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PCE Communication Protocol (PCEP) Extensions for Using PCE as a Central  
Controller (PCECC) for Segment Routing (SR) MPLS Segment Identifier  
(SID) Allocation and Distribution  
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## Abstract

The Path Computation Element (PCE) is a core component of Software-Defined Networking (SDN) systems.

A PCE-based Central Controller (PCECC) can simplify the processing of a distributed control plane by blending it with elements of SDN and without necessarily completely replacing it. Thus, the Label Switched Path (LSP) can be calculated/set up/initiated and the label forwarding entries can also be downloaded through a centralized PCE server to each network device along the path while leveraging the existing PCE technologies as much as possible.

This document specifies the procedures and PCE Communication Protocol (PCEP) extensions when a PCE-based controller is also responsible for configuring the forwarding actions on the routers, in addition to computing the paths for packet flows in a segment routing (SR) network and telling the edge routers what instructions to attach to packets as they enter the network. PCECC as defined in RFC 9050 is further enhanced for SR-MPLS SID (Segment Identifier) allocation and distribution.

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## 1. Introduction

The PCE [RFC4655] was developed to offload the path computation function from routers in an MPLS traffic-engineered network. It can compute optimal paths for traffic across a network and can also update the paths to reflect changes in the network or traffic demands. Since then, the role and function of the PCE has grown to cover a number of other uses (such as GMPLS [RFC7025]) and to allow delegated control [RFC8231] and PCE-initiated use of network resources [RFC8281].

According to [RFC7399], Software-Defined Networking (SDN) refers to a separation between the control elements and the forwarding components so that software running in a centralized system, called a controller, can act to program the devices in the network to behave in specific ways. A required element in an SDN architecture is a component that plans how the network resources will be used and how the devices will be programmed. It is possible to view this component as performing specific computations to place traffic flows within the network given knowledge of the availability of the network resources, how other forwarding devices are programmed, and the way that other flows are routed. This is the function and purpose of a PCE, and the way that a PCE integrates into a wider network control system (including an SDN system) is presented in [RFC7491].

In early PCE implementations, where the PCE was used to derive paths for MPLS Label Switched Paths (LSPs), paths were requested by the network elements (known as Path Computation Clients (PCCs)), and the results of the path computations were supplied to network elements using the PCE Communication Protocol (PCEP) [RFC5440]. This protocol was later extended to allow a PCE to send unsolicited requests to the network for LSP establishment [RFC8281].

PCE was developed to derive paths for MPLS Label Switched Paths (LSPs), which are supplied to the head end of the LSP using PCEP. But SDN has a broader applicability than signaled (G)MPLS traffic-engineered (TE) networks, and the PCE may be used to determine paths in a range of use cases. PCEP has been proposed as a control protocol for use in these environments to allow the PCE to be fully enabled as a central controller.

[RFC8283] introduces the architecture for PCE as a central controller as an extension of the architecture described in [RFC4655] and assumes the continued use of PCEP as the protocol used between PCE and PCC. [RFC8283] further examines the motivations and applicability of PCEP as a Southbound Interface (SBI), and introduces the implications for the protocol. [RFC9689] describes the use cases for the PCE-based Central Controller (PCECC) architecture. As described in [RFC8283], PCECC simplifies the processing of a distributed IGP-based control plane by blending it with elements of SDN, without replacing it.

[RFC9050] specify the procedures and PCEP extensions for using the PCE as the central controller for static LSPs, where LSPs can be provisioned as explicit label instructions at each hop on the end-to-end path.

Segment Routing (SR) technology leverages the source routing and tunneling paradigms. A source node can choose a path without relying on hop-by-hop signaling protocols such as LDP or RSVP-TE. Each path is specified as a set of "segments" advertised by link-state routing protocols (Intermediate System-to-Intermediate System (IS-IS) or Open Shortest Path First (OSPF)). [RFC8402] provides an introduction to SR architecture. The corresponding IS-IS and OSPF extensions are specified in [RFC8667] and [RFC8665], respectively. It relies on a series of forwarding instructions being placed in the header of a packet. The segment routing architecture supports operations that can be used to steer packet flows in a network, thus providing a form of traffic engineering. [RFC8664] specify the SR-specific PCEP extensions.

Segment Routing Policy for Traffic Engineering [RFC9256] details the concepts of SR Policy and approaches to steering traffic into an SR Policy. An SR Policy contains one or more SR Policy Candidate Paths where one or more such paths can be computed via PCE.

[I-D.ietf-pce-segment-routing-policy-cp] specifies PCEP extensions to signal additional information to map candidate paths to their SR policies.

PCECC may further use PCEP for SR SID (Segment Identifier) allocation and distribution to all the SR nodes with some benefits. The SR nodes continue to rely on IGP for distributed computation (nexthop selection, protection etc) where PCE (and PCEP) does only the allocation and distribution of SIDs in the network. Note that the topology at PCE is still learned via existing mechanisms.

This document specifies the procedures and PCEP extensions when a PCE-based controller is also responsible for configuring the forwarding actions on the routers (i.e. the SR SID allocation and distribution in this case), in addition to computing the SR paths for packet flows in a segment routing network and telling the edge routers what instructions to attach to packets as they enter the network as described in [RFC8283].

Only SR using MPLS dataplane (SR-MPLS) is in the scope of this document. Refer [I-D.ietf-pce-pcep-extension-pce-controller-srv6] for use of PCECC technique for SR in IPv6 (SRv6) dataplane.

## 2. Terminology

Terminologies used in this document are the same as described in the [RFC8283].

### 2.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

## 3. PCECC SR-MPLS

[RFC8664] specifies extensions to PCEP that allows a stateful PCE to compute, update, or initiate SR-TE paths. An ingress node of an SR-TE path appends all outgoing packets with a list of MPLS labels (SIDs). This is encoded in SR-ERO subobject, capable of carrying a label (SID) as well as the identity of the node/adjacency.

The notion of segment and SID is defined in [RFC8402], which fits the MPLS architecture [RFC3031] as the label which is managed by a local allocation process of LSR (similar to other MPLS signaling protocols) [RFC8660]. The SR information such as node/adjacency label (SID) is flooded via IGP as specified in [RFC8667] and [RFC8665].

