated SR Policies, on page 129 section.

SR-TE Policy Path Types

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

An SR-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 (BSID) – A BSID conflict occurs when there are different SR policies with the same BSID. In this case, the policy that is installed first gets the BSID 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.

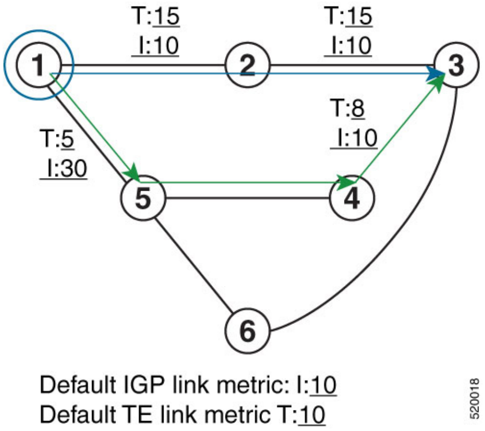
Dynamic Paths

Optimization Objectives

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

- IGP metric — Refer to the "Implementing IS-IS" and "Implementing OSPF" chapters in the *Routing Configuration Guide for Series Routers*.
- TE metric — See the Configure Interface TE Metrics, on page 94 section for information about configuring TE metrics.

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) = SID-list <16003>; cumulative IGP metric: 20
- The green path uses the minimum TE metric: Min-Metric (1 → 3, TE) = SID-list <16005, 16004, 16003>; cumulative TE metric: 23

Configure Interface TE Metrics

Use the **metric** *value* command in SR-TE interface submode to configure the TE metric for interfaces. 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
```

Configuring TE Metric: Example

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:

- 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 SR policy path and link colors. SR-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 SR-TE Affinity Maps, on page 94 section for information on named interface link admin groups and SR-TE Affinity Maps.

- Disjoint — SR-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).

- Flexible Algorithm — Flexible Algorithm allows for user-defined algorithms where the IGP computes paths based on a user-defined combination of metric type and constraint.

Named Interface Link Admin Groups and SR-TE Affinity Maps

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

Use the **affinity name** *NAME* command in SR-TE interface submode to assign affinity to interfaces. Configure this on routers with interfaces that have an associated admin group attribute.

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# interface TenGigE0/0/1/2
Router(config-sr-if)# affinity
Router(config-sr-if-affinity)# name RED
```

Use the **affinity-map name** *NAME* **bit-position** *bit-position* command in SR-TE sub-mode to define affinity maps. The *bit-position* range is from 0 to 255.

Configure affinity maps on the following routers:

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

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# affinity-map
Router(config-sr-te-affinity-map)# name RED bit-position 23
```

Configuring Link Admin Group: Example

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

```
segment-routing
 traffic-eng
  interface TenGigE0/0/1/1
   affinity
    name CROSS
    name RED
   !
  !
  interface TenGigE0/0/1/2
   affinity
    name RED
   !
  !
  interface TenGigE0/0/2/0
   affinity
    name BLUE
   !
  !
  affinity-map
   name RED bit-position 23
   name BLUE bit-position 24
   name CROSS bit-position 25
  !
end
```

Configure SR Policy with Dynamic Path

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

1. Define the optimization objectives. See the Optimization Objectives, on page 93 section.
2. Define the constraints. See the Constraints, on page 94 section.
3. Create the policy.

Behaviors and Limitations

Examples

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

```
segment-routing
 traffic-eng
  policy foo
   color 100 end-point ipv4 10.1.1.2
   candidate-paths
    preference 100
     dynamic
      metric
       type te
      !
     !
     constraints
      affinity
       exclude-any
        name RED
       !
      !
     !
    !
   !
  !
```

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

```
segment-routing
 traffic-eng
  policy baa
   color 101 end-point ipv4 10.1.1.2
   candidate-paths
    preference 100
     dynamic
      pcep
      !
      metric
       type te
      !
     !
     constraints
```

```
      affinity
       exclude-any
        name BLUE
       !
      !
     !
    !
   !
  !
```

Explicit Paths

Configure SR-TE Policy with Explicit Path

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

1. Create the segment lists.
2. Create the SR-TE policy.

Behaviors and Limitations

A segment list can use IP addresses or MPLS labels, or a combination of both.

- The IP address can be link or a Loopback address.
- Once you enter an MPLS label, you cannot enter an IP address.

When configuring an explicit path using IP addresses of links along the path, the SR-TE process selects either the protected or the unprotected Adj-SID of the link, depending on the order in which the Adj-SIDs were received.

Configure Local SR-TE Policy Using Explicit Paths

Create a segment list with IP addresses:

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# segment-list name SIDLIST1
Router(config-sr-te-sl)# index 10 address ipv4 10.1.1.2
Router(config-sr-te-sl)# index 20 address ipv4 10.1.1.3
Router(config-sr-te-sl)# index 30 address ipv4 10.1.1.4
Router(config-sr-te-sl)# exit
```

Create a segment list with MPLS labels:

```
Router(config-sr-te)# segment-list name SIDLIST2
Router(config-sr-te-sl)# index 10 mpls label 16002
Router(config-sr-te-sl)# index 20 mpls label 16003
Router(config-sr-te-sl)# index 30 mpls label 16004
Router(config-sr-te-sl)# exit
```

Create a segment list with invalid MPLS label:

```
Router(config-sr-te)# segment-list name SIDLIST4
Router(config-sr-te-sl)# index 10 mpls label 16009
Router(config-sr-te-sl)# index 20 mpls label 16003
Router(config-sr-te-sl)# index 30 mpls label 16004
Router(config-sr-te-sl)# exit
```

Create a segment list with IP addresses and MPLS labels:

```
Router(config-sr-te)# segment-list name SIDLIST3
Router(config-sr-te-sl)# index 10 address ipv4 10.1.1.2
Router(config-sr-te-sl)# index 20 mpls label 16003
Router(config-sr-te-sl)# index 30 mpls label 16004
Router(config-sr-te-sl)# exit
```

Create the SR-TE policy:

```
Router(config-sr-te)# policy POLICY2
Router(config-sr-te-policy)# color 20 end-point ipv4 10.1.1.4
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 SIDLIST2
Router(config-sr-te-pp-info)# exit
Router(config-sr-te-policy-path-pref)# exit
Router(config-sr-te-policy-path)# preference 200
Router(config-sr-te-policy-path-pref)# explicit segment-list SIDLIST1
Router(config-sr-te-pp-info)# exit
Router(config-sr-te-policy-path-pref)# explicit segment-list SIDLIST4
Router(config-sr-te-pp-info)# exit
Router(config-sr-te-policy-path-pref)# exit
```

Running Configuration

```
Router# show running-configuration
segment-routing
 traffic-eng
  segment-list SIDLIST1
   index 10 address ipv4 10.1.1.2
   index 20 address ipv4 10.1.1.3
   index 30 address ipv4 10.1.1.4
  !
  segment-list SIDLIST2
   index 10 mpls label 16002
   index 20 mpls label 16003
   index 30 mpls label 16004
  !
  segment-list SIDLIST3
   index 10 address ipv4 10.1.1.2
   index 20 mpls label 16003
   index 30 mpls label 16004
  !
  segment-list SIDLIST4
   index 10 mpls label 16009
   index 20 mpls label 16003
   index 30 mpls label 16004
  !
  policy POLICY1
   color 10 end-point ipv4 10.1.1.4
   candidate-paths
    preference 100
     explicit segment-list SIDLIST1
     !
    !
   !
  !
  policy POLICY2
   color 20 end-point ipv4 10.1.1.4
   candidate-paths
    preference 100
     explicit segment-list SIDLIST1
     !
    !
    preference 200
     explicit segment-list SIDLIST2
     !
     explicit segment-list SIDLIST4
     !
    !
   !
  !
  policy POLICY3
   color 30 end-point ipv4 10.1.1.4
   candidate-paths
    preference 100
     explicit segment-list SIDLIST3
     !
    !
   !
  !
!
!
```

Verification

Verify the SR-TE policy configuration using:

```
Router# show segment-routing traffic-eng policy name srte_c_20_ep_10.1.1.4

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

Color: 20, End-point: 10.1.1.4
  Name: srte_c_20_ep_10.1.1.4
  Status:
    Admin: up  Operational: up for 00:00:15 (since Jul 14 00:53:10.615)
  Candidate-paths:
    Preference: 200 (configuration) (active)
      Name: POLICY2
      Requested BSID: dynamic
        Protection Type: protected-preferred
        Maximum SID Depth: 8
      Explicit: segment-list SIDLIST2 (active)
        Weight: 1, Metric Type: TE
          16002
          16003
          16004
    Attributes:
    Binding SID: 51301
   Forward Class: Not Configured
    Steering labeled-services disabled: no
    Steering BGP disabled: no
    IPv6 caps enable: yes
    Invalidation drop enabled: no
```

Configuring Explicit Path with Affinity Constraint Validation

To fully configure SR-TE flexible name-based policy constraints, you must complete these high-level tasks in order:

1. Assign Color Names to Numeric Values
2. Associate Affinity-Names with SR-TE Links
3. Associate Affinity Constraints for SR-TE Policies

```
/* Enter the global configuration mode and assign color names to numeric values
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# affinity-map
Router(config-sr-te-affinity-map)# blue bit-position 0
Router(config-sr-te-affinity-map)# green bit-position 1
Router(config-sr-te-affinity-map)# red bit-position 2
Router(config-sr-te-affinity-map)# exit


/* Associate affinity-names with SR-TE links
Router(config-sr-te)# interface Gi0/0/0/0
Router(config-sr-te-if)# affinity
Router(config-sr-te-if-affinity)# blue
Router(config-sr-te-if-affinity)# exit
Router(config-sr-te-if)# exit
Router(config-sr-te)# interface Gi0/0/0/1
Router(config-sr-te-if)# affinity
Router(config-sr-te-if-affinity)# blue
Router(config-sr-te-if-affinity)# green
Router(config-sr-te-if-affinity)# exit
Router(config-sr-te-if)# exit
Router(config-sr-te)#


/* Associate affinity constraints for SR-TE policies
Router(config-sr-te)# segment-list name SIDLIST1
Router(config-sr-te-sl)# index 10 address ipv4 10.1.1.2
Router(config-sr-te-sl)# index 20 address ipv4 2.2.2.23
Router(config-sr-te-sl)# index 30 address ipv4 10.1.1.4
Router(config-sr-te-sl)# exit
Router(config-sr-te)# segment-list name SIDLIST2
Router(config-sr-te-sl)# index 10 address ipv4 10.1.1.2
Router(config-sr-te-sl)# index 30 address ipv4 10.1.1.4
Router(config-sr-te-sl)# exit
Router(config-sr-te)# segment-list name SIDLIST3
Router(config-sr-te-sl)# index 10 address ipv4 10.1.1.5
Router(config-sr-te-sl)# index 30 address ipv4 10.1.1.4
Router(config-sr-te-sl)# exit

Router(config-sr-te)# policy POLICY1
Router(config-sr-te-policy)# color 20 end-point ipv4 10.1.1.4
Router(config-sr-te-policy)# binding-sid mpls 1000
Router(config-sr-te-policy)# candidate-paths
Router(config-sr-te-policy-path)# preference 200
Router(config-sr-te-policy-path-pref)# constraints affinity exclude-any red
Router(config-sr-te-policy-path-pref)# explicit segment-list SIDLIST1
Router(config-sr-te-pp-info)# exit
Router(config-sr-te-policy-path-pref)# explicit segment-list SIDLIST2
Router(config-sr-te-pp-info)# exit
Router(config-sr-te-policy-path-pref)# exit
Router(config-sr-te-policy-path)# preference 100
Router(config-sr-te-policy-path-pref)# explicit segment-list SIDLIST3
```

Running Configuration

```
Router# show running-configuration
segment-routing
 traffic-eng

  interface GigabitEthernet0/0/0/0
   affinity
    blue
   !
  !
  interface GigabitEthernet0/0/0/1
   affinity
    blue
    green
   !
  !


  segment-list name SIDLIST1
   index 10 address ipv4 10.1.1.2
   index 20 address ipv4 2.2.2.23
   index 30 address ipv4 10.1.1.4
  !
  segment-list name SIDLIST2
   index 10 address ipv4 10.1.1.2
   index 30 address ipv4 10.1.1.4
  !
  segment-list name SIDLIST3
   index 10 address ipv4 10.1.1.5
   index 30 address ipv4 10.1.1.4
  !
  policy POLICY1
   binding-sid mpls 1000
   color 20 end-point ipv4 10.1.1.4
   candidate-paths
    preference 100
     explicit segment-list SIDLIST3
     !
    !
    preference 200
     explicit segment-list SIDLIST1
     !
     explicit segment-list SIDLIST2
     !
     constraints
      affinity
       exclude-any
        red
       !
      !
     !
    !
   !
  !
  affinity-map
   blue bit-position 0
   green bit-position 1
   red bit-position 2
  !
 !
```

```
!
```

Protocols

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.

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.

Configure the PCC to Establish a Connection to the PCE

Use the **segment-routing traffic-eng pcc** command to configure the PCC source address, the SR-PCE address, and SR-PCE options.

A PCE can be given an optional precedence. If a PCC is connected to multiple PCEs, the PCC selects a PCE with the lowest precedence value. If there is a tie, a PCE with the highest IP address is chosen for computing path. The precedence *value* range is from 0 to 255.

```
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# pcc
Router(config-sr-te-pcc)# source-address ipv4 local-source-address
Router(config-sr-te-pcc)# pce address ipv4 PCE-address[precedence value]
Router(config-sr-te-pcc)# pce address ipv4 PCE-address[keychain WORD]
```

Configure PCEP-Related Timers

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

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

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

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

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

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

PCE-Initiated SR Policy Timers

Use the **timers initiated orphans** command 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. The range is from 10 to 180 seconds; the default value is 180.

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

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

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

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.

Enable SR-TE SYSLOG Alarms

Use the **logging policy status** command to enable SR-TE related SYSLOG alarms.

```
Router(config-sr-te)# logging policy status
```

Enable PCEP Reports to SR-PCE

Use the **report-all** command to enable the PCC to report all SR policies in its database to the PCE.

```
Router(config-sr-te-pcc)# report-all
```

Customize MSD Value at PCC

Use the **maximum-sid-depth** *value* command to customize the Maximum SID Depth (MSD) signaled by PCC during PCEP session establishment.

The default MSD *value* is equal to the maximum MSD supported by the platform (5).

```
Router(config-sr-te)# maximum-sid-depth value
```

Note The platform's SR-TE label imposition capabilities are as follows:

- Up to 5 transport labels when no service labels are imposed
- Up to 3 transport labels when service labels are imposed

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** *value* command
- During PCEP LSP path request – The signaled MSD is treated as an LSP property.
  - On-demand (ODN) SR Policy: MSD is configured using the **segment-routing traffic-eng on-demand color** *color* **maximum-sid-depth** *value* command
  - Local SR Policy: MSD is configured using the **segment-routing traffic-eng policy** *WORD* **candidate-paths preference** *preference* **dynamic metric sid-limit** *value* 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 label stack size is verified against the MSD requirement.

- If the label 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 label 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 labels, but a sub-optimal path exists (with accumulated metric of 110) requiring 4 labels, then the sub-optimal path is installed.

Customize the SR-TE Path Calculation

Use the **te-latency** command to enable ECMP-aware path computation for TE metric.

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

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

Configure PCEP Redundancy Type

Use the **redundancy pcc-centric** command to enable PCC-centric high-availability model. 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
```

Configuring Head-End Router as PCEP PCC and Customizing SR-TE Related Options: 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 3 PCEP servers (PCE) with different precedence values. The PCE with IP address 10.1.1.57 is selected as BEST.
- 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.

```
segment-routing
 traffic-eng
  pcc
   source-address ipv4 10.1.1.2
   pce address ipv4 10.1.1.57
    precedence 150
    password clear <password>
   !
   pce address ipv4 10.1.1.58
    precedence 200
    password clear <password>
   !
   pce address ipv4 10.1.1.59
    precedence 250
    password clear <password>
   !
  !
  logging
   policy status
  !
  maximum-sid-depth 5
  pcc
   report-all
  !
 !
```

```
!
end
```

Verification

```
RP/0/RSP0/CPU0:Router# show segment-routing traffic-eng pcc ipv4 peer

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

Peer address: 10.1.1.57, Precedence: 150, (best PCE)
  State up
  Capabilities: Stateful, Update, Segment-Routing, Instantiation

Peer address: 10.1.1.58, Precedence: 200
  State up
  Capabilities: Stateful, Update, Segment-Routing, Instantiation

Peer address: 10.1.1.59, Precedence: 250
  State up
  Capabilities: Stateful, Update, Segment-Routing, Instantiation
```

BGP SR-TE

BGP may be used to distribute SR Policy candidate paths to an SR-TE head-end. Dedicated BGP SAFI and NLRI have been defined to advertise a candidate path of an SR Policy. The advertisement of Segment Routing policies in BGP is documented in the IETF drafthttps://datatracker.ietf.org/doc/draft-ietf-idr-segment-routing-te-policy/

SR policies with IPv4 and IPv6 end-points can be advertised over BGPv4 or BGPv6 sessions between the SR-TE controller and the SR-TE headend.

The Cisco IOS-XR implementation supports the following combinations:

- IPv4 SR policy advertised over BGPv4 session
- IPv6 SR policy advertised over BGPv4 session
- IPv6 SR policy advertised over BGPv6 session

Configure BGP SR Policy Address Family at SR-TE Head-End

Perform this task to configure BGP SR policy address family at SR-TE head-end:

Procedure

	Command or Action	Purpose
Step 1	**configure**	
Step 2	**router bgp** *as-number* **Example:** `RP/0/RP0/CPU0:router(config)# router bgp 65000`	Specifies the BGP AS number and enters the BGP configuration mode, allowing you to configure the BGP routing process.

	Command or Action	Purpose
Step 3	**bgp router-id** *ip-address* **Example:** `RP/0/RP0/CPU0:router(config-bgp)#` **`bgp router-id 10.1.1.1`**	Configures the local router with a specified router ID.
Step 4	**address-family** {**ipv4** | **ipv6**} **sr-policy** **Example:** `RP/0/RP0/CPU0:router(config-bgp)#` **`address-family ipv4 sr-policy`**	Specifies either the IPv4 or IPv6 address family and enters address family configuration submode.
Step 5	**exit**	
Step 6	**neighbor** *ip-address* **Example:** `RP/0/RP0/CPU0:router(config-bgp)#` **`neighbor 10.10.0.1`**	Places the router in neighbor configuration mode for BGP routing and configures the neighbor IP address as a BGP peer.
Step 7	**remote-as** *as-number* **Example:** `RP/0/RP0/CPU0:router(config-bgp-nbr)#` **`remote-as 1`**	Creates a neighbor and assigns a remote autonomous system number to it.
Step 8	**address-family** {**ipv4** | **ipv6**} **sr-policy** **Example:** `RP/0/RP0/CPU0:router(config-bgp-nbr)#` **`address-family ipv4 sr-policy`**	Specifies either the IPv4 or IPv6 address family and enters address family configuration submode.

Step 9	**route-policy** *route-policy-name* {**in** | **out**}
	Example:
	`RP/0/RP0/CPU0:router(config-bgp-nbr-af)#` **`route-policy pass out`**
		Applies the specified policy to IPv4 or IPv6 unicast routes.

Example: BGP SR-TE with BGPv4 Neighbor to BGP SR-TE Controller

The following configuration shows the an SR-TE head-end with a BGPv4 session towards a BGP SR-TE controller. This BGP session is used to signal both IPv4 and IPv6 SR policies.

```
router bgp 65000
bgp router-id 10.1.1.1
 !
 address-family ipv4 sr-policy
 !
 address-family ipv6 sr-policy
 !
 neighbor 10.1.3.1
  remote-as 10
  description *** eBGP session to BGP SRTE controller ***
  address-family ipv4 sr-policy
   route-policy pass in
   route-policy pass out
  !
  address-family ipv6 sr-policy
   route-policy pass in
   route-policy pass out
  !
 !
!
```

Example: BGP SR-TE with BGPv6 Neighbor to BGP SR-TE Controller

The following configuration shows an SR-TE head-end with a BGPv6 session towards a BGP SR-TE controller. This BGP session is used to signal IPv6 SR policies.

```
router bgp 65000
bgp router-id 10.1.1.1
 address-family ipv6 sr-policy
 !
 neighbor 3001::10:1:3:1
  remote-as 10
  description *** eBGP session to BGP SRTE controller ***
  address-family ipv6 sr-policy
   route-policy pass in
   route-policy pass out
  !
 !
!
```

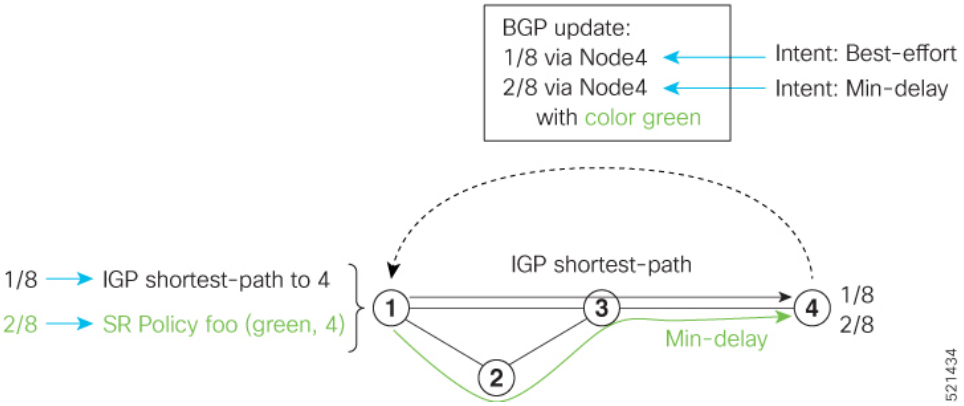
Traffic Steering

Automated Steering

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

With AS, BGP automatically steers traffic onto an SR 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 SR Policy, BGP automatically installs the route resolving onto the BSID of the matching SR Policy. Recall that an SR 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 SR Policy, the BGP process installs the route on the SR 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

AS behaviors apply regardless of the instantiation method of the SR policy, including:

- On-demand SR policy
- Manually provisioned SR policy
- PCE-initiated SR policy

See the Verifying BGP VRF Information, on page 68 and Verifying Forwarding (CEF) Table, on page 69 sections for sample output that shows AS implementation.

Color-Only Automated Steering

Color-only steering is a traffic steering mechanism where a policy is created with given color, regardless of the endpoint.

You can create an SR-TE policy for a specific color that uses a NULL end-point (0.0.0.0 for IPv4 NULL, and ::0 for IPv6 NULL end-point). This means that you can have a single policy that can steer traffic that is based on that color and a NULL endpoint for routes with a particular color extended community, but different destinations (next-hop).

Note Every SR-TE policy with a NULL end-point must have an explicit path-option. The policy cannot have a dynamic path-option (where the path is computed by the head-end or PCE) since there is no destination for the policy.

You can also specify a color-only (CO) flag in the color extended community for overlay routes. The CO flag allows the selection of an SR-policy with a matching color, regardless of endpoint Sub-address Family Identifier (SAFI) (IPv4 or IPv6). See Setting CO Flag, on page 110.

Configure Color-Only Steering

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# policy P1
Router(config-sr-te-policy)# color 1 end-point ipv4 0.0.0.0

Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# policy P2
Router(config-sr-te-policy)# color 2 end-point ipv6 ::0
```

```
Router# show running-configuration
segment-routing
 traffic-eng
  policy P1
   color 1 end-point ipv4 0.0.0.0
  !
  policy P2
   color 2 end-point ipv6 ::
  !
 !
!
end
```

Setting CO Flag

The BGP-based steering mechanism matches BGP color and next-hop with that of an SR-TE policy. If the policy does not exist, BGP requests SR-PCE to create an SR-TE policy with the associated color, end-point, and explicit paths. For color-only steering (NULL end-point), you can configure a color-only (CO) flag as part of the color extended community in BGP.

Note See Color-Only Automated Steering, on page 55 for information about color-only steering (NULL end-point).

The behavior of the steering mechanism is based on the following values of the CO flags:

co-flag 00	**1.** The BGP next-hop and color <N, C> is matched with an SR-TE policy of same <N, C>. **2.** If a policy does not exist, then IGP path for the next-hop N is chosen.

co-flag 01	1. The BGP next-hop and color <N, C> is matched with an SR-TE policy of same <N, C>. 2. If a policy does not exist, then an SR-TE policy with NULL end-point with the same address-family as N and color C is chosen. 3. If a policy with NULL end-point with same address-family as N does not exist, then an SR-TE policy with any NULL end-point and color C is chosen. 4. If no match is found, then IGP path for the next-hop N is chosen.

Configuration Example

```
Router(config)# extcommunity-set opaque overlay-color
Router(config-ext)# 1 co-flag 01
Router(config-ext)# end-set
Router(config)#
Router(config)# route-policy color
Router(config-rpl)# if destination in (5.5.5.1/32) then
Router(config-rpl-if)# set extcommunity color overlay-color
Router(config-rpl-if)# endif
Router(config-rpl)# pass
Router(config-rpl)# end-policy
Router(config)#
```

Address-Family Agnostic Automated Steering

Address-family agnostic steering uses an SR-TE policy to steer both labeled and unlabeled IPv4 and IPv6 traffic. This feature requires support of IPv6 encapsulation (IPv6 caps) over IPV4 endpoint policy.

IPv6 caps for IPv4 NULL end-point is enabled automatically when the policy is created in Segment Routing Path Computation Element (SR-PCE). The binding SID (BSID) state notification for each policy contains an "ipv6_caps" flag that notifies SR-PCE clients (PCC) of the status of IPv6 caps (enabled or disabled).

An SR-TE policy with a given color and IPv4 NULL end-point could have more than one candidate path. If any of the candidate paths has IPv6 caps enabled, then all of the remaining candidate paths need IPv6 caps enabled. If IPv6 caps is not enabled on all candidate paths of same color and end-point, traffic drops can occur.

You can disable IPv6 caps for a particular color and IPv4 NULL end-point using the **ipv6 disable** command on the local policy. This command disables IPv6 caps on all candidate paths that share the same color and IPv4 NULL end-point.