[RFC8283] examines the motivations and applicability for PCECC and use of PCEP as an SBI. Section 3.1.5. of [RFC8283] highlights the use of PCECC for configuring the forwarding actions on the routers and assumes responsibility for managing the label space. It simplifies the processing of a distributed control plane by blending it with elements of SDN without necessarily completely replacing it. This allows the operator to introduce the advantages of SDN (such as programmability) into the network. Further Section 3.2. of [RFC9689] describes some of the scenarios where the PCECC technique could be useful. Section 4 of [RFC8283] also describe the implications of the protocol when used as an SDN SBI. The operator needs to evaluate the advantages offered by PCECC against the operational and scalability needs of the PCECC.

Thus, PCE as a central controller can allocate and provision the node/prefix/adjacency label (SID) via PCEP. The rest of the processing is similar to existing stateful PCE with SR mechanism.

For the purpose of this document, it is assumed that the label/SID range to be used by a PCE is set on both PCEP peers. The PCC MUST NOT make allocations from the label space set aside for the PCE to avoid overlap and collisions of label allocations. Further, a global label/SID range is assumed to be set on all PCEP peers in the SR domain. A future extension could add the capability to advertise this range via a possible PCEP extension as well (see [I-D.li-pce-controlled-id-space]). This document also allows a case where the label/SID space is maintained by PCC and the labels/SID are allocated by it. In this case, the PCE should request the allocation from PCC as described in Section 5.5.1.6.

#### 4. PCEP Requirements

Following key requirements for PCECC-SR should be considered when designing the PCECC-based solution:

- \* A PCEP speaker supporting this document needs to have the capability to advertise its PCECC-SR capability to its peers.
- \* PCEP procedures need to allow for PCC-based label/SID allocations.

- \* PCEP procedures need to provide a means to update (or clean up) label-mapping entries downloaded to the PCC.
- \* PCEP procedures need to provide a means to synchronize the SR label/SID allocations between the PCE to the PCC via PCEP messages.

## 5. Procedures for Using the PCE as a Central Controller (PCECC) in Segment Routing

### 5.1. Stateful PCE Model

Active stateful PCE is described in [RFC8231]. PCE as a Central Controller (PCECC) reuses the existing active stateful PCE mechanism as much as possible to control the LSPs.

### 5.2. New LSP Functions

Several new functions are required in PCEP to support PCECC as described in [RFC9050]. This document reuses the existing messages to support PCECC-SR.

The PCEP messages PCRpt, PCInitiate, and PCUpd are used to send LSP Reports, LSP setup, and LSP update respectively. The extended PCInitiate message described in [RFC9050] is used to download or clean up the central controller's instructions (CCIs) (SR SID in the scope of this document). The extended PCRpt message described in [RFC9050] is also used to report the CCIs (SR SIDs) from PCC to PCE.

[RFC9050] specify an object called CCI for the encoding of the central controller's instructions for Label. This document extends the CCI by defining a new object-type for SR-MPLS. The PCEP messages are extended in this document to handle the PCECC operations for SR.

### 5.3. PCECC Capability Advertisement

During PCEP Initialization Phase, PCEP Speakers (PCE or PCC) advertise their support of PCECC extensions. A PCEP Speaker includes the "PCECC Capability" sub-TLV, described in [RFC9050].

A new S-bit is added in the PCECC-CAPABILITY sub-TLV to indicate support for PCECC-SR for SR-MPLS. A PCC MUST set the S-bit in the PCECC-CAPABILITY sub-TLV and include the SR-PCE-CAPABILITY sub-TLV ([RFC8664]) in the OPEN Object (inside the PATH-SETUP-TYPE-CAPABILITY TLV) to support the PCECC SR-MPLS extensions defined in this document. If the S-bit is set in the PCECC-CAPABILITY sub-TLV and the SR-PCE-CAPABILITY sub-TLV is not advertised in the OPEN Object,

PCE MUST send a PCErr message with Error-Type=19 (Invalid Operation) and Error-value=TBD4 (SR capability was not advertised) and terminate the session.

The rest of the processing is as per [RFC9050].

#### 5.4. PCEP session IP address and TED Router ID

A PCE may construct its Traffic Engineering Database (TED) by participating in the IGP ([RFC3630] and [RFC5305] for MPLS-TE; [RFC4203] and [RFC5307] for GMPLS). An alternative is offered by BGP-LS [RFC9552] or [I-D.ietf-pce-pcep-ls].

A PCEP [RFC5440] speaker could use any local IP address while creating a TCP session. It is important to link the session IP address with the Router ID in TED for successful PCECC operations.

During the PCEP Initialization Phase, the PCC SHOULD advertise the TE mapping information by including the "Router-ID TLVs" Section 7.1.2 with the IPv4/IPv6 Router-ID of Local Node, in the OPEN Object for this purpose. [RFC9552] describes the usage as auxiliary Router-IDs that the IGP might be using, e.g., for TE purposes. If there are more than one auxiliary Router-ID of a given type, then multiple TLVs can be used to encode them.

If Router-ID TLVs are not present, the TCP session IP address is directly used for the mapping purpose.

#### 5.5. LSP Operations

[RFC8664] specify the PCEP extension to allow a stateful PCE to compute and initiate SR-TE paths, as well as a PCC to request a path subject to certain constraint(s) and optimization criteria in SR networks.

The Path Setup Type for segment routing (PST=1) is used on the PCEP session with the Ingress as per [RFC8664].

##### 5.5.1. PCECC Segment Routing (SR)

Segment Routing (SR) as described in [RFC8402] depends on "segments" that are advertised by Interior Gateway Protocols (IGPs). The SR-node allocates and advertises the SID (node, adj, etc) and floods them via the IGP. This document proposes a new mechanism where PCE allocates the SID (label/index/SID) centrally and uses PCEP to distribute them to all nodes. In some deployments, PCE (and PCEP) are better suited than IGP because of the centralized nature of PCE and direct TCP-based PCEP sessions to all the nodes. Note that only

the SID allocation and distribution is done by the PCEP, all other SR operations (nexthop selection, protection, etc) are still done by the node (and the IGP).

#### 5.5.1.1. PCECC SR Node/Prefix SID Allocation

Each node (PCC) is allocated a node-SID by the PCECC. The PCECC sends PCInitiate message to update the label mapping of each node to all the nodes in the domain. The TE router ID is determined from the TED or from the Router-ID TLVs Section 7.1.2, in the OPEN Object Section 5.4. The LSP object is included in the central controller instructions to continue using the flag field of the LSP object as per [RFC8231] and [RFC8281]. The PLSP-ID is set to the reserved value 0. As per [RFC8281], the LSP object also includes the SPEAKER-ENTITY-ID TLV to identify the PCE that initiated these instructions.