Disable IPv6 Encapsulation

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# policy P1
Router(config-sr-te-policy)# color 1 end-point ipv4 0.0.0.0
Router(config-sr-te-policy)# ipv6 disable
```

Using Binding Segments

The binding segment is a local segment identifying an SR-TE policy. Each SR-TE policy is associated with a binding segment ID (BSID). The BSID is a local label that is automatically allocated for each SR-TE policy when the SR-TE policy is instantiated.

BSID can be used to steer traffic into the SR-TE policy and across domain borders, creating seamless end-to-end inter-domain SR-TE policies. Each domain controls its local SR-TE policies; local SR-TE policies can be validated and rerouted if needed, independent from the remote domain's head-end. Using binding segments isolates the head-end from topology changes in the remote domain.

Packets received with a BSID as top label are steered into the SR-TE policy associated with the BSID. When the BSID label is popped, the SR-TE policy's SID list is pushed.

BSID can be used in the following cases:

- Multi-Domain (inter-domain, inter-autonomous system)—BSIDs can be used to steer traffic across domain borders, creating seamless end-to-end inter-domain SR-TE policies.
- Large-Scale within a single domain—The head-end can use hierarchical SR-TE policies by nesting the end-to-end (edge-to-edge) SR-TE policy within another layer of SR-TE policies (aggregation-to-aggregation). The SR-TE policies are nested within another layer of policies using the BSIDs, resulting in seamless end-to-end SR-TE policies.
- Label stack compression—If the label-stack size required for an SR-TE policy exceeds the platform capability, the SR-TE policy can be seamlessly stitched to, or nested within, other SR-TE policies using a binding segment.

Explicit Binding SID

Use the **binding-sid mpls** *label* command in SR-TE policy configuration mode to specify the explicit BSID. Explicit BSIDs are allocated from the segment routing local block (SRLB) or the dynamic range of labels. A best-effort is made to request and obtain the BSID for the SR-TE policy. If requested BSID is not available (if it does not fall within the available SRLB or is already used by another application or SR-TE policy), the policy stays down.

Use the **binding-sid explicit** {**fallback-dynamic** | **enforce-srlb**} command to specify how the BSID allocation behaves if the BSID value is not available.

- Fallback to dynamic allocation – If the BSID is not available, the BSID is allocated dynamically and the policy comes up:

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# binding-sid explicit fallback-dynamic
```

- Strict SRLB enforcement – If the BSID is not within the SRLB, the policy stays down:

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)# binding-sid explicit enforce-srlb
```

This example shows how to configure an SR policy to use an explicit BSID of 1000. If the BSID is not available, the BSID is allocated dynamically and the policy comes up.

```
segment-routing
 traffic-eng
  binding-sid explicit fallback-dynamic
  policy goo
   binding-sid mpls 1000
  !
 !
!
```

L2VPN Preferred Path

EVPN VPWS Preferred Path over SR-TE Policy feature allows you to set the preferred path between the two end-points for EVPN VPWS pseudowire (PW) using SR-TE policy.

L2VPN VPLS or VPWS Preferred Path over SR-TE Policy feature allows you to set the preferred path between the two end-points for L2VPN Virtual Private LAN Service (VPLS) or Virtual Private Wire Service (VPWS) using SR-TE policy.

Refer to the EVPN VPWS Preferred Path over SR-TE Policy and L2VPN VPLS or VPWS Preferred Path over SR-TE Policy sections in the "L2VPN Services over Segment Routing for Traffic Engineering Policy" chapter of the *L2VPN and Ethernet Services Configuration Guide*.

Static Route over Segment Routing Policy

This feature allows you to specify a Segment Routing (SR) policy as an interface type when configuring static routes for MPLS data planes.

For information on configuring static routes, see the "Implementing Static Routes" chapter in the *Routing Configuration Guide for Cisco NCS 560 Series Routers*.

Configuration Example

The following example depicts a configuration of a static route for an IPv4 destination over an SR policy according to following parameters:

- Target SR policy:
  - Color = 200
  - End-point = 10.1.1.4
  - Auto-generated SR policy name = srte_c_200_ep_10.1.1.4

Note Use the auto-generated SR-TE policy name to attach the SR policy to the static route. Auto-generated SR policy names use the following naming convention: **srte_c_***color_val***_ep_***endpoint-address*.

Use the show segment-routing traffic-eng policy color <color_val> endpoint ipv4 <ip_addr> command to display the auto-generated policy name.

- Admin distance = 40

- Load metric = 150
- Install the route in RIB regardless of reachability

```
Router(config)# router static
Router(config-static)# address-family ipv4 unicast
Router(config-static-afi)# 10.1.1.4/32 sr-policy srte_c_200_ep_10.1.1.4 40 permanent metric
 150
```

Running Configuration

```
router static
 address-family ipv4 unicast
  10.1.1.4/32 sr-policy srte_c_200_ep_10.1.1.4 40 permanent metric 150
 !
!
```

Verification

```
RP/0/RP0/CPU0:RTR-1# show run segment-routing traffic-eng policy sample-policy-foo
Tue Feb 16 17:40:16.759 PST
segment-routing
 traffic-eng
  policy sample-policy-foo
   color 200 end-point ipv4 10.1.1.4
   candidate-paths
    preference 100
     dynamic
      metric
       type te
      !
     !
    !
   !
  !
 !
!

RP/0/RP0/CPU0:RTR-1# show segment-routing traffic-eng policy color 200 endpoint ipv4 10.1.1.4
Tue Feb 16 17:17:45.724 PST

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

Color: 200, End-point: 10.1.1.4
  Name: srte_c_200_ep_10.1.1.4
  Status:
    Admin: up  Operational: up for 5d04h (since Feb 11 12:22:59.054)
  Candidate-paths:
    Preference: 100 (configuration) (active)
      Name: sample-policy-foo
      Requested BSID: dynamic
        Protection Type: protected-preferred
        Maximum SID Depth: 10
      Dynamic (valid)
        Metric Type: TE,   Path Accumulated Metric: 14
          16005 [Prefix-SID, 10.1.1.5]
          16004 [Prefix-SID, 10.1.1.4]
  Attributes:
    Binding SID: 24014
    Forward Class: Not Configured
    Steering labeled-services disabled: no
    Steering BGP disabled: no
    IPv6 caps enable: yes
    Invalidation drop enabled: no

RP/0/RP0/CPU0:RTR-1# show static sr-policy srte_c_200_ep_10.1.1.4
Tue Feb 16 17:50:19.932 PST

Interface                VRF                 State     Paths
srte_c_200_ep_10.1.1.4   default             Up        10.1.1.4/32
Reference Count(in path with both intf<-->NH):0
Last IM notification was Up at Feb 16 17:09:08.325

     Global ifh          : 0x0000007c
     IM state            : up
     RSI registration    : Yes
     Table IDs           : 0xe0000000

     Address Info:
      10.1.1.1/32
      Route tag: 0x00000000 Flags: 0x00000000 Prefix SID: False [Active]

IP-STATIC-IDB-CLASS
 Total entries : 1
 Interface     : sr-srte_c_200_ep_10.1.1.4
| Event Name               | Time Stamp           | S, M
| idb-create               | Feb 16 17:09:08.352  | 0, 0


RP/0/RP0/CPU0:RTR-1# show route 10.1.1.4/32
Tue Feb 16 17:09:21.164 PST

Routing entry for 10.1.1.4/32
  Known via "static", distance 40, metric 0 (connected)
  Installed Feb 16 17:09:08.325 for 00:00:13
  Routing Descriptor Blocks
    directly connected, via srte_c_200_ep_10.1.1.4, permanent
      Route metric is 0, Wt is 150
  No advertising protos.


RP/0/RP0/CPU0:RTR-1# show route 10.1.1.4/32 detail
Tue Feb 16 17:09:36.718 PST

Routing entry for 10.1.1.4/32
  Known via "static", distance 40, metric 0 (connected)
  Installed Feb 16 17:09:08.325 for 00:00:28
  Routing Descriptor Blocks
    directly connected, via srte_c_200_ep_10.1.1.4, permanent
      Route metric is 0, Wt is 150
      Label: None
      Tunnel ID: None
      Binding Label: None
      Extended communities count: 0
      NHID:0x0(Ref:0)
  Route version is 0x4a (74)
  Local Label: 0x3e84 (16004)
  IP Precedence: Not Set
  QoS Group ID: Not Set
  Flow-tag: Not Set
  Fwd-class: Not Set
  Route Priority: RIB_PRIORITY_RECURSIVE (9) SVD Type RIB_SVD_TYPE_LOCAL
  Download Priority 3, Download Version 258
  No advertising protos.

RP/0/RP0/CPU0:RTR-1# show cef 10.1.1.4/32 detail
Tue Feb 16 17:10:06.956 PST
10.1.1.4/32, version 258, attached, internal 0x1000441 0x30 (ptr 0xd3f0d30) [1], 0x0
(0xe46f960), 0xa20 (0xe9694e0)
 Updated Feb 16 17:09:08.328
 Prefix Len 32, traffic index 0, precedence n/a, priority 3
  gateway array (0xe2d9a08) reference count 2, flags 0x8068, source rib (7), 0 backups
                [3 type 4 flags 0x108401 (0xe9aeb98) ext 0x0 (0x0)]
  LW-LDI[type=1, refc=1, ptr=0xe46f960, sh-ldi=0xe9aeb98]
  gateway array update type-time 1 Feb 16 17:07:59.946
 LDI Update time Feb 16 17:07:59.946
 LW-LDI-TS Feb 16 17:07:59.946
   via srte_c_200_ep_10.1.1.4, 5 dependencies, weight 0, class 0 [flags 0xc]
    path-idx 0 NHID 0x0 [0xf3b1a30 0x0]
    local adjacency
     local label 16004      labels imposed {None}

    Load distribution: 0 (refcount 3)

    Hash  OK  Interface                 Address
    0     Y   srte_c_200_ep_10.1.1.4    point2point

RP/0/RP0/CPU0:RTR-1# show mpls forwarding labels 16004 detail
Tue Feb 16 17:27:59.831 PST
Local  Outgoing    Prefix             Outgoing     Next Hop        Bytes
Label  Label       or ID              Interface                    Switched
------ ----------- ------------------ ------------ --------------- ------------
16004  Unlabelled  SR Pfx (idx 4)     srte_c_200_e point2point     990
     Updated: Feb 16 17:07:59.945
     Path Flags: 0xc [  ]
     Version: 258, Priority: 3
     Label Stack (Top -> Bottom): { Unlabelled Unlabelled }
     NHID: 0x0, Encap-ID: N/A, Path idx: 0, Backup path idx: 0, Weight: 0
     MAC/Encaps: 0/0, MTU: 0
     Outgoing Interface: srte_c_200_ep_10.1.1.4 (ifhandle 0x0000007c)
     Packets Switched: 20
```

Autoroute Include

You can configure SR-TE policies with Autoroute Include to steer specific IGP (IS-IS, OSPF) prefixes, or all prefixes, over non-shortest paths and to divert the traffic for those prefixes on to the SR-TE policy.

The **autoroute include all** option applies Autoroute Announce functionality for all destinations or prefixes.

The **autoroute include ipv4** *address* option applies Autoroute Destination functionality for the specified destinations or prefixes. This option is supported for IS-IS only; it is not supported for OSPF.

The Autoroute SR-TE policy adds the prefixes into the IGP, which determines if the prefixes on the endpoint or downstream of the endpoint are eligible to use the SR-TE policy. If a prefix is eligible, then the IGP checks if the prefix is listed in the Autoroute Include configuration. If the prefix is included, then the IGP downloads the prefix route with the SR-TE policy as the outgoing path.

Usage Guidelines and Limitations

- Autoroute Include supports three metric types:
  - Default (no metric): The path over the SR-TE policy inherits the shortest path metric.

- Absolute (constant) metric: The shortest path metric to the policy endpoint is replaced with the configured absolute metric. The metric to any prefix that is Autoroute Included is modified to the absolute metric. Use the **autoroute metric constant** *constant-metric* command, where *constant-metric* is from 1 to 2147483647.
- Relative metric: The shortest path metric to the policy endpoint is modified with the relative value configured (plus or minus). Use the **autoroute metric relative** *relative-metric* command, where *relative-metric* is from -10 to +10.

Note To prevent load-balancing over IGP paths, you can specify a metric that is lower than the value that IGP takes into account for autorouted destinations (for example, **autoroute metric relative -1**).

Configuration Examples

The following example shows how to configure autoroute include for all prefixes:

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)#policy P1
Router(config-sr-te-policy)# color 20 end-point ipv4 10.1.1.2
Router(config-sr-te-policy)# autoroute include all
Router(config-sr-te-policy)# candidate-paths
Router(config-sr-te-policy-path)# preference 100
Router(config-sr-te-pp-index)# explicit segment-list Plist-1
```

The following example shows how to configure autoroute include for the specified IPv4 prefixes:

Note This option is supported for IS-IS only; it is not supported for OSPF.

```
Router# configure
Router(config)# segment-routing
Router(config-sr)# traffic-eng
Router(config-sr-te)#policy P1
Router(config-sr-te-policy)# color 20 end-point ipv4 10.1.1.2
Router(config-sr-te-policy)# autoroute include ipv4 10.1.1.21/32
Router(config-sr-te-policy)# autoroute include ipv4 10.1.1.23/32
Router(config-sr-te-policy)# autoroute metric constant 1
Router(config-sr-te-policy)# candidate-paths
Router(config-sr-te-policy-path)# preference 100
Router(config-sr-te-pp-index)# explicit segment-list Plist-1
```

Miscellaneous

LDP over Segment Routing Policy

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)
```

SR-TE MPLS Label Imposition Enhancement

The SR-TE MPLS Label Imposition Enhancement feature increases the maximum label imposition capabilities of the platform.

In previous releases, the platform supported:

- Up to 5 MPLS transport labels when no MPLS service labels are imposed
- Up to 3 MPLS transport labels when MPLS service labels are imposed

With the SR-TE MPLS Label Imposition Enhancement feature, the platform supports the following:

- Up to 12 MPLS transport labels when no MPLS service labels are imposed
- Up to 9 MPLS transport labels when MPLS service labels are imposed

This enhancement is enabled and disabled dynamically, as the label count changes. For example, if a path requires only 3 MPLS transport labels, the MPLS Label Imposition Enhancement feature is not enabled.

You can disable labeled services for SR-TE policies. The label switching database (LSD) needs to know if labeled services are disabled on top of an SR-TE policy to perform proper label stack splitting.

Disable Labeled Services per Local Policy

Use the **labeled-services disable** command to disable steering for labeled services for a configured policy. This configuration applies per policy.

```
segment-routing
  traffic-eng
    policy policy name
      steering
        labeled-services disable
```

Disable Labeled Services per ODN color

Use the **labeled-services disable** command to disable steering of labeled-services for on-demand color policies. This configuration applies for a specific ODN color.

```
segment-routing
  traffic-eng
    on-demand color color
      steering
        labeled-services disable
```

Disable Labeled Services per Policy Type

Use the **labeled-services disable** command to disable steering of labeled services for all policies for the following policy types:

- **all** — all policies
- **local** — all locally configured policies
- **on-demand** — all BGP on-demand color policies
- **bgp-srte** — all controller-initiated BGP SR-TE policies
- **pcep** — all PCE-initiated policies

Note You can specify more than one policy type.

```
segment-routing
  traffic-eng
    steering
      labeled-services
         disable {all | local | on-demand | bgp-srte | pcep}
```

Verification

Use the **show segment-routing traffic-eng policy** command to display SR policy information. The following output shows that steering of labeled services for the on-demand SR policy are disabled.

```
Router# show segment-routing traffic-eng policy color 10
Thu Jul 18 11:35:25.124 PDT

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

Color: 10, End-point: 10.1.1.8
  Name: srte_c_10_ep_10.1.1.8
  Status:
    Admin: up  Operational: up for 00:00:06 (since Jul 18 11:35:19.350)
  Candidate-paths:
    Preference: 1 (configuration) (active)
      Name: test_pol_2
      Requested BSID: dynamic
      Dynamic (valid)
        Metric Type: TE,   Path Accumulated Metric: 10
          24004 [Adjacency-SID, 10.1.1.1 - 10.1.1.2]
  Attributes:
    Binding SID: 24011
    Forward Class: 0
    Steering labeled-services disabled: yes
    Steering BGP disabled: no
    IPv6 caps enable: yes
```

SR-TE Reoptimization Timers

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

Re-optimization can occur due to the following events:

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

For event-based re-optimization, you can specify various delay timers for path re-optimization. For example, you can specify how long to wait before switching to a reoptimized path

Additionally, you can configure a timer to specify how often to perform reoptimization of policies. You can also trigger an immediate reoptimization for a specific policy or for all policies.

SR-TE Reoptimization

To trigger an immediate SR-TE reoptimization, use the **segment-routing traffic-eng reoptimization** command in Exec mode:

```
Router# segment-routing traffic-eng reoptimization {all | name  policy}
```

Use the **all** option to trigger an immediate reoptimization for all policies. Use the **name** *policy* option to trigger an immediate reoptimization for a specific policy.

Configuring SR-TE Reoptimization Timers

Use these commands in SR-TE configuration mode to configure SR-TE reoptimization timers:

- **timers candidate-path cleanup-delay** *seconds*—Specifies the delay before cleaning up candidate paths, in seconds. The range is from 0 (immediate clean-up) to 86400; the default value is 120
- **timers cleanup-delay** *seconds*—Specifies the delay before cleaning up previous path, in seconds. The range is from 0 (immediate clean-up) to 300; the default value is 10.
- **timers init-verify-restart** *seconds* —Specifies the delay for topology convergence after the topology starts populating due to a restart, in seconds. The range is from 10 to 10000; the default is 40.
- **timers init-verify-startup** *seconds*—Specifies the delay for topology convergence after topology starts populating for due to startup, in seconds. The range is from 10 to 10000; the default is 300
- **timers init-verify-switchover** *seconds*—Specifies the delay for topology convergence after topology starts populating due to a switchover, in seconds. The range is from 10 to 10000; the default is 60.
- **timers install-delay** *seconds*—Specifies the delay before switching to a reoptimized path, in seconds. The range is from 0 (immediate installation of new path) to 300; the default is 10.
- **timers periodic-reoptimization** *seconds*—Specifies how often to perform periodic reoptimization of policies, in seconds. The range is from 0 to 86400; the default is 600.

Example Configuration

```
Router(config)# segment-routing traffic-eng
Router(config-sr-te)# timers
Router(config-sr-te-timers)# candidate-path cleanup-delay 600
Router(config-sr-te-timers)# cleanup-delay 60
Router(config-sr-te-timers)# init-verify-restart 120
Router(config-sr-te-timers)# init-verify-startup 600
Router(config-sr-te-timers)# init-verify-switchover 30
Router(config-sr-te-timers)# install-delay 60
Router(config-sr-te-timers)# periodic-reoptimization 3000
```

Running Config

```
segment-routing
 traffic-eng
  timers
   install-delay 60
   periodic-reoptimization 3000
   cleanup-delay 60
   candidate-path cleanup-delay 600
   init-verify-restart 120
   init-verify-startup 600
   init-verify-switchover 30
  !
 !
!
```

CHAPTER 7

Configure Segment Routing Path Computation Element

The Segment Routing Path Computation Element (SR-PCE) provides stateful PCE functionality by extending the existing IOS-XR PCEP functionality with additional capabilities. SR-PCE is supported on the MPLS data plane and IPv4 control plane.

Note The Cisco IOS XRv 9000 is the recommended platform to act as the SR-PCE. Refer to the Cisco IOS XRv 9000 Router Installation and Configuration Guide for more information.

About SR-PCE

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.

SR-PCE learns topology information by way of IGP (OSPF or IS-IS) or through BGP Link-State (BGP-LS).

SR-PCE is capable of computing paths using the following methods:

- TE metric—SR-PCE uses the TE metric in its path calculations to optimize cumulative TE metric.
- IGP metric—SR-PCE uses the IGP metric in its path calculations to optimize reachability.
- LSP Disjointness—SR-PCE uses the path computation algorithms to compute a pair of disjoint LSPs. The disjoint paths can originate from the same head-end or different head-ends. Disjoint level refers to the type of resources that should not be shared by the two computed paths. SR-PCE supports the following disjoint path computations:
    - Link – Specifies that links are not shared on the computed paths.

- Node – Specifies that nodes are not shared on the computed paths.
- SRLG – Specifies that links with the same SRLG value are not shared on the computed paths.
- SRLG-node – Specifies that SRLG and nodes are not shared on the computed paths.

When the first request is received with a given disjoint-group ID, the first LSP is computed, encoding the shortest path from the first source to the first destination. When the second LSP request is received with the same disjoint-group ID, information received in both requests is used to compute two disjoint paths: one path from the first source to the first destination, and another path from the second source to the second destination. Both paths are computed at the same time.

Configure SR-PCE

This task explains how to configure SR-PCE.

Before you begin

The Cisco IOS XRv 9000 is the recommended platform to act as the SR-PCE.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**pce** **Example:** `RP/0/RP0/CPU0:router(config)# pce`	Enables PCE and enters PCE configuration mode.
Step 3	**address ipv4** *address* **Example:** `RP/0/RP0/CPU0:router(config-pce)# address ipv4 192.168.0.1`	Configures a PCE IPv4 address.
Step 4	**state-sync ipv4** *address* **Example:** `RP/0/RP0/CPU0:router(config-pce)# state-sync ipv4 192.168.0.3`	Configures the remote peer for state synchronization.

	Command or Action	Purpose
Step 5	**tcp-buffer size** *size* **Example:** `RP/0/RP0/CPU0:router(config-pce)# tcp-buffer size 1024000`	Configures the transmit and receive TCP buffer size for each PCEP session, in bytes. The default buffer size is 256000. The valid range is from 204800 to 1024000.
Step 6	**password** {**clear** | **encrypted**} *password* **Example:** `RP/0/RP0/CPU0:router(config-pce)# password encrypted pwd1`	Enables TCP MD5 authentication for all PCEP peers. 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.

Step 7	**segment-routing** {**strict-sid-only** | **te-latency**}
	Example:
	`RP/0/RP0/CPU0:router(config-pce)# segment-routing strict-sid-only`
		Configures the segment routing algorithm to use strict SID or TE latency.
		Note This setting is global and applies to all LSPs that request a path from this controller.

Step 8	**timers** **Example:** `RP/0/RP0/CPU0:router(config-pce)# timers`	Enters timer configuration mode.
Step 9	**keepalive** *time* **Example:** `RP/0/RP0/CPU0:router(config-pce-timers)# keepalive 60`	Configures the timer value for locally generated keep-alive messages. The default time is 30 seconds.
Step 10	**minimum-peer-keepalive** *time* **Example:** `RP/0/RP0/CPU0:router(config-pce-timers)# minimum-peer-keepalive 30`	Configures the minimum acceptable keep-alive timer that the remote peer may propose in the PCEP OPEN message during session establishment. The default time is 20 seconds.
Step 11	**reoptimization** *time* **Example:** `RP/0/RP0/CPU0:router(config-pce-timers)# reoptimization 600`	Configures the re-optimization timer. The default timer is 1800 seconds.

	Command or Action	Purpose
Step 12	**exit** **Example:** `RP/0/RP0/CPU0:router(config-pce-timers)# exit`	Exits timer configuration mode and returns to PCE configuration mode.

Configure the Disjoint Policy (Optional)

This task explains how to configure the SR-PCE to compute disjointness for a pair of LSPs signaled by PCCs that do not include the PCEP association group-ID object in their PCEP request. This can be beneficial for deployments where PCCs do not support this PCEP object or when the network operator prefers to manage the LSP disjoint configuration centrally.

Procedure

	Command or Action	Purpose
Step 1	**disjoint-path** **Example:** `RP/0/RP0/CPU0:router(config-pce)# disjoint-path`	Enters disjoint configuration mode.
Step 2	**group-id** *value* **type** {**link** | **node** | **srlg** | **srlg-node**} [**sub-id** *value*] **Example:** `RP/0/RP0/CPU0:router(config-pce-disjoint)# group-id 1 type node sub-id 1`	Configures the disjoint group ID and defines the preferred level of disjointness (the type of resources that should not be shared by the two paths): • **link**—Specifies that links are not shared on the computed paths. • **node**—Specifies that nodes are not shared on the computed paths. • **srlg**—Specifies that links with the same SRLG value are not shared on the computed paths. • **srlg-node**—Specifies that SRLG and nodes are not shared on the computed paths. If a pair of paths that meet the requested disjointness level cannot be found, then the paths will automatically fallback to a lower level:

	Command or Action	Purpose
		• If the requested disjointness level is SRLG or node, then link-disjoint paths will be computed. • If the requested disjointness level was link, or if the first fallback from SRLG or node disjointness failed, then the lists of segments encoding two shortest paths, without any disjointness constraint, will be computed.
Step 3	**strict** **Example:** `RP/0/RP0/CPU0:router(config-pce-disjoint)# strict`	(Optional) Prevents the automatic fallback behavior of the preferred level of disjointness. If a pair of paths that meet the requested disjointness level cannot be found, the disjoint calculation terminates and no new path is provided. The existing path is not modified.

Step 4	**lsp** {**1** | **2**} **pcc ipv4** *address* **lsp-name** *lsp_name* [**shortest-path**]
	Example:
	`RP/0/RP0/CPU0:router(config-pce-disjoint)# lsp 1 pcc ipv4 192.168.0.1 lsp-name rtrA_t1 shortest-path`
	`RP/0/RP0/CPU0:router(config-pce-disjoint)# lsp 2 pcc ipv4 192.168.0.5 lsp-name rtrE_t2`
		Adds LSPs to the disjoint group.
		The **shortest-path** keyword forces one of the disjoint paths to follow the shortest path from the source to the destination. This option can only be applied to the the first LSP specified.

PCE-Initiated SR Policies

An SR-TE policy can be configured on the path computation element (PCE) to reduce link congestion or to minimize the number of network touch points.

Note The PCE-initiated SR-TE policies are entered in PCE configuration mode. For more information on configuring SR-TE policies, see the SR-TE Policy Overview, on page 53.

To minimize the number of network touch points, an application, such as a Network Services Orchestrator (NSO), can request the PCE to create an SR-TE policy. PCE deploys the SR-TE policy using PCC-PCE communication protocol (PCEP).

1. PCE sends a PCInitiate message to the PCC.
2. If the PCInitiate message is valid, the PCC sends a PCRpt message; otherwise, it sends PCErr message.
3. If the PCInitiate message is accepted, the PCE updates the SR-TE policy by sending PCUpd message.

You can achieve high-availability by configuring multiple PCEs with SR-TE policies. If the head-end (PCC) loses connectivity with one PCE, another PCE can assume control of the SR-TE policy.

Configuration Example: PCE-Initiated SR Policy with Explicit SID List

To configure a PCE-initiated SR-TE policy, you must complete the following configurations:

1. Enter PCE configuration mode.
2. Create the segment list.

Note When configuring an explicit path using IP addresses of intermediate links, the SR-TE process selects either the protected or the unprotected Adj-SID of the link, depending on the order in which the Adj-SIDs were received.

3. Create the policy.