It is RECOMMENDED that the PCEP session with PCECC-SR capability use a different session IP address during TCP session establishment than the node Router ID in TEDB, to make sure that the PCEP session does not get impacted by the SR Node/Prefix Label mappings (Section 5.4). Otherwise, the PCEP session itself might get impacted when the label mapping is downloaded for the node.

If a node (PCC) receives a PCInitiate message with a CCI object-type=TBD6 encoding a SID, out of the range set aside for the SR Global Block (SRGB), it MUST send a PCErr message with Error-type=31 (PCECC failure) and Error-value=1 (Label out of range) (defined in [RFC9050]) and MUST include the SRP object to specify the error is for the corresponding central control instruction via the PCInitiate message.

On receiving the label mapping, each node (PCC) uses the local routing information via IGP to determine the next-hop and download the label forwarding instructions accordingly as shown in Figure 1. The PCInitiate message in this case uses a new FEC object defined in Section 7.4.

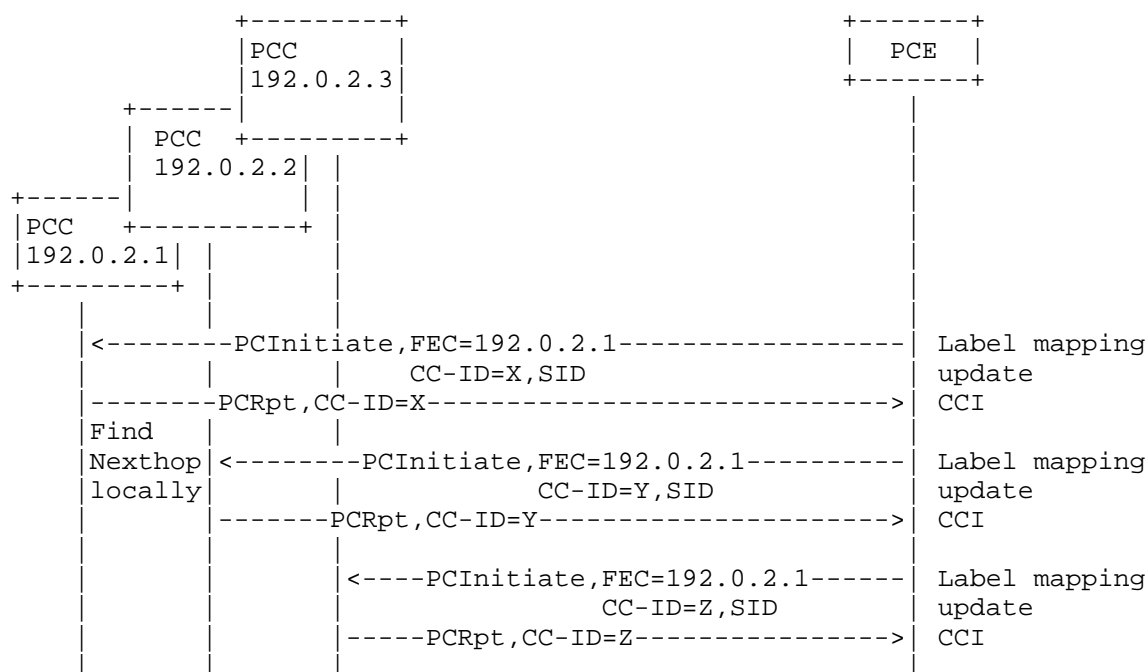


Figure 1: PCECC SR Node/Prefix SID allocation

The forwarding behavior and the end result are similar to IGP-based "Node-SID" in SR. Thus, from anywhere in the domain, it enforces the ECMP-aware shortest-path forwarding of the packet towards the related node as per [RFC8402].

PCE relies on the Node/Prefix Label clean up using the same PCInitiate message as per [RFC8281].

The above example Figure 1 depicts the FEC and PCEP speakers that uses IPv4 address. Similarly, an IPv6 address (such as 2001:db8::1) can be used during PCEP session establishment in the FEC object as described in this specification.

In the case where the label/SID allocation is made by the PCC itself (see Section 5.5.1.6), the PCE could request an allocation to be made by the PCC, and where the PCC would send a PCRpt with the allocated label/SID encoded in the CC-ID object as shown in Figure 2.

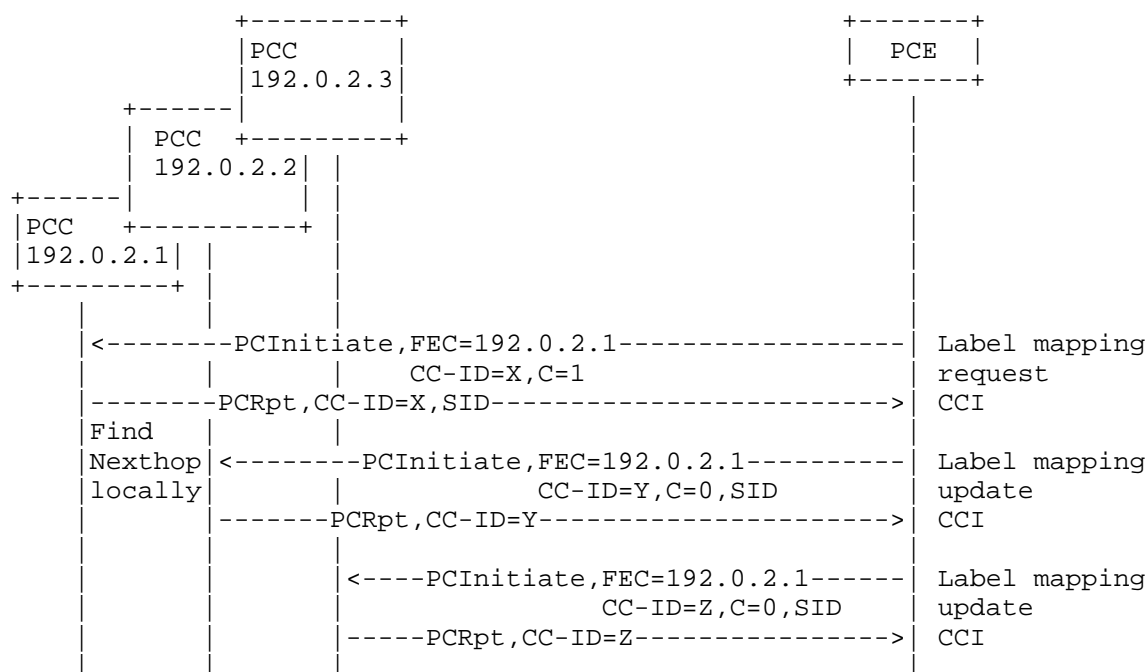


Figure 2: PCECC SR Node/Prefix SID (PCC allocation)

It should be noted that in this example (Figure 2), the request is made to the node 192.0.2.1 with C bit set in the CCI object to indicate that the allocation needs to be done by this PCC and it responds with the allocated label/SID to the PCE. The PCE would further inform the other nodes (PCCs) in the network about the label mapping allocation without setting the C bit as before.

All other distributed operations such as nexthop change, protection, etc are handled by the local node as before.

#### 5.5.1.2. PCECC SR Adjacency Label/SID Allocation

For PCECC-SR, apart from node-SID, Adj-SID is used where each adjacency is allocated an Adj-SID by the PCECC. The PCECC sends the PCInitiate message to update the label mapping of each adjacency to all the nodes in the domain as shown in Figure 3. Each node (PCC) downloads the label forwarding instructions accordingly. Similar to SR Node/Prefix Label allocation, the PCInitiate message in this case does not use the LSP object but uses the new FEC object defined in this document.

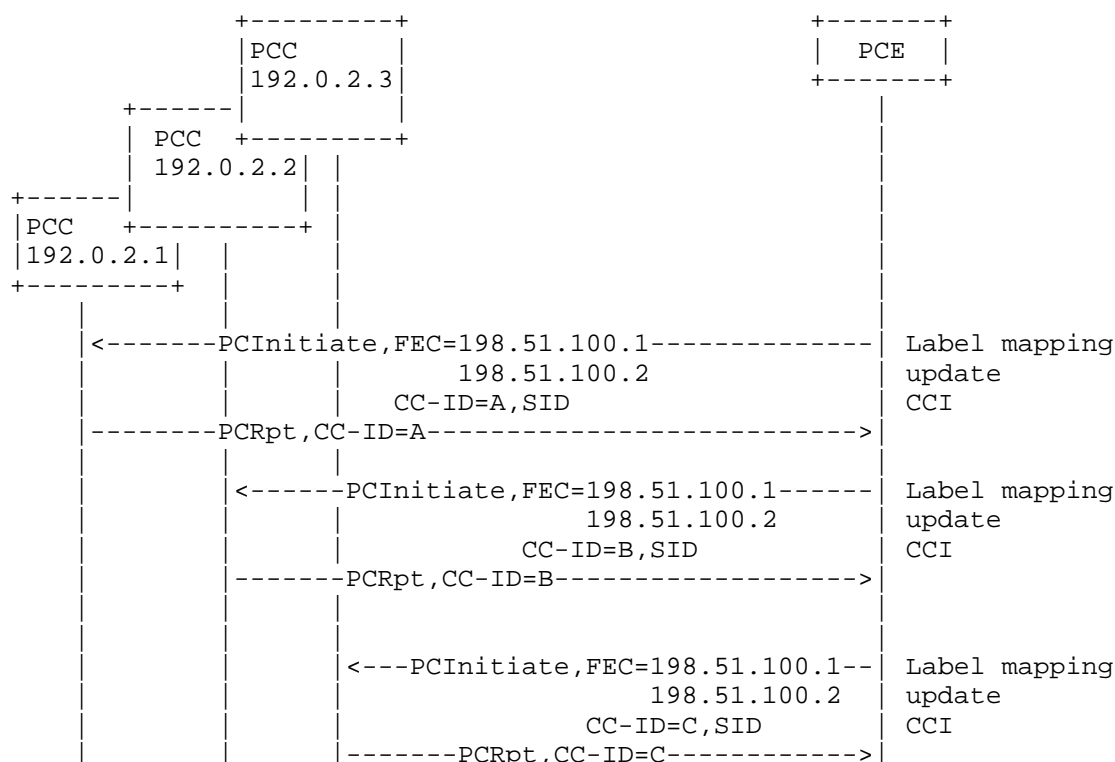


Figure 3: PCECC SR Adjacency Label allocation

The forwarding behavior and the end result are similar to Interior Gateway Protocol (IGP) based "Adj-SID" in SR. The Adj-SID is distributed to all nodes to enable SR-TE and TI-LFA.

PCE relies on the Adj SID/label clean up using the same PCInitiate message as per [RFC8281].

The above example (Figure 3) depicts FEC object and PCEP speakers that uses an IPv4 address. Similarly, an IPv6 address (such as 2001:db8::1, 2001:db8::2) can be used during the PCEP session establishment in the FEC object as described in this specification.

The handling of adjacencies on the LAN subnetworks is specified in [RFC8402]. PCECC MUST assign Adj-SID for every pair of routers in the LAN. The rest of the protocol mechanism remains the same.

In the case where the label/SID mapping allocation is made by the PCC itself (see Section 5.5.1.6), the PCE could request an allocation to be made by the PCC, and where the PCC would send a PCRpt with the allocated label/SID encoded in the CC-ID object as shown in Figure 4.