```
/* Enter PCE configuration mode and create the SR-TE segment lists */
Router# configure
Router(config)# pce

/* Create the SR-TE segment lists */
Router(config-pce)# segment-routing
Router(config-pce-sr)# traffic-eng
Router(config-pce-sr-te)# segment-list name addr2a
Router(config-pce-sr-te-sl)# index 10 address ipv4 10.1.1.2
Router(config-pce-sr-te-sl)# index 20 address ipv4 10.2.3.2
Router(config-pce-sr-te-sl)# index 30 address ipv4 10.1.1.4
Router(config-pce-sr-te-sl)# exit

/* Create the SR-TE policy */
Router(config-pce-sr-te)# peer ipv4 10.1.1.1
Router(config-pce-sr-te)# policy P1
Router(config-pce-sr-te-policy)# color 2 end-point ipv4 2.2.2.2
Router(config-pce-sr-te-policy)# candidate-paths
Router(config-pce-sr-te-policy-path)# preference 50
Router(config-pce-sr-te-policy-path-preference)# explicit segment-list addr2a
Router(config-pce-sr-te-pp-info)# commit
Router(config-pce-sr-te-pp-info)# end
Router(config)#
```

Running Config

```
pce
 segment-routing
  traffic-eng
   segment-list name addr2a
    index 10 address ipv4 10.1.1.2
    index 20 address ipv4 10.2.3.2
    index 30 address ipv4 10.1.1.4
   !
   peer ipv4 10.1.1.1
    policy P1
     color 2 end-point ipv4 2.2.2.2
     candidate-paths
     preference 50
      explicit segment-list addr2a
     !
    !
```

ACL Support for PCEP Connection

PCE protocol (PCEP) (RFC5440) is a client-server model running over TCP/IP, where the server (PCE) opens a port and the clients (PCC) initiate connections. After the peers establish a TCP connection, they create a PCE session on top of it.

The ACL Support for PCEP Connection feature provides a way to protect a PCE server using an Access Control List (ACL) to restrict IPv4 PCC peers at the time the TCP connection is created based on the source address of a client. When a client initiates the TCP connection, the ACL is referenced, and the client source address is compared. The ACL can either permit or deny the address and the TCP connection will proceed or not.

Refer to the Implementing Access Lists and Prefix Lists chapter in the *IP Addresses and Services Configuration Guide for Cisco NCS 560 Series Routers* for detailed ACL configuration information.

To apply an ACL to the PCE, use the **pce peer-filter ipv4 access-list** *acl_name* command.

The following example shows how to configure an ACL and apply it to the PCE:

```
pce
 address ipv4 10.1.1.5
 peer-filter ipv4 access-list sample-peer-filter
!
ipv4 access-list sample-peer-filter
 10 permit ipv4 host 10.1.1.6 any
 20 permit ipv4 host 10.1.1.7 any
 30 deny ipv4 any any
!
```

CHAPTER 8

Configure Topology-Independent Loop-Free Alternate (TI-LFA)

Topology-Independent Loop-Free Alternate (TI-LFA) uses segment routing to provide link, node, and Shared Risk Link Groups (SRLG) protection in topologies where other fast reroute techniques cannot provide protection.

- Classic Loop-Free Alternate (LFA) is topology dependent, and therefore cannot protect all destinations in all networks. A limitation of LFA is that, even if one or more LFAs exist, the optimal LFA may not always be provided.
- Remote LFA (RLFA) extends the coverage to 90-95% of the destinations, but it also does not always provide the most desired repair path. RLFA also adds more operational complexity by requiring a targeted LDP session to the RLFAs to protect LDP traffic.

TI-LFA provides a solution to these limitations while maintaining the simplicity of the IPFRR solution.

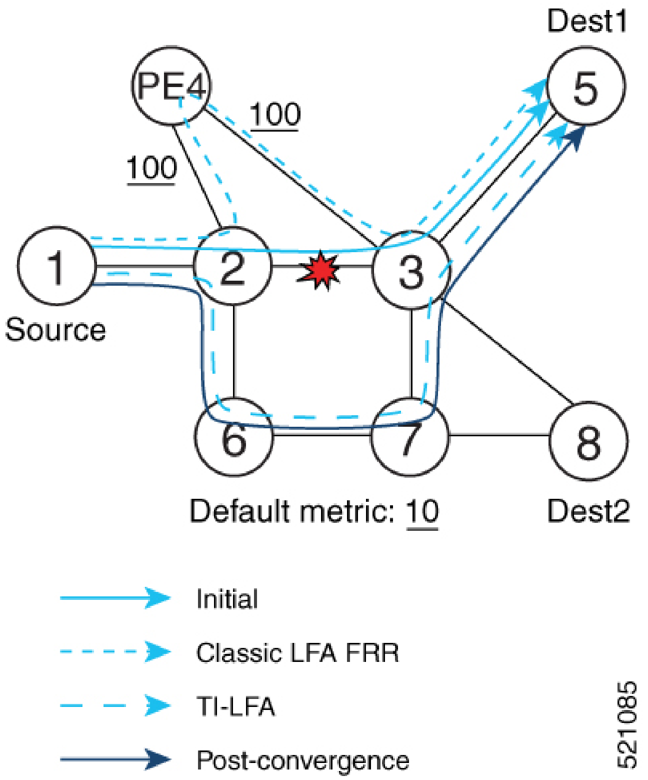
The goal of TI-LFA is to reduce the packet loss that results while routers converge after a topology change due to a link or node failure. Rapid failure repair (< 50 msec) is achieved through the use of pre-calculated backup paths that are loop-free and safe to use until the distributed network convergence process is completed.

The optimal repair path is the path that the traffic will eventually follow after the IGP has converged. This is called the post-convergence path. This path is preferred for the following reasons:

- Optimal for capacity planning — During the capacity-planning phase of the network, the capacity of a link is provisioned while taking into consideration that such link with be used when other links fail.
- Simple to operate — There is no need to perform a case-by-case adjustments to select the best LFA among multiple candidate LFAs.
- Fewer traffic transitions — Since the repair path is equal to the post-convergence path, the traffic switches paths only once.

The following topology illustrates the optimal and automatic selection of the TI-LFA repair path.

Figure 4: TI-LFA Repair Path



Node 2 protects traffic to destination Node 5.

With classic LFA, traffic would be steered to Node 4 after a failure of the protected link. This path is not optimal, since traffic is routed over edge node Node 4 that is connected to lower capacity links.

TI-LFA calculates a post-convergence path and derives the segment list required to steer packets along the post-convergence path without looping back.

In this example, if the protected link fails, the shortest path from Node2 to Node5 would be:

Node2 → Node6 → Node7 → Node3 → Node5

Node7 is the PQ-node for destination Node5. TI-LFA encodes a single segment (prefix SID of Node7) in the header of the packets on the repair path.

TI-LFA Protection Types

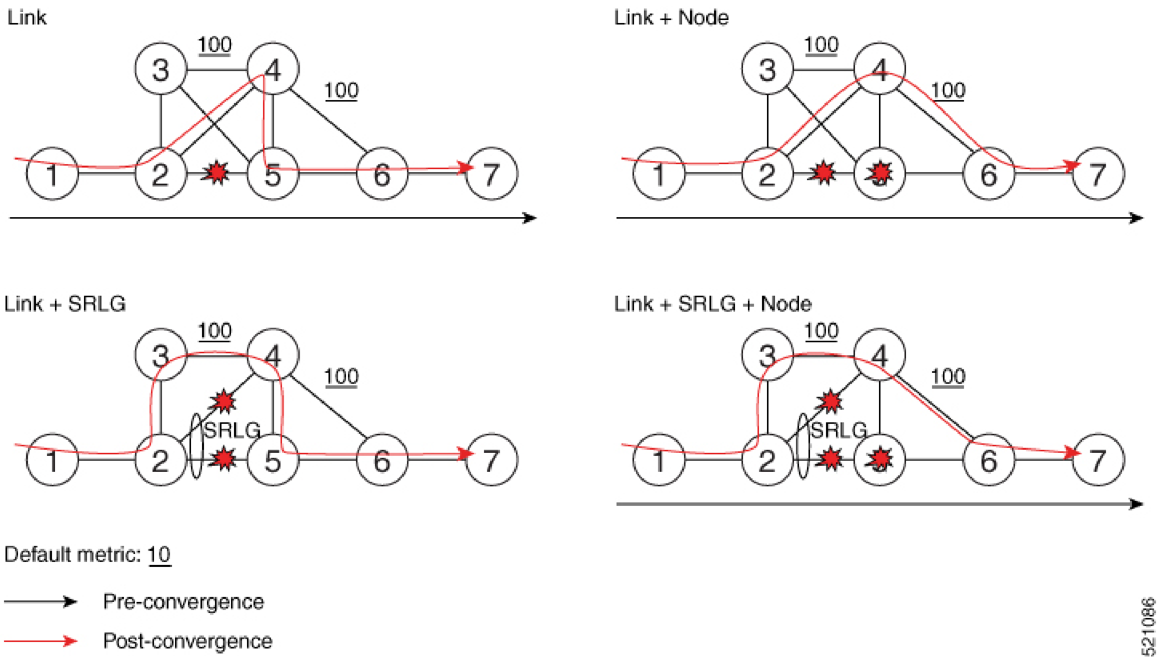
TI-LFA supports the following protection:

- Link protection — The link is excluded during the post-convergence backup path calculation.
- Node protection — The neighbor node is excluded during the post convergence backup path calculation.
- Shared Risk Link Groups (SRLG) protection — SRLG refer to situations in which links in a network share a common fiber (or a common physical attribute). These links have a shared risk: when one link fails, other links in the group might also fail. TI-LFA SRLG protection attempts to find the post-convergence backup path that excludes the SRLG of the protected link. All local links that share any SRLG with the protecting link are excluded.

When you enable link protection, you can also enable node protection, SRLG protection, or both, and specify a tiebreaker priority in case there are multiple LFAs.

The following example illustrates the link, node, and SRLG protection types. In this topology, Node2 applies different protection models to protect traffic to Node7.

Figure 5: TI-LFA Protection Types



Limitations

Only two backup labels are supported.

Usage Guidelines and Limitations

The TI-LFA guidelines and limitations are listed below:

TI-LFA Functionality	**IS-IS**[1]	**OSPFv2**
Protected Traffic Types		
Protection for SR labeled traffic	Supported	Supported

TI-LFA Functionality	IS-IS[1]	OSPFv2
Protection of IPv4 unlabeled traffic	Supported (IS-ISv4)	Supported
Protection of IPv6 unlabeled traffic	Unsupported	N/A
Protection Types		
Link Protection	Supported	Supported
Node Protection	Supported	Supported
Local SRLG Protection	Supported	Supported
Weighted Remote SRLG Protection	Unsupported	Unsupported
Line Card Disjoint Protection	Unsupported	Unsupported
Interface Types		
Ethernet Interfaces	Supported	Supported
Ethernet Bundle Interfaces	Unsupported	Unsupported
TI-LFA over GRE Tunnel as Protecting Interface	Unsupported	Unsupported
Additional Functionality		
BFD-triggered	Unsupported	Unsupported
BFDv6-triggered	Unsupported	N/A
Prefer backup path with lowest total metric	Unsupported	Unsupported
Prefer backup path from ECMP set	Supported	Supported
Prefer backup path from non-ECMP set	Supported	Supported
Load share prefixes across multiple backups paths	Unsupported	Unsupported
Limit backup computation up to the prefix priority	Supported	Supported

[1] Unless specified, IS-IS support is IS-ISv4 and IS-ISv6

Configuring TI-LFA for IS-IS

This task describes how to enable per-prefix Topology Independent Loop-Free Alternate (TI-LFA) computation to converge traffic flows around link, node, and SRLG failures.

Before you begin

Ensure that the following topology requirements are met:

- Router interfaces are configured as per the topology.
- Routers are configured with IS-IS.

- Segment routing for IS-IS is configured. See Enabling Segment Routing for IS-IS Protocol, on page 15.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router isis** *instance-id* **Example:** `RP/0/RP0/CPU0:router(config)# router isis 1`	Enables IS-IS routing for the specified routing instance, and places the router in router configuration mode. **Note** You can change the level of routing to be performed by a particular routing instance by using the **is-type** router configuration command.
Step 3	**interface** *type interface-path-id* **Example:** `RP/0/RP0/CPU0:router(config-isis)# interface GigabitEthernet0/0/0/1`	Enters interface configuration mode.
Step 4	**address-family ipv4** [**unicast**] **Example:** `RP/0/RP0/CPU0:router(config-isis-if)# address-family ipv4 unicast`	Specifies the IPv4 address family, and enters router address family configuration mode.
Step 5	**fast-reroute per-prefix** **Example:** `RP/0/RP0/CPU0:router(config-isis-if-af)# fast-reroute per-prefix`	Enables per-prefix fast reroute.
Step 6	**fast-reroute per-prefix ti-lfa** **Example:** `RP/0/RP0/CPU0:router(config-isis-if-af)# fast-reroute per-prefix ti-lfa`	Enables per-prefix TI-LFA fast reroute link protection.
Step 7	**fast-reroute per-prefix tiebreaker** {**node-protecting** | **srlg-disjoint**} **index** *priority* **Example:**	Enables TI-LFA node or SRLG protection and specifies the tiebreaker priority. Valid *priority* values are from 1 to 255. The lower the *priority* value, the higher the priority of the rule. Link

	Command or Action	Purpose
	`RP/0/RP0/CPU0:router(config-isis-if-af)# fast-reroute per-prefix tie-breaker srlg-disjoint index 100`	protection always has a lower priority than node or SRLG protection. **Note** The same attribute cannot be configured more than once on an interface. **Note** For IS-IS, TI-LFA node protection and SRLG protection can be configured on the interface or the instance.

TI-LFA has been successfully configured for segment routing.

Configuring TI-LFA for OSPF

This task describes how to enable per-prefix Topology Independent Loop-Free Alternate (TI-LFA) computation to converge traffic flows around link, node, and SRLG failures.

Note TI-LFA can be configured on the instance, area, or interface. When configured on the instance or area, all interfaces in the instance or area inherit the configuration.

Before you begin

Ensure that the following topology requirements are met:

- Router interfaces are configured as per the topology.
- Routers are configured with OSPF.
- Segment routing for OSPF is configured. See Enabling Segment Routing for OSPF Protocol, on page 31.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router ospf** *process-name* **Example:** `RP/0/RP0/CPU0:router(config)# router ospf 1`	Enables OSPF routing for the specified routing process, and places the router in router configuration mode.

	Command or Action	Purpose
Step 3	**area** *area-id* **Example:** `RP/0/RP0/CPU0:router(config-ospf)# area 1`	Enters area configuration mode.
Step 4	**interface** *type interface-path-id* **Example:** `RP/0/RP0/CPU0:router(config-ospf-ar)# interface GigabitEthernet0/0/0/1`	Enters interface configuration mode.
Step 5	**fast-reroute per-prefix** **Example:** `RP/0/RP0/CPU0:router(config-ospf-ar-if)# fast-reroute per-prefix`	Enables per-prefix fast reroute.
Step 6	**fast-reroute per-prefix ti-lfa** **Example:** `RP/0/RP0/CPU0:router(config-ospf-ar-if)# fast-reroute per-prefix ti-lfa`	Enables per-prefix TI-LFA fast reroute link protection.
Step 7	**fast-reroute per-prefix tiebreaker** {**node-protecting** | **srlg-disjoint**} **index** *priority* **Example:** `RP/0/RP0/CPU0:router(config-ospf-ar-if)# fast-reroute per-prefix tie-breaker srlg-disjoint index 100`	Enables TI-LFA node or SRLG protection and specifies the tiebreaker priority. Valid *priority* values are from 1 to 255. The lower the *priority* value, the higher the priority of the rule. Link protection always has a lower priority than node or SRLG protection. **Note** The same attribute cannot be configured more than once on an interface.

TI-LFA has been successfully configured for segment routing.

TI-LFA Node and SRLG Protection: Examples

The following examples show the configuration of the tiebreaker priority for TI-LFA node and SRLG protection, and the behavior of post-convergence backup-path. These examples use OSPF, but the same configuration and behavior applies to IS-IS.

Example: Enable link-protecting and node-protecting TI-LFA