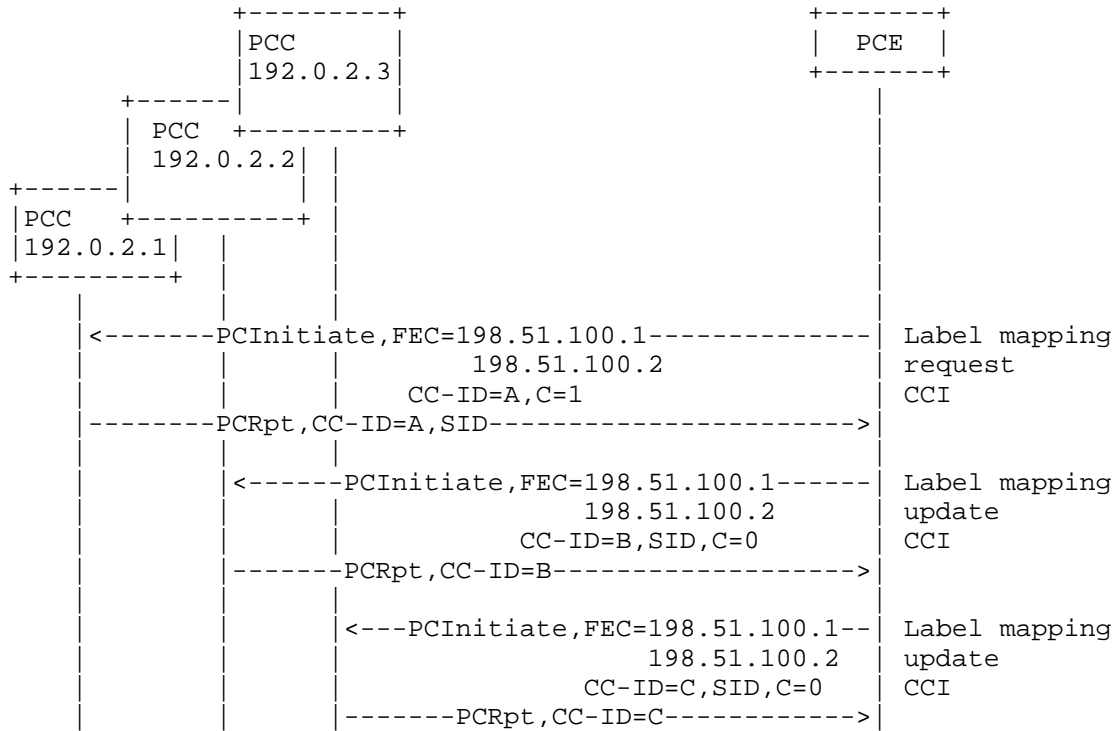


Figure 4: PCECC SR Adjacency Label/SID (PCC allocation)

In this example (Figure 4), the request is made to the node 192.0.2.1 with the C bit set in the CCI object to indicate that the allocation needs to be done by this PCC for the adjacency (198.51.100.1 - 198.51.100.2) and it responds with the allocated label/SID to the PCE. The PCE further distributes this to other nodes without setting the C bit as before.

#### 5.5.1.3. Redundant PCEs

[I-D.ietf-pce-state-sync] describes the synchronization mechanism between the stateful PCEs. As per [RFC9050], the SR SIDs allocated by a PCE must also be synchronized among PCEs for PCECC SR state synchronization. Note that the SR SIDs are independent of the SR-TE LSPs, and remains intact till any topology change. The redundant PCEs need to maintain a common view of all SR SIDs allocated in the domain.

#### 5.5.1.4. Re-Delegation and Clean up

As described in [RFC8281], a new PCE can gain control over an orphaned LSP. In the case of a PCECC, the new PCE MUST also gain control over the central controller instructions in the same way by sending a PCInitiate message that includes the SRP, LSP, CCI, and FEC objects and carries the CC-ID and SPEAKER-ENTITY-ID TLV (original PCE) identifying the instruction that it wants to take control of.

Further, as described in [RFC8281], the State Timeout Interval timer ensures that a PCE crash does not result in automatic and immediate disruption for the services using PCE-initiated LSPs. Similarly, as per [RFC9050], the central controller instructions are not removed immediately upon PCE failure. Instead, they could be cleaned up on the expiration of this timer. This allows for network clean up without manual intervention. The PCC MUST support the removal of CCI as one of the behaviors applied on the expiration of the State Timeout Interval timer. Note that the usual policy would be for the CCI Object-Type=TBD6 to remain intact until explicitly removed by a PCE or via manual intervention.

#### 5.5.1.5. Synchronization of Label Allocations

[RFC9050] describes the synchronization of Central Controller's Instructions (CCI) via LSP state synchronization as described in [RFC8231] and [RFC8232]. Same procedures are applied for the CCI for SR SID as well.

#### 5.5.1.6. PCC-Based Allocations

The PCE can request the PCC to allocate the label/SID using the PCInitiate message. The C flag in the CCI object is set to 1 to indicate that the allocation needs to be done by the PCC. The PCC would allocate the SID/Label/Index and would report to the PCE using the PCRpt message.

If the value of the SID/Label/Index is 0 and the C flag is set to 1, it indicates that the PCE is requesting the allocation to be done by the PCC. If the SID/Label/Index is 'n' and the C flag is set to 1 in the CCI object, it indicates that the PCE requests a specific value 'n' for the SID/Label/Index. If the allocation is successful, the PCC should report via PCRpt message with the CCI object. Otherwise, it MUST send a PCErr message with Error-Type=31 ("PCECC failure") and Error Value=3 ("Invalid CCI") (defined in [RFC9050]). If the value of the SID/Label/Index in the CCI object is valid, but the PCC is unable to allocate it, it MUST send a PCErr message with Error-Type=31 ("PCECC failure") and Error Value=4 ("Unable to allocate the specified CCI") (defined in [RFC9050]).

If the PCC wishes to withdraw or modify the previously assigned label/SID, it MUST send a PCRpt message without any SID/Label/Index or with the SID/Label/Index containing the new value respectively in the CCI object. The PCE would further trigger the removal of the central controller instruction as per this document.

#### 5.5.1.7. Binding SID

A PCECC can allocate and provision the node/prefix/adjacency label (SID) via PCEP. Another SID called binding SID is described in [RFC9604], the PCECC mechanism can also be used to allocate the binding SID.

A procedure for binding label/SID allocation is described in [RFC9050] and is applicable for all path setup types (including SR paths).

#### 5.5.1.8. Anycast SID

As per [RFC8402], an anycast segment or Anycast-SID enforces the ECMP-aware shortest-path forwarding towards the closest node of the anycast set. Note that the anycast prefix segments can also be allocated and distributed in the same way as described in Section 5.5.1.1.

### 6. PCEP Messages

As defined in [RFC5440], a PCEP message consists of a common header followed by a variable-length body made of a set of objects that can be either mandatory or optional. An object is said to be mandatory in a PCEP message when the object must be included for the message to be considered valid. For each PCEP message type, a set of rules is defined that specify the set of objects that the message can carry. An implementation MUST form the PCEP messages using the object ordering specified in this document.

Message formats in this section are presented using Routing Backus-Naur Format (RBNF) as specified in [RFC5511].

## 6.1. Central Control Instructions

### 6.1.1. The PCInitiate Message

The PCInitiate message defined in [RFC8281] and extended in [RFC9050] is further extended to support SR-based central control instructions.

The format of the extended PCInitiate message is as follows:

```

<PCInitiate Message> ::= <Common Header>
                           <PCE-initiated-lsp-list>
Where:
  <Common Header> is defined in [RFC5440]

  <PCE-initiated-lsp-list> ::= <PCE-initiated-lsp-request>
                               [<PCE-initiated-lsp-list>]

  <PCE-initiated-lsp-request> ::=
    (<PCE-initiated-lsp-instantiation>|
     <PCE-initiated-lsp-deletion>|
     <PCE-initiated-lsp-central-control>)

  <PCE-initiated-lsp-central-control> ::= <SRP>
                                           <LSP>
                                           (<cci-list>|
                                           (<FEC>
                                           <CCI>))

  <cci-list> ::= <CCI>
                [<cci-list>]

```

Where:  
 <PCE-initiated-lsp-instantiation> and  
 <PCE-initiated-lsp-deletion> are as per  
 [RFC8281].

The LSP and SRP object is defined in [RFC8231].

Figure 5

When the PCInitiate message is used to distribute SR SIDs, the SRP, the LSP, the FEC and the CCI object of object-type=TBD6 MUST be present. The error handling for missing SRP, LSP, or CCI objects is as per [RFC9050]. If the FEC object is missing, the receiving PCC MUST send a PCErr message with Error-type=6 (Mandatory Object

missing) and Error-value=TBD5 (FEC object missing). The LSP Object is included with PLSP-ID set to the reserved value 0. The flags in the LSP object are set as per [RFC8281].

To clean up, the R (remove) bit in the SRP object and the corresponding FEC and the CCI object are included.

#### 6.1.2. The PCRpt message

The PCRpt message can be used to report the SR central controller instructions received from the PCECC during the state synchronization phase or as an acknowledgment to the PCInitiate message.

The format of the PCRpt message is as follows:

```
<PCRpt Message> ::= <Common Header>
                        <state-report-list>
```

Where:

```
<state-report-list> ::= <state-report>[<state-report-list>]
```

```
<state-report> ::= (<lsp-state-report>|
                    <central-control-report>)
```

```
<lsp-state-report> ::= [<SRP>]
                        <LSP>
                        <path>
```

```
<central-control-report> ::= [<SRP>]
                             <LSP>
                             (<cci-list>|
                              (<FEC>
                               <CCI>))
```

```
<cci-list> ::= <CCI>
               [<cci-list>]
```

Where:

<path> is as per [RFC8231] and the LSP and SRP objects are also defined in [RFC8231].

Figure 6

When the PCRpt message is used to report the label mapping allocations, the LSP, the FEC, and CCI object of object-type=TBD6 MUST be present. The error handling for the missing LSP and CCI object is as per [RFC9050]. If the FEC object is missing, the

receiving PCE MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=TBD5 (FEC object missing). The LSP Object is included with PLSP-ID set to the reserved value 0. The flags in the LSP object are set as per [RFC8231] and [RFC8281].

## 7. PCEP Objects

### 7.1. OPEN Object

#### 7.1.1. PCECC Capability sub-TLV

[RFC9050] defined the PCECC-CAPABILITY sub-TLV.

A new S-bit is added in PCECC-CAPABILITY sub-TLV for PCECC-SR:

S (PCECC-SR-CAPABILITY - 1 bit - TBD1): If set to 1 by a PCEP speaker, it indicates that the PCEP speaker is capable of PCECC-SR for SR-MPLS and the PCE allocates the Node and Adj label/SID on this session.

#### 7.1.2. Router-ID TLVs

The Router-ID TLV described in this document is generic and not specific to any specific path-setup type or use case. One or more Router-ID TLV MAY be carried in the OPEN object and does not require the exchange of the capability described in Section 5.3.

As described in Section 5.4, for the purposes of this document, the PCC advertises the TE mapping information by including the Router-ID TLVs in the OPEN object. Two new TLVs are defined:

Type: IPv4-ROUTER-ID (TBD7)

Length: 4

Value: IPv4 32-bit Router ID

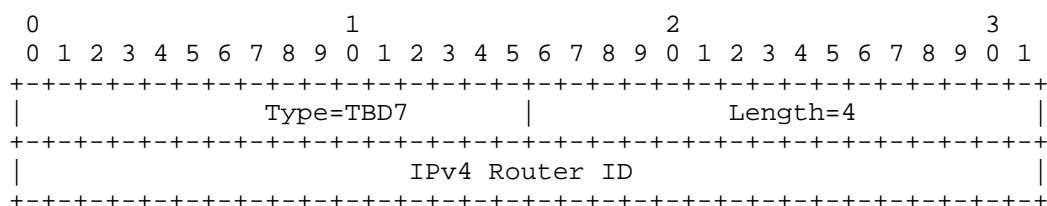


Figure 7

Type: IPv6-ROUTER-ID (TBD8)

Length: 16

Value: IPv6 128-bit Router ID

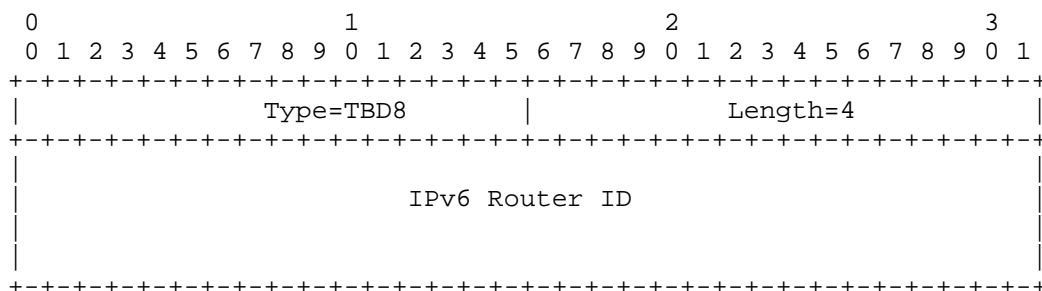


Figure 8

## 7.2. SR-TE Path Setup

The PATH-SETUP-TYPE TLV is defined in [RFC8408]. A PST value of 1 is used when Path is setup via SR mode as per [RFC8664]. The procedure for SR-TE path setup as specified in [RFC8664] remains unchanged.

## 7.3. CCI Object

The Central Control Instructions (CCI) Object used by the PCE to specify the controller instructions is defined in [RFC9050]. This document defines another object-type for SR-MPLS.

CCI Object-Type is TBD6 for SR-MPLS as below -

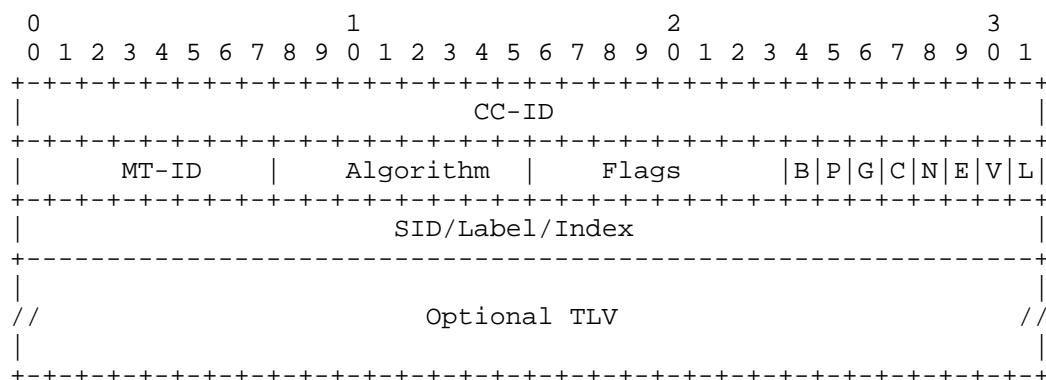


Figure 9

The field CC-ID is as described in [RFC9050]. The following new fields are defined for CCI Object-Type TBD6 -

MT-ID:

Multi-Topology ID (as defined in [RFC4915]).