```
router ospf 1
 area 1
  interface GigabitEthernet0/0/2/1
```

```
    fast-reroute per-prefix
    fast-reroute per-prefix ti-lfa
    fast-reroute per-prefix tiebreaker node-protecting index 100
```

Both link-protecting and node-protecting TI-LFA backup paths will be computed. If the priority associated with the node-protecting tiebreaker is higher than any other tiebreakers, then node-protecting post-convergence backup paths will be selected, if it is available.

Example: Enable link-protecting and SRLG-protecting TI-LFA

```
router ospf 1
 area 1
  interface GigabitEthernet0/0/2/1
    fast-reroute per-prefix
    fast-reroute per-prefix ti-lfa
    fast-reroute per-prefix tiebreaker srlg-disjoint index 100
```

Both link-protecting and SRLG-protecting TI-LFA backup paths will be computed. If the priority associated with the SRLG-protecting tiebreaker is higher than any other tiebreakers, then SRLG-protecting post-convergence backup paths will be selected, if it is available.

Example: Enable link-protecting, node-protecting and SRLG-protecting TI-LFA

```
router ospf 1
 area 1
  interface GigabitEthernet0/0/2/1
    fast-reroute per-prefix
    fast-reroute per-prefix ti-lfa
    fast-reroute per-prefix tiebreaker node-protecting index 100
    fast-reroute per-prefix tiebreaker srlg-disjoint index 200
```

Link-protecting, node-protecting, and SRLG-protecting TI-LFA backup paths will be computed. If the priority associated with the node-protecting tiebreaker is highest from all tiebreakers, then node-protecting post-convergence backup paths will be selected, if it is available. If the node-protecting backup path is not available, SRLG-protecting post-convergence backup path will be used, if it is available.

Configuring Global Weighted SRLG Protection

A shared risk link group (SRLG) is a set of links sharing a common resource and thus shares the same risk of failure. The existing loop-free alternate (LFA) implementations in interior gateway protocols (IGPs) support SRLG protection. However, the existing implementation considers only the directly connected links while computing the backup path. Hence, SRLG protection may fail if a link that is not directly connected but shares the same SRLG is included while computing the backup path. Global weighted SRLG protection feature provides better path selection for the SRLG by associating a weight with the SRLG value and using the weights of the SRLG values while computing the backup path.

To support global weighted SRLG protection, you need information about SRLGs on all links in the area topology. For IS-IS, you can flood SRLGs for remote links or manually configuring SRLGs on remote links.

The administrative weight (cost) of the SRLG can be configured using the **admin-weight** command. This command can be applied for all SRLG (global), or for a specific (named) SRLG. The default (global) admin-weight value is 1 for IS-IS.

Configuration Examples: Global Weighted SRLG Protection for IS-IS

There are three types of configurations that are supported for the global weighted SRLG protection feature for IS-IS:

- Local SRLG with global weighted SRLG protection
- Remote SRLG flooding
- Remote SRLG static provisioning

This example shows how to configure the local SRLG with global weighted SRLG protection feature.

```
RP/0/RP0/CPU0:router(config)# srlg
RP/0/RP0/CPU0:router(config-srlg)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-srlg-if)# name group1
RP/0/RP0/CPU0:router(config-srlg-if)# exit
RP/0/RP0/CPU0:router(config-srlg)# interface TenGigE0/0/0/1
RP/0/RP0/CPU0:router(config-srlg-if)# name group1
RP/0/RP0/CPU0:router(config-srlg)# exit
RP/0/RP0/CPU0:router(config-srlg)# name group1 value 100
RP/0/RP0/CPU0:router(config-srlg)# exit
RP/0/RP0/CPU0:router(config)# router isis 1
RP/0/RP0/CPU0:router(config-isis)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-isis-af)# fast-reroute per-prefix srlg-protection weighted-global
RP/0/RP0/CPU0:router(config-isis-af)# fast-reroute per-prefix tiebreaker srlg-disjoint index
 1
RP/0/RP0/CPU0:router(config-isis-af)# exit
RP/0/RP0/CPU0:router(config-isis)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-isis-if)# point-to-point
RP/0/RP0/CPU0:router(config-isis-if)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-isis-if-af)# fast-reroute per-prefix
RP/0/RP0/CPU0:router(config-isis-if-af)# fast-reroute per-prefix ti-lfa
RP/0/RP0/CPU0:router(config-isis-if-af)# exit
RP/0/RP0/CPU0:router(config-isis-if)# exit
RP/0/RP0/CPU0:router(config-isis)# srlg
RP/0/RP0/CPU0:router(config-isis-srlg)# name group1
RP/0/RP0/CPU0:router(config-isis-srlg-name)# admin-weight 5000
```

This example shows how to configure the global weighted SRLG protection feature with remote SRLG flooding. The configuration includes local and remote router configuration. On the local router, the global weighted SRLG protection is enabled by using the **fast-reroute per-prefix srlg-protection weighted-global** command. In the remote router configuration, you can control the SRLG value flooding by using the **advertise application lfa link-attributes srlg** command. You should also globally configure SRLG on the remote router.

The local router configuration for global weighted SRLG protection with remote SRLG flooding is as follows:

```
RP/0/RP0/CPU0:router(config)# router isis 1
RP/0/RP0/CPU0:router(config-isis)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-isis-af)# fast-reroute per-prefix srlg-protection weighted-global
RP/0/RP0/CPU0:router(config-isis-af)# fast-reroute per-prefix tiebreaker srlg-disjoint index
 1
RP/0/RP0/CPU0:router(config-isis-af)# exit
RP/0/RP0/CPU0:router(config-isis)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-isis-if)# point-to-point
RP/0/RP0/CPU0:router(config-isis-if)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-isis-if-af)# fast-reroute per-prefix
RP/0/RP0/CPU0:router(config-isis-if-af)# fast-reroute per-prefix ti-lfa
RP/0/RP0/CPU0:router(config-isis-if-af)# exit
RP/0/RP0/CPU0:router(config-isis-if)# exit
```

```
RP/0/RP0/CPU0:router(config-isis)# srlg
RP/0/RP0/CPU0:router(config-isis-srlg)# name group1
RP/0/RP0/CPU0:router(config-isis-srlg-name)# admin-weight 5000
```

The remote router configuration for global weighted SRLG protection with remote SRLG flooding is as follows:

```
RP/0/RP0/CPU0:router(config)# srlg
RP/0/RP0/CPU0:router(config-srlg)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-srlg-if)# name group1
RP/0/RP0/CPU0:router(config-srlg-if)# exit
RP/0/RP0/CPU0:router(config-srlg)# interface TenGigE0/0/0/1
RP/0/RP0/CPU0:router(config-srlg-if)# name group1
RP/0/RP0/CPU0:router(config-srlg-if)# exit
RP/0/RP0/CPU0:router(config-srlg)# name group1 value 100
RP/0/RP0/CPU0:router(config-srlg)# exit
RP/0/RP0/CPU0:router(config)# router isis 1
RP/0/RP0/CPU0:router(config-isis)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-isis-af)# advertise application lfa link-attributes srlg
```

This example shows configuring the global weighted SRLG protection feature with static provisioning of SRLG values for remote links. You should perform these configurations on the local router.

```
RP/0/RP0/CPU0:router(config)# srlg
RP/0/RP0/CPU0:router(config-srlg)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-srlg-if)# name group1
RP/0/RP0/CPU0:router(config-srlg-if)# exit
RP/0/RP0/CPU0:router(config-srlg)# interface TenGigE0/0/0/1
RP/0/RP0/CPU0:router(config-srlg-if)# name group1
RP/0/RP0/CPU0:router(config-srlg-if)# exit
RP/0/RP0/CPU0:router(config-srlg)# name group1 value 100
RP/0/RP0/CPU0:router(config-srlg)# exit
RP/0/RP0/CPU0:router(config)# router isis 1
RP/0/RP0/CPU0:router(config-isis)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-isis-af)# fast-reroute per-prefix srlg-protection weighted-global
RP/0/RP0/CPU0:router(config-isis-af)# fast-reroute per-prefix tiebreaker srlg-disjoint index
 1
RP/0/RP0/CPU0:router(config-isis-af)# exit
RP/0/RP0/CPU0:router(config-isis)# interface TenGigE0/0/0/0
RP/0/RP0/CPU0:router(config-isis-if)# point-to-point
RP/0/RP0/CPU0:router(config-isis-if)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-isis-if-af)# fast-reroute per-prefix
RP/0/RP0/CPU0:router(config-isis-if-af)# fast-reroute per-prefix ti-lfa
RP/0/RP0/CPU0:router(config-isis-if-af)# exit
RP/0/RP0/CPU0:router(config-isis-if)# exit
RP/0/RP0/CPU0:router(config-isis)# srlg
RP/0/RP0/CPU0:router(config-isis-srlg)# name group1
RP/0/RP0/CPU0:router(config-isis-srlg-name)# admin-weight 5000
RP/0/RP0/CPU0:router(config-isis-srlg-name)# static ipv4 address 10.0.4.1 next-hop ipv4
address 10.0.4.2
RP/0/RP0/CPU0:router(config-isis-srlg-name)# static ipv4 address 10.0.4.2 next-hop ipv4
address 10.0.4.1
```

CHAPTER 9

Configure Segment Routing Microloop Avoidance

The Segment Routing Microloop Avoidance feature enables link-state routing protocols, such as IS-IS and OSPF, to prevent or avoid microloops during network convergence after a topology change.

About Segment Routing Microloop Avoidance

Microloops are brief packet loops that occur in the network following a topology change (link down, link up, or metric change events). Microloops are caused by the non-simultaneous convergence of different nodes in the network. If nodes converge and send traffic to a neighbor node that has not converged yet, traffic may be looped between these two nodes, resulting in packet loss, jitter, and out-of-order packets.

The Segment Routing Microloop Avoidance feature detects if microloops are possible following a topology change. If a node computes that a microloop could occur on the new topology, the node creates a loop-free SR-TE policy path to the destination using a list of segments. After the RIB update delay timer expires, the SR-TE policy is replaced with regular forwarding paths.

Segment Routing Microloop Avoidance Limitations

For IS-IS, Segment Routing Microloop Avoidance is not supported when incremental shortest path first (ISPF) is configured.

Configure Segment Routing Microloop Avoidance for IS-IS

This task describes how to enable Segment Routing Microloop Avoidance and set the Routing Information Base (RIB) update delay value for IS-IS.

Before you begin

Ensure that the following topology requirements are met:

- Router interfaces are configured as per the topology.

- Routers are configured with IS-IS.
- Segment routing for IS-IS is configured. See Enabling Segment Routing for IS-IS Protocol, on page 15.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router isis** *instance-id* **Example:** `RP/0/RP0/CPU0:router(config)#` **`router isis 1`**	Enables IS-IS routing for the specified routing instance, and places the router in router configuration mode. You can change the level of routing to be performed by a particular routing instance by using the **is-type** router configuration command.

Step 3	**address-family ipv4** [**unicast**]
	Example:
	`RP/0/RP0/CPU0:router(config-isis)#`
	`address-family ipv4 unicast`
		Specifies the IPv4 address family and enters router address family configuration mode.

Step 4	**microloop avoidance segment-routing**
	Example:
	`RP/0/RP0/CPU0:router(config-isis-af)#`
	`microloop avoidance segment-routing`
		Enables Segment Routing Microloop Avoidance.

Step 5	**microloop avoidance rib-update-delay** *delay-time*
	Example:
	`RP/0/RP0/CPU0:router(config-isis-af)#`
	`microloop avoidance rib-update-delay 3000`
		Specifies the amount of time the node uses the microloop avoidance policy before updating its forwarding table. The *delay-time* is in milliseconds. The range is from 1-60000. The default value is 5000.

Configure Segment Routing Microloop Avoidance for OSPF

This task describes how to enable Segment Routing Microloop Avoidance and set the Routing Information Base (RIB) update delay value for OSPF.

Before you begin

Ensure that the following topology requirements are met:

- Router interfaces are configured as per the topology.

- Routers are configured with OSPF.
- Segment routing for OSPF is configured. See Enabling Segment Routing for OSPF Protocol, on page 31.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.
Step 2	**router ospf** *process-name* **Example:** `RP/0/RP0/CPU0:router(config)# router ospf 1`	Enables OSPF routing for the specified routing process, and places the router in router configuration mode.
Step 3	**microloop avoidance segment-routing** **Example:** `RP/0/RP0/CPU0:router(config-ospf)# microloop avoidance segment-routing`	Enables Segment Routing Microloop Avoidance.
Step 4	**microloop avoidance rib-update-delay** *delay-time* **Example:** `RP/0/RP0/CPU0:router(config-ospf)# microloop avoidance rib-update-delay 3000`	Specifies the amount of time the node uses the microloop avoidance policy before updating its forwarding table. The *delay-time* is in milliseconds. The range is from 1-60000. The default value is 5000.

CHAPTER 10

Configure Segment Routing Mapping Server

The mapping server is a key component of the interworking between LDP and segment routing. It enables SR-capable nodes to interwork with LDP nodes. The mapping server advertises Prefix-to-SID mappings in IGP on behalf of other non-SR-capable nodes.

Segment Routing Mapping Server

The mapping server functionality in Cisco IOS XR segment routing centrally assigns prefix-SIDs for some or all of the known prefixes. A router must be able to act as a mapping server, a mapping client, or both.

- A router that acts as a mapping server allows the user to configure SID mapping entries to specify the prefix-SIDs for some or all prefixes. This creates the local SID-mapping policy. The local SID-mapping policy contains non-overlapping SID-mapping entries. The mapping server advertises the local SID-mapping policy to the mapping clients.

- A router that acts as a mapping client receives and parses remotely received SIDs from the mapping server to create remote SID-mapping entries.

- A router that acts as a mapping server and mapping client uses the remotely learnt and locally configured mapping entries to construct the non-overlapping consistent active mapping policy. IGP instance uses the active mapping policy to calculate the prefix-SIDs of some or all prefixes.

The mapping server automatically manages the insertions and deletions of mapping entries to always yield an active mapping policy that contains non-overlapping consistent SID-mapping entries.

- Locally configured mapping entries must not overlap each other.

- The mapping server takes the locally configured mapping policy, as well as remotely learned mapping entries from a particular IGP instance, as input, and selects a single mapping entry among overlapping mapping entries according to the preference rules for that IGP instance. The result is an active mapping policy that consists of non-overlapping consistent mapping entries.

- At steady state, all routers, at least in the same area or level, must have identical active mapping policies.

Usage Guidelines and Restrictions

- The position of the mapping server in the network is not important. However, since the mapping advertisements are distributed in IGP using the regular IGP advertisement mechanism, the mapping server needs an IGP adjacency to the network.
- The role of the mapping server is crucial. For redundancy purposes, you should configure multiple mapping servers in the networks.
- The mapping server functionality does not support a scenario where SID-mapping entries learned through one IS-IS instance are used by another IS-IS instance to determine the prefix-SID of a prefix. For example, mapping entries learnt from remote routers by 'router isis 1' cannot be used to calculate prefix-SIDs for prefixes learnt, advertised, or downloaded to FIB by 'router isis 2'. A mapping server is required for each IS-IS instance.
- Segment Routing Mapping Server does not support Virtual Routing and Forwarding (VRF) currently.

Segment Routing and LDP Interoperability

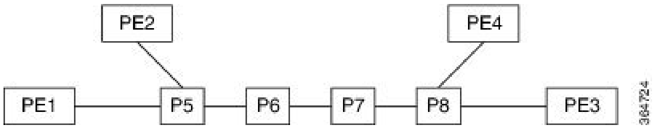
IGP provides mechanisms through which segment routing (SR) interoperate with label distribution protocol (LDP). The control plane of segment routing co-exists with LDP.

The Segment Routing Mapping Server (SRMS) functionality in SR is used to advertise SIDs for destinations, in the LDP part of the network, that do not support SR. SRMS maintains and advertises segment identifier (SID) mapping entries for such destinations. IGP propagates the SRMS mapping entries and interacts with SRMS to determine the SID value when programming the forwarding plane. IGP installs prefixes and corresponding labels, into routing information base (RIB), that are used to program the forwarding information base (FIB).

Example: Segment Routing LDP Interoperability

Consider a network with a mix of segment routing (SR) and label distribution protocol (LDP). A continuous multiprotocol label switching (MPLS) LSP (Labeled Switched Path) can be established by facilitating interoperability. One or more nodes in the SR domain act as segment routing mapping server (SRMS). SRMS advertises SID mappings on behalf of non-SR capable nodes. Each SR-capable node learns about SID assigned to non-SR capable nodes without explicitly configuring individual nodes.

Consider a network as shown in the following image. This network is a mix of both LDP and SR-capable nodes.



In this mixed network:

- Nodes P6, P7, P8, PE4 and PE3 are LDP-capable
- Nodes PE1, PE2, P5 and P6 are SR-capable
- Nodes PE1, PE2, P5 and P6 are configured with segment routing global block (SRGB) of (100, 200)
- Nodes PE1, PE2, P5 and P6 are configured with node segments of 101, 102, 105 and 106 respectively

A service flow must be established from PE1 to PE3 over a continuous MPLS tunnel. This requires SR and LDP to interoperate.

LDP to SR

The traffic flow from LDP to SR (right to left) involves:

1. PE3 learns a service route whose nhop is PE1. PE3 has an LDP label binding from the nhop P8 for the FEC PE1. PE3 forwards the packet P8.
2. P8 has an LDP label binding from its nhop P7 for the FEC PE1. P8 forwards the packet to P7.
3. P7 has an LDP label binding from its nhop P6 for the FEC PE1. P7 forwards the packet to P6.
4. P6 does not have an LDP binding from its nhop P5 for the FEC PE1. But P6 has an SR node segment to the IGP route PE1. P6 forwards the packet to P5 and swaps its local LDP label for FEC PE1 by the equivalent node segment 101. This process is called label merging.
5. P5 pops 101, assuming PE1 has advertised its node segment 101 with the penultimate-pop flag set and forwards to PE1.
6. PE1 receives the tunneled packet and processes the service label.

The end-to-end MPLS tunnel is established from an LDP LSP from PE3 to P6 and the related node segment from P6 to PE1.

SR to LDP

Suppose that the operator configures P5 as a Segment Routing Mapping Server (SRMS) and advertises the mappings (P7, 107), (P8, 108), (PE3, 103) and (PE4, 104). If PE3 was SR-capable, the operator may have configured PE3 with node segment 103. Because PE3 is non-SR capable, the operator configures that policy at the SRMS; the SRMS advertises the mapping on behalf of the non-SR capable nodes. Multiple SRMS servers can be provisioned in a network for redundancy. The mapping server advertisements are only understood by the SR-capable nodes. The SR capable routers install the related node segments in the MPLS data plane in exactly the same manner if node segments were advertised by the nodes themselves.

The traffic flow from SR to LDP (left to right) involves:

1. PE1 installs the node segment 103 with nhop P5 in exactly the same manner if PE3 had advertised node segment 103.
2. P5 swaps 103 for 103 and forwards to P6.
3. The nhop for P6 for the IGP route PE3 is non-SR capable. (P7 does not advertise the SR capability.) However, P6 has an LDP label binding from that nhop for the same FEC. (For example, LDP label 103.) P6 swaps 103 for 103 and forwards to P7. We refer to this process as label merging.
4. P7 swaps this label with the LDP label received from P8 and forwards to P8.
5. P8 pops the LDP label and forwards to PE3.
6. PE3 receives the packet and processes as required.

The end-to-end MPLS LSP is established from an SR node segment from PE1 to P6 and an LDP LSP from P6 to PE3.

Configuring Mapping Server

Perform these tasks to configure the mapping server and to add prefix-SID mapping entries in the active local mapping policy.

Procedure

	Command or Action	Purpose
Step 1	**configure** **Example:** `RP/0/RP0/CPU0:router# configure`	Enters mode.

Step 2	**segment-routing**
	Example:
	`RP/0/RP0/CPU0:router(config)#`
	`segment-routing`
		Enables segment routing.

Step 3	**mapping-server**
	Example:
	`RP/0/RP0/CPU0:router(config-sr)#`
	`mapping-server`
		Enables mapping server configuration mode.

Step 4	**prefix-sid-map**
	Example:
	`RP/0/RP0/CPU0:router(config-sr-ms)#`
	`prefix-sid-map`
		Enables prefix-SID mapping configuration mode.
		Note Two-way prefix SID can be enabled directly under IS-IS or through a mapping server.

Step 5	**address-family ipv4** | **ipv6**
	Example:
	This example shows the address-family for ipv4:
	`RP/0/RP0/CPU0:router(config-sr-ms-map)#`
	`address-family ipv4`
	This example shows the address-family for ipv6:
	`RP/0/RP0/CPU0:router(config-sr-ms-map)#`
	`address-family ipv6`
		Configures address-family for IS-IS.

Step 6	*ip-address/prefix-length first-SID-value* **range** *range*	Adds SID-mapping entries in the active local mapping policy. In the configured example:

	Command or Action	Purpose
	Example: RP/0/RP0/CPU0:router(config-sr-ms-map-af)# **10.1.1.1/32 10 range 200** RP/0/RP0/CPU0:router(config-sr-ms-map-af)# **20.1.0.0/16 400 range 300**	• Prefix 10.1.1.1/32 is assigned prefix-SID 10, prefix 10.1.1.2/32 is assigned prefix-SID 11,…, prefix 10.1.1.199/32 is assigned prefix-SID 200 • Prefix 20.1.0.0/16 is assigned prefix-SID 400, prefix 20.2.0.0/16 is assigned prefix-SID 401,…, and so on.
Step 7	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

Verify information about the locally configured prefix-to-SID mappings.

Note Specify the address family for IS-IS.

```
RP/0/RP0/CPU0:router# show segment-routing mapping-server prefix-sid-map ipv4
Prefix               SID Index    Range        Flags
20.1.1.0/24          400          300
10.1.1.1/32          10           200

Number of mapping entries: 2

RP/0/RP0/CPU0:router# show segment-routing mapping-server prefix-sid-map ipv4 detail
Prefix
20.1.1.0/24
    SID Index:      400
    Range:          300
    Last Prefix:    20.2.44.0/24
    Last SID Index: 699
    Flags:
10.1.1.1/32
    SID Index:      10
    Range:          200
    Last Prefix:    10.1.1.200/32
    Last SID Index: 209
    Flags:

Number of mapping entries: 2
```

What to do next

Enable the advertisement of the local SID-mapping policy in the IGP.

Enable Mapping Advertisement

In addition to configuring the static mapping policy, you must enable the advertisement of the mappings in the IGP.

Perform these steps to enable the IGP to advertise the locally configured prefix-SID mapping.

Configure Mapping Advertisement for IS-IS

Procedure

	Command or Action	Purpose
Step 1	**router isis** *instance-id* **Example:** `RP/0/RP0/CPU0:router(config)# router isis 1`	Enables IS-IS routing for the specified routing instance, and places the router in router configuration mode. • You can change the level of routing to be performed by a particular routing instance by using the **is-type** router configuration command.
Step 2	**address-family** { **ipv4** | **ipv6** } [**unicast**] **Example:** The following is an example for ipv4 address family: `RP/0/RP0/CPU0:router(config-isis)# address-family ipv4 unicast`	Specifies the IPv4 or IPv6 address family, and enters router address family configuration mode.
Step 3	**segment-routing prefix-sid-map advertise-local** **Example:** `RP/0/RP0/CPU0:router(config-isis-af)# segment-routing prefix-sid-map advertise-local`	Configures IS-IS to advertise locally configured prefix-SID mappings.
Step 4	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions:

	Command or Action	Purpose
		• **Yes** — Saves configuration changes and exits the configuration session. • **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

Verify IS-IS prefix-SID mapping advertisement and TLV.

```
RP/0/RP0/CPU0:router# show isis database verbose

<...removed...>

 SID Binding:  10.1.1.1/32 F:0 M:0 S:0 D:0 A:0 Weight:0 Range:200
    SID: Start:10, Algorithm:0, R:0 N:0 P:0 E:0 V:0 L:0
 SID Binding:  20.1.1.0/24 F:0 M:0 S:0 D:0 A:0 Weight:0 Range:300
    SID: Start:400, Algorithm:0, R:0 N:0 P:0 E:0 V:0 L:0
```

Configure Mapping Advertisement for OSPF

Procedure

	Command or Action	Purpose
Step 1	**router ospf** *process-name* **Example:** `RP/0/RP0/CPU0:router(config)# router ospf 1`	Enables OSPF routing for the specified routing instance, and places the router in router configuration mode.
Step 2	**segment-routing prefix-sid-map advertise-local** **Example:** `RP/0/RP0/CPU0:router(config-ospf)# segment-routing prefix-sid-map advertise-local`	Configures OSPF to advertise locally configured prefix-SID mappings.
Step 3	Use the **commit** or **end** command.	**commit** —Saves the configuration changes and remains within the configuration session. **end** —Prompts user to take one of these actions: • **Yes** — Saves configuration changes and exits the configuration session.

	Command or Action	Purpose
		• **No** —Exits the configuration session without committing the configuration changes. • **Cancel** —Remains in the configuration session, without committing the configuration changes.

Verify OSP prefix-SID mapping advertisement and TLV.