Algorithm:

Single octet identifying the algorithm the SID is associated with.  
See [RFC8665].

Flags:

is used to carry any additional information pertaining to the CCI.  
The following bits are defined -

- \* L-Bit (Local/Global): If set, then the value/index carried by the CCI object has local significance. If not set, then the value/index carried by this object has a global significance.
- \* V-Bit (Value/Index): If set, then the CCI carries an absolute value. If not set, then the CCI carries an 32-bit index.
- \* E-Bit (Explicit-Null): If set, any upstream neighbor of the node that advertised the SID MUST replace the SID with the Explicit-NULL label (0 for IPv4) before forwarding the packet.
- \* N-Bit (No-PHP): If set, then the penultimate hop MUST NOT pop the SID before delivering packets to the node that advertised the SID.
- \* C-Bit (PCC Allocation): If the bit is set to 1, it indicates that the SR SID/label allocation needs to be done by the PCC for this central controller instruction. A PCE set this bit to request the PCC to make an allocation from its SR label/ID space. A PCC would set this bit to indicate that it has allocated the SR SID/label and report it to the PCE.
- \* The following bits are applicable when the SID represents an Adj-SID only, it MUST be ignored for others -
- \* G-Bit (Group): When set, the G-Flag indicates that the Adj-SID refers to a group of adjacencies (and therefore MAY be assigned to other adjacencies as well).
- \* P-Bit (Persistent): When set, the P-Flag indicates that the Adj-SID is persistently allocated, i.e., the Adj-SID value remains consistent across router restart and/or interface flap.

- \* B-Bit (Backup): If set, the Adj-SID refers to an adjacency that is eligible for protection (e.g., using IP Fast Reroute or MPLS-FRR (MPLS-Fast Reroute) as described in Section 2.1 of [RFC8402].
- \* All unassigned bits MUST be set to zero at transmission and ignored at receipt.

SID/Label/Index:

A 32-bit field. According to the V flags, it contains either:

- \* 32-bit SID index defining the offset in the SID/Label space advertised by this router.
- \* A 20-bit label where the 20 rightmost bits are used for encoding the label value. Other bits are ignored.

#### 7.4. FEC Object

The FEC Object is used to specify the FEC information and MAY be carried within PCInitiate or PCRpt message.

FEC Object-Class is TBD3.

The FEC objects are as follows:

1 - IPv4 Node ID: where IPv4 Node ID is specified as an IPv4 address of the Node. The FEC Object-type is 1, and the Object-Length is 4 in this case. The object body is same as NAI field of IPv4 Node ID [RFC8664].

2- IPv6 Node ID: where IPv6 Node ID is specified as an IPv6 address of the Node. The FEC Object-type is 2, and the Object-Length is 16 in this case. The object body is same as NAI field of IPv6 Node ID [RFC8664].

3 - IPv4 Adjacency: where Local and Remote IPv4 address is specified as pair of IPv4 addresses of the adjacency. The FEC Object-type is 3, and the Object-Length is 8 in this case. The object body is same as NAI field of IPv4 Adjacency [RFC8664].

4 - IPv6 Global Adjacency: where Local and Remote global IPv6 address is specified as pair of IPv6 addresses of the adjacency. The FEC Object-type is 4, and the Object-Length is 32 in this case. The object body is same as NAI field of IPv6 Global Adjacency [RFC8664].

5 - Unnumbered Adjacency with IPv4 NodeID: where a pair of Node ID / Interface ID tuple is used. The FEC Object-type is 5, and the Object-Length is 16 in this case. The object body is same as NAI field of Unnumbered Adjacency with IPv4 NodeIDs [RFC8664].

6 - IPv6 Linklocal Adjacency: where a pair of (global IPv6 address, interface ID) tuple is used. The FEC object-type is 6, and the Object-Length is 40 in this case. The object body is same as NAI field of IPv6 Link-Local Adjacency [RFC8664].

## 8. Implementation Status

[Note to the RFC Editor - remove this section before publication, as well as remove the reference to RFC 7942.]

This section records the status of known implementations of the protocol defined by this specification at the time of posting of this Internet-Draft, and is based on a proposal described in [RFC7942]. The description of implementations in this section is intended to assist the IETF in its decision processes in progressing drafts to RFCs. Please note that the listing of any individual implementation here does not imply endorsement by the IETF. Furthermore, no effort has been spent to verify the information presented here that was supplied by IETF contributors. This is not intended as, and must not be construed to be, a catalog of available implementations or their features. Readers are advised to note that other implementations may exist.

According to [RFC7942], "this will allow reviewers and working groups to assign due consideration to documents that have the benefit of running code, which may serve as evidence of valuable experimentation and feedback that have made the implemented protocols more mature. It is up to the individual working groups to use this information as they see fit".

### 8.1. Huawei's Proof of Concept based on ONOS

The PCE function was developed in the ONOS open source platform. This extension was implemented on a private version as a proof of concept for PCECC.

- \* Organization: Huawei
- \* Implementation: Huawei's PoC based on ONOS
- \* Description: PCEP as a southbound plugin was added to ONOS. To support PCECC-SR, an earlier version of this I-D was implemented. Refer <https://wiki.onosproject.org/display/ONOS/PCEP+Protocol>
- \* Maturity Level: Prototype
- \* Coverage: Partial

\* Contact: pengshuping@huawei.com

## 9. Security Considerations

As per [RFC8283], the security considerations for a PCE-based controller is a little different from those for any other PCE system. That is, the operation relies heavily on the use and security of PCEP, so consideration should be given to the security features discussed in [RFC5440] and the additional mechanisms described in [RFC8253]. It further lists the vulnerability of a central controller architecture, such as a central point of failure, denial-of-service, and a focus for interception and modification of messages sent to individual Network Elements (NEs).

The PCECC extension builds on the existing PCEP messages and thus the security considerations described in [RFC5440], [RFC8231], [RFC8281], and [RFC9050] continue to apply. As per [RFC9050], for the PCECC operations, the PCEP sessions are also required for the internal routers, thus increasing the resources required for the session management at the PCE. The PCECC has the capability to allocate or remove SIDs at the PCC, which can cause the SR paths/policies to behave inappropriately and cause a major impact on the network. Similarly, an out-of-sync PCEP speaker with a conflicting view of SR SIDs allocation can have major impact.

Thus, it is RECOMMENDED that these PCEP extensions be activated on mutually authenticated and encrypted sessions across PCEs and PCCs belonging to the same administrative authority, using Transport Layer Security (TLS) [RFC8253][I-D.ietf-pce-pceps-tls13] as per the recommendations and best current practices in BCP 195 [RFC9325].

## 10. Manageability Considerations

### 10.1. Control of Function and Policy

A PCE or PCC implementation SHOULD allow the PCECC-SR capability to be enabled/disabled as part of the global configuration. The implementation SHOULD also allow setting the local IP address used by the PCEP session with the PCECC-SR capability. As per Section 5.5.1.1, the PCEP session with this capability set ought to use a different session IP address during TCP session establishment than the node Router ID in the TEDB.

## 10.2. Information and Data Models

A future augmentation of the PCEP YANG module [RFC9826] needs to support a way to enable/disable PCECC SR capability. The `"/pcep/entity/addr"` can be used to set the local IP address used by the PCEP session.

## 10.3. Liveness Detection and Monitoring

Mechanisms defined in this document do not imply any new liveness detection and monitoring requirements for PCEP, in addition to those already listed in [RFC5440].

## 10.4. Verify Correct Operations

Mechanisms defined in this document do not imply any new operation verification requirements for PCEP, in addition to those already listed in [RFC5440], [RFC8231], and [RFC9050] to verify the PCEP operations that now include SID allocation and distribution. As per [RFC9050], any rejection of CCI, including those related to SID allocation and distribution, is logged with the reason.

## 10.5. Requirements On Other Protocols

PCEP extensions defined in this document do not put new requirements on other protocols.

## 10.6. Impact On Network Operations

PCEP extensions defined in this document allow SR SID Label allocation to be done from a central controller, thus simplifying the SID allocation and distribution. While the forwarding behavior is consistent with SR-MPLS, introducing PCECC-SR changes operational dependencies by making SID allocation/distribution reliant on the PCE. Operators should consider resilience of the PCECC deployment (e.g., redundant PCEs, state synchronization, and failure recovery behavior) and the impact of partial or inconsistent SID distribution.

## 10.7. Migration Considerations

Nodes that do not support PCECC-SR will not receive SID mappings via PCEP and therefore cannot participate in centrally distributed allocations; operators should plan migration such that centrally allocated SIDs are only relied upon where all relevant nodes have the necessary capability and connectivity to the PCE. During migration from IGP-based SID distribution to PCECC-SR SID allocation and distribution by a PCE, care is required to avoid disruption to existing services. To support a smooth transition, it may be useful

to allocate PCE-controlled SIDs from a separate SID space. This allows PCE-based allocation and IGP-based allocation to coexist for a limited period of time, enabling services to be gradually migrated from IGP-based SR to PCE-controlled SR without impacting network stability.

PCECC-SR may be introduced in networks that do not currently use SR. In such cases, the migration considerations for SR-MPLS are not specific to PCE control, and the general considerations for introducing SR-MPLS into an existing network apply.

## 11. IANA Considerations

### 11.1. PCECC-CAPABILITY sub-TLV

[RFC9050] defines the PCECC-CAPABILITY sub-TLV and requests that IANA to create a new sub-registry to manage the value of the PCECC-CAPABILITY sub-TLV's Flag field.

IANA is requested to allocate a new bit in the PCECC-CAPABILITY sub-TLV Flag Field sub-registry, as follows:

+=====+=====+=====+		
Bit	Description	Reference
+=====+=====+=====+		
TBD1	SR-MPLS	This document
+-----+-----+-----+		

Table 1: The PCECC-CAPABILITY sub-TLV

### 11.2. PCEP Object

IANA is requested to allocate new code-points for the new FEC object and a new Object-Type for the CCI object in the "PCEP Objects" sub-registry as follows:

Object-Class Value	Name	Object-Type	Reference
TBD3	FEC	1: IPv4 Node ID	This document
		2: IPv6 Node ID	This document
		3: IPv4 Adjacency	This document
		4: IPv6 Global Adjacency	This document
		5: Unnumbered Adjacency with IPv4 NodeID	This document
		6: IPv6 Linklocal Adjacency	This document
44	CCI		[RFC9050]
		TBD6: SR-MPLS	This document

Table 2: The PCEP Objects

### 11.3. PCEP-Error Object

IANA is requested to allocate new error-values within the "PCEP-ERROR Object Error Types and Values" sub-registry of the PCEP Numbers registry for the following errors:

Error-Type	Meaning	Error-value	Reference
6	Mandatory Object missing	TBD5: FEC object missing	This document
19	Invalid Operation	TBD4: SR capability was not advertised	This document

Table 3: The PCEP-Error

#### 11.4. CCI Object Flag Field for SR

IANA is requested to create a new sub-registry to manage the Flag field of the CCI Object-Type=TBD6 for SR called "CCI Object Flag Field for SR". New values are to be assigned by Standards Action [RFC8126]. Each bit should be tracked with the following qualities:

- \* Bit number (counting from bit 0 as the most significant bit)
- \* Capability description
- \* Defining RFC

Following bits are defined for the CCI Object flag field for SR in this document as follows:

Bit	Description	Reference
0-7	Unassigned	This document
8	B-Bit - Backup	This document
9	P-Bit - Persistent	This document
10	G-Bit - Group	This document
11	C-Bit - PCC Allocation	This document
12	N-Bit - No-PHP	This document
13	E-Bit - Explicit-Null	This document
14	V-Bit - Value/Index	This document
15	L-Bit - Local/Global	This document

Table 4: The CCI Object Flag Field for SR

#### 11.5. PCEP TLV Type Indicators

IANA maintains a subregistry called "PCEP TLV Type Indicators". IANA is requested to make an assignment from this subregistry as follows:

Value	Meaning	Reference
TBD7 (IPv4-ROUTER-ID)	IPv4 Router ID	This document
TBD8 (IPv6-ROUTER-ID)	IPv6 Router ID	This document

Table 5: The PCEP TLV

## 12. Acknowledgments

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Figure 10

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