```
RP/0/RP0/CPU0:router# show ospf database opaque-area

<...removed...>

    Extended Prefix Range TLV: Length: 24
      AF        : 0
      Prefix    : 10.1.1.1/32
      Range Size: 200
      Flags     : 0x0

      SID sub-TLV: Length: 8
        Flags     : 0x60
        MTID      : 0
        Algo      : 0
        SID Index : 10
```

Enable Mapping Client

By default, mapping client functionality is enabled.

You can disable the mapping client functionality by using the **segment-routing prefix-sid-map receive disable** command.

You can re-enable the mapping client functionality by using the **segment-routing prefix-sid-map receive** command.

The following example shows how to enable the mapping client for IS-IS:

```
RP/0/RP0/CPU0:router(config)# router isis 1
RP/0/RP0/CPU0:router(config-isis)# address-family ipv4 unicast
RP/0/RP0/CPU0:router(config-isis-af)# segment-routing prefix-sid-map receive
```

The following example shows how to enable the mapping client for OSPF:

```
RP/0/RP0/CPU0:router(config)# router ospf 1
RP/0/RP0/CPU0:router(config-ospf)# segment-routing prefix-sid-map receive disable
RP/0/RP0/CPU0:router(config-ospf)# commit
```

CHAPTER 11

Enabling Segment Routing Flexible Algorithm

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

The SR architecture associates prefix-SIDs to an algorithm which defines how the path is computed. Flexible Algorithm allows for user-defined algorithms where the IGP computes paths based on a user-defined combination of metric type and constraint.

This document describes the IS-IS extension to support Segment Routing Flexible Algorithm on an MPLS data-plane.

Prerequisites for Flexible Algorithm

Segment routing must be enabled on the router before the Flexible Algorithm functionality is activated.

Building Blocks of Segment Routing Flexible Algorithm

This section describes the building blocks that are required to support the SR Flexible Algorithm functionality in IS-IS .

Flexible Algorithm Definition

Many possible constraints may be used to compute a path over a network. Some networks are deployed with multiple planes. A simple form of constraint may be to use a particular plane. A more sophisticated form of constraint can include some extended metric, like delay, as described in [RFC7810]. Even more advanced case could be to restrict the path and avoid links with certain affinities. Combinations of these are also possible. To provide a maximum flexibility, the mapping between the algorithm value and its meaning can be defined by the user. When all the routers in the domain have the common understanding what the particular algorithm value represents, the computation for such algorithm is consistent and the traffic is not subject to looping. Here, since the meaning of the algorithm is not defined by any standard, but is defined by the user, it is called a Flexible Algorithm.

Flexible Algorithm Membership

An algorithm defines how the best path is computed by IGP. Routers advertise the support for the algorithm as a node capability. Prefix-SIDs are also advertised with an algorithm value and are tightly coupled with the algorithm itself.

An algorithm is a one octet value. Values from 128 to 255 are reserved for user defined values and are used for Flexible Algorithm representation.

Flexible Algorithm Definition Advertisement

To guarantee the loop free forwarding for paths computed for a particular Flexible Algorithm, all routers in the network must share the same definition of the Flexible Algorithm. This is achieved by dedicated router(s) advertising the definition of each Flexible Algorithm. Such advertisement is associated with the priority to make sure that all routers will agree on a single and consistent definition for each Flexible Algorithm.

Definition of Flexible Algorithm includes:

- Metric type
- Affinity constraints

To enable the router to advertise the definition for the particular Flexible Algorithm, **advertise-definition** command is used. At least one router in the area, preferably two for redundancy, must advertise the Flexible Algorithm definition. Without the valid definition being advertised, the Flexible Algorithm will not be functional.

Flexible Algorithm Prefix-SID Advertisement

To be able to forward traffic on a Flexible Algorithm specific path, all routers participating in the Flexible Algorithm will install a MPLS labeled path for the Flexible Algorithm specific SID that is advertised for the prefix. Only prefixes for which the Flexible Algorithm specific Prefix-SID is advertised is subject to Flexible Algorithm specific forwarding.

Calculation of Flexible Algorithm Path

A router may compute path for multiple Flexible Algorithms. A router must be configured to support particular Flexible Algorithm before it can compute any path for such Flexible Algorithm. A router must have a valid definition of the Flexible Algorithm before Flexible Algorithm is used.

When computing the shortest path tree for particular Flexible Algorithm:

- All nodes that don't advertise support for Flexible Algorithm are pruned from the topology.
- If the Flexible Algorithm definition includes affinities that are excluded, then all links for which any of such affinities are advertised will be pruned from the topology.

- Router uses the metric that is part of the Flexible Algorithm definition. If the metric isn't advertised for the particular link, the link is pruned from the topology.

Configuring Microloop Avoidance for Flexible Algorithm

By default, Microloop Avoidance per Flexible Algorithm instance follows Microloop Avoidance configuration for algo-0. For information about configuring Microloop Avoidance, see Configure Segment Routing Microloop Avoidance, on page 143.

You can disable Microloop Avoidance for Flexible Algorithm using the following commands:

```
router isis instance flex-algo algo microloop avoidance disable
```

```
router ospf process flex-algo algo microloop avoidance disable
```

Configuring LFA / TI-LFA for Flexible Algorithm

By default, LFA/TI-LFA per Flexible Algorithm instance follows LFA/TI-LFA configuration for algo-0. For information about configuring TI-LFA, see Configure Topology-Independent Loop-Free Alternate (TI-LFA), on page 133.

You can disable TI-LFA for Flexible Algorithm using the following commands:

```
router isis instance flex-algo algo fast-reroute disable
```

```
router ospf process flex-algo algo fast-reroute disable
```

Installation of Forwarding Entries for Flexible Algorithm Paths

Flexible Algorithm path to any prefix must be installed in the forwarding using the Prefix-SID that was advertised for such Flexible Algorithm. If the Prefix-SID for Flexible Algorithm is not known, such Flexible Algorithm path is not installed in forwarding for such prefix..

Only MPLS to MPLS entries are installed for a Flexible Algorithm path. No IP to IP or IP to MPLS entries are installed. These follow the native IPG paths computed based on the default algorithm and regular IGP metrics.

Configuring Flexible Algorithm

The following ISIS configuration sub-mode is used to configure Flexible Algorithm:

```
router isis instance flex-algo algo
```

```
router ospf process flex-algo algo
```

algo—value from 128 to 255

Configuring Flexible Algorithm Definitions

The following commands are used to configure Flexible Algorithm definition under the flex-algo sub-mode:

- `metric-type delay`

Note By default the regular IGP metric is used. If delay metric is enabled, the advertised delay on the link is used as a metric for Flexible Algorithm computation.

- **affinity exclude-any** *name1, name2, …*

  name—name of the affinity map

- **priority** *priority value*

  priority value—priority used during the Flexible Algorithm definition election.

The following command is used to enable advertisement of the Flexible Algorithm definition in IS-IS:

```
router isis instance flex-algo algo advertise-definition
```

Configuring Affinity

The following command is used for defining the affinity-map. Affinity-map associates the name with the particular bit positions in the Extended Admin Group bitmask.

```
router isis instance flex-algo algo affinity-map name bit-position bit number
```

```
router ospf process flex-algo algo affinity-map name bit-position bit number
```

- *name*—name of the affinity-map.
- *bit number*—bit position in the Extended Admin Group bitmask.

The following command is used to associate the affinity with an interface:

```
router isis instance interface type interface-path-id affinity flex-algo name 1, name 2, …
```

```
router ospf process area area interface type interface-path-id affinity flex-algo name 1,
name 2, …
```

name—name of the affinity-map

Configuring Prefix-SID Advertisement

The following command is used to advertise prefix-SID for default and strict-SPF algorithm:

```
router isis instance interface type interface-path-id address-family {ipv4 | ipv6} [unicast]
 prefix-sid [strict-spf | algorithm algorithm-number]  [index | absolute] sid value
```

```
router ospf process area area interface Loopback interface-instance prefix-sid [strict-spf
 | algorithm algorithm-number]  [index | absolute] sid value
```

- *algorithm-number*—Flexible Algorithm number
- *sid value*—SID value

Example: Configuring IS-IS Flexible Algorithm

```
router isis 1
 affinity-map red bit-position 65
 affinity-map blue bit-position 8
 affinity-map green bit-position 201

 flex-algo 128
  advertise-definition
  affinity exclude-any red
  affinity include-any blue
 !
 flex-algo 129
  affinity exclude-any green
 !
!
address-family ipv4 unicast
 segment-routing mpls
!
interface Loopback0
 address-family ipv4 unicast
  prefix-sid algorithm 128 index 100
  prefix-sid algorithm 129 index 101
!
!
interface GigabitEthernet0/0/0/0
 affinity flex-algo red
!
interface GigabitEthernet0/0/0/1
 affinity flex-algo blue red
!
interface GigabitEthernet0/0/0/2
 affinity flex-algo blue
!
```

Example: Traffic Steering to Flexible Algorithm Paths

BGP Routes on PE – Color Based Steering

SR-TE On Demand Next-Hop (ODN) feature can be used to steer the BGP traffic towards the Flexible Algorithm paths.

The following example configuration shows how to setup BGP steering local policy, assuming two router: R1 (2.2.2.2) and R2 (4.4.4.4), in the topology.

Configuration on router R1:

```
vrf Test
address-family ipv4 unicast
  import route-target
   1:150
  !
  export route-policy SET_COLOR_RED_HI_BW
  export route-target
   1:150
  !
!
```

```
!
interface Loopback0
ipv4 address 2.2.2.2 255.255.255.255
!
interface Loopback150
vrf Test
ipv4 address 2.2.2.222 255.255.255.255
!
interface TenGigE0/1/0/3/0
description exr1 to cxr1
ipv4 address 10.0.20.2 255.255.255.0
!
extcommunity-set opaque color129-red-igp
  129
end-set
!
route-policy PASS
  pass
end-policy
!
route-policy SET_COLOR_RED_HI_BW
  set extcommunity color color129-red-igp
  pass
end-policy
!
router isis 1
is-type level-2-only
net 49.0001.0000.0000.0002.00
log adjacency changes
affinity-map RED bit-position 28
flex-algo 128
  priority 228
!
address-family ipv4 unicast
  metric-style wide
  advertise link attributes
  router-id 2.2.2.2
  segment-routing mpls
!
interface Loopback0
  address-family ipv4 unicast
   prefix-sid index 2
   prefix-sid algorithm 128 index 282
  !
!
interface TenGigE0/1/0/3/0
  point-to-point
  address-family ipv4 unicast
  !
!
!
router bgp 65000
bgp router-id 2.2.2.2
address-family ipv4 unicast
!
address-family vpnv4 unicast
  retain route-target all
!
neighbor-group RR-services-group
  remote-as 65000
  update-source Loopback0
  address-family ipv4 unicast
  !
  address-family vpnv4 unicast
  !
!
neighbor 4.4.4.4
  use neighbor-group RR-services-group
!
vrf Test
  rd auto
  address-family ipv4 unicast
   redistribute connected
  !
segment-routing
traffic-eng
  logging
   policy status
  !
  segment-list sl-cxr1
   index 10 mpls label 16294
  !
  policy pol-foo
   color 129 end-point ipv4 4.4.4.4
   candidate-paths
    preference 100
     explicit segment-list sl-cxr1
     !
    !
   !
  !
!
!
```

Configuration on router R2:

```
vrf Test
address-family ipv4 unicast
  import route-target
   1:150
  !
  export route-policy SET_COLOR_RED_HI_BW
  export route-target
   1:150
  !
!
!
interface TenGigE0/1/0/1
description cxr1 to exr1
ipv4 address 10.0.20.1 255.255.255.0
!
extcommunity-set opaque color129-red-igp
  129
end-set
!
route-policy PASS
  pass
end-policy
!
route-policy SET_COLOR_RED_HI_BW
  set extcommunity color color129-red-igp
  pass
end-policy
!
router isis 1
is-type level-2-only
net 49.0001.0000.0000.0004.00
log adjacency changes
```

```
affinity-map RED bit-position 28
affinity-map BLUE bit-position 29
affinity-map GREEN bit-position 30
flex-algo 128
  priority 228
!
flex-algo 129
  priority 229
!
flex-algo 130
  priority 230
!
address-family ipv4 unicast
  metric-style wide
  advertise link attributes
  router-id 4.4.4.4
  segment-routing mpls
!
interface Loopback0
  address-family ipv4 unicast
   prefix-sid index 4
   prefix-sid algorithm 128 index 284
   prefix-sid algorithm 129 index 294
   prefix-sid algorithm 130 index 304
  !
!
interface GigabitEthernet0/0/0/0
  point-to-point
  address-family ipv4 unicast
  !
!
interface TenGigE0/1/0/1
  point-to-point
  address-family ipv4 unicast
  !
!
router bgp 65000
bgp router-id 4.4.4.4
address-family ipv4 unicast
!
address-family vpnv4 unicast
!
neighbor-group RR-services-group
  remote-as 65000
  update-source Loopback0
  address-family ipv4 unicast
  !
  address-family vpnv4 unicast
  !
!
neighbor 10.1.1.1
  use neighbor-group RR-services-group
!
neighbor 2.2.2.2
  use neighbor-group RR-services-group
!
vrf Test
  rd auto
  address-family ipv4 unicast
   redistribute connected
  !
  neighbor 25.1.1.2
   remote-as 4
   address-family ipv4 unicast
```

```
    route-policy PASS in
    route-policy PASS out
   !
  !
!
!
segment-routing
!
end
```