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**PCEP Procedures and Protocol Extensions for Using PCE as a Central
Controller (PCECC) of SR-LSPs
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Abstract

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

PCE was developed to derive paths for MPLS Label Switched Paths (LSPs), which are supplied to the head end of the LSP using the Path Computation Element Communication Protocol (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.

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 LSP can be calculated/setup/initiated and the label forwarding entries can also be downloaded through a centralized PCE server to each network devices along the path while leveraging the existing PCE technologies as much as possible.

This document specifies the procedures and PCEP protocol 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 network and telling the edge routers what instructions to attach to packets as they enter the network.

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1. Introduction

The Path Computation Element (PCE) [[RFC4655](#)] was developed to offload path computation function from routers in an MPLS traffic-engineered network. 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 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 network elements (known as Path Computation Clients (PCCs)), and the results of the path computations were supplied to network elements using the Path Computation Element Communication Protocol (PCEP) [\[RFC5440\]](#). This protocol was later extended to allow a PCE to send unsolicited requests to the network for LSP establishment [\[RFC8281\]](#).

[\[RFC8283\]](#) 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 for PCEP as a Southbound Interface (SBI), and introduces the implications for the protocol. [\[I-D.ietf-teas-pcecc-use-cases\]](#) describes the use cases for the PCECC architecture.

[\[I-D.ietf-pce-pcep-extension-for-pce-controller\]](#) specify the procedures and PCEP protocol 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 (IS-IS or 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.

PCECC may further use PCEP protocol for SR SID (Segment Identifier) distribution on the SR nodes with some benefits.

This document specifies the procedures and PCEP protocol extensions when a PCE-based controller is also responsible for configuring the forwarding actions on the routers (SR SID distribution in this case), in addition to computing the 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.

1.1. 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.

2. Terminology

Terminologies used in this document is same as described in the draft [[RFC8283](#)] and [[I-D.ietf-teas-pcecc-use-cases](#)].

3. PCECC SR

[[RFC8664](#)] specifies extensions to PCEP that allow 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 label (SID).

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 (similarly 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](#)].

As per [[RFC8283](#)], PCE as a central controller can allocate and provision the node/prefix/adjacency label (SID) via PCEP.

Rest of the processing is similar to existing stateful PCE with SR mechanism.

For the purpose of this document, it is assumed that label range to be used by a PCE is set on both PCEP peers. Further, a global label range is assumed to be set on all PCEP peers in the SR domain. This document also allow a case where the label space is maintained by PCC

itself, and the labels are allocated by the PCC, 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:

- o PCEP speaker supporting this draft MUST have the capability to advertise its PCECC-SR capability to its peers.
- o PCEP speaker not supporting this draft MUST be able to reject PCECC-SR related message with a reason code that indicates no support for PCECC.
- o PCEP procedures MUST provide a means to update (or cleanup) the label- map entry to the PCC.
- o PCEP procedures SHOULD provide a means to synchronize the SR labels allocations between PCE to PCC in the PCEP messages.
- o PCEP procedures MAY allow for PCC based label allocations.

5. Procedures for Using the PCE as the 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 existing Active stateful PCE mechanism as much as possible to control the LSP.

5.2. New LSP Functions

Several new functions are required in PCEP to support PCECC as described in [[I-D.ietf-pce-pcep-extension-for-pce-controller](#)]. This document reuses the existing messages to support PCECC-SR.

The PCEP messages PCRpt, PCInitiate, PCUpd are used to send LSP Reports, LSP setup and LSP update respectively. The extended PCInitiate message described in [[I-D.ietf-pce-pcep-extension-for-pce-controller](#)] is used to download or cleanup central controller's instructions (CCIs) (SR SID in scope of this document). The extended PCRpt message described in [[I-D.ietf-pce-pcep-extension-for-pce-controller](#)] is also used to report the CCIs (SR SIDs) from PCC to PCE.

[I-D.ietf-pce-pcep-extension-for-pce-controller] specify an object called CCI for the encoding of central controller's instructions. This document extends the CCI by defining a new object-type for segment routing. 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 [\[I-D.ietf-pce-pcep-extension-for-pce-controller\]](#).

A new S-bit is added in PCECC-CAPABILITY sub-TLV to indicate support for PCECC-SR. A PCC MUST set S-bit in PCECC-CAPABILITY sub-TLV and include SR-PCE-CAPABILITY sub-TLV ([\[RFC8664\]](#)) in OPEN Object (inside the the PATH-SETUP-TYPE-CAPABILITY TLV) to support the PCECC SR extensions defined in this document. If S-bit is set in PCECC-CAPABILITY sub-TLV and SR-PCE-CAPABILITY sub-TLV is not advertised in OPEN Object, PCE SHOULD send a PCErr message with Error-Type=19 (Invalid Operation) and Error-value=TBD(SR capability was not advertised) and terminate the session.

5.4. PCEP session IP address and TEDB Router ID

PCE may construct its TEDB by participating in the IGP ([\[RFC3630\]](#) and [\[RFC5305\]](#) for MPLS-TE; [\[RFC4203\]](#) and [\[RFC5307\]](#) for GMPLS). An alternative is offered by BGP-LS [\[RFC7752\]](#) and [\[I-D.dhodylee-pce-pcep-ls\]](#).

PCEP [\[RFC5440\]](#) speaker MAY use any IP address while creating a TCP session. It is important to link the session IP address with the Router ID in TEDB for successful PCECC operations.

During PCEP Initialization Phase, PCC SHOULD advertise the TE mapping information. Thus a PCC includes the "Node Attributes TLV" [\[I-D.dhodylee-pce-pcep-ls\]](#) with "IPv4/IPv6 Router-ID of Local Node", in the OPEN Object for this purpose. [\[RFC7752\]](#) 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 are used to encode them.

If "IPv4/IPv6 Router-ID" TLV is not present, the TCP session IP address is directly used for the mapping purpose.

5.5. LSP Operations

The PCEP messages pertaining to PCECC-SR MUST include PATH-SETUP-TYPE TLV [[RFC8408](#)] with PST=TBD in the SRP object to clearly identify the PCECC-SR LSP is intended.

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 flood via the IGP. This document proposes a new mechanism where PCE allocates the SID (label/index/SID) centrally and uses PCEP to advertise the SID. In some deployments PCE (and PCEP) are better suited than IGP because of centralized nature of PCE and direct TCP based PCEP session to the node.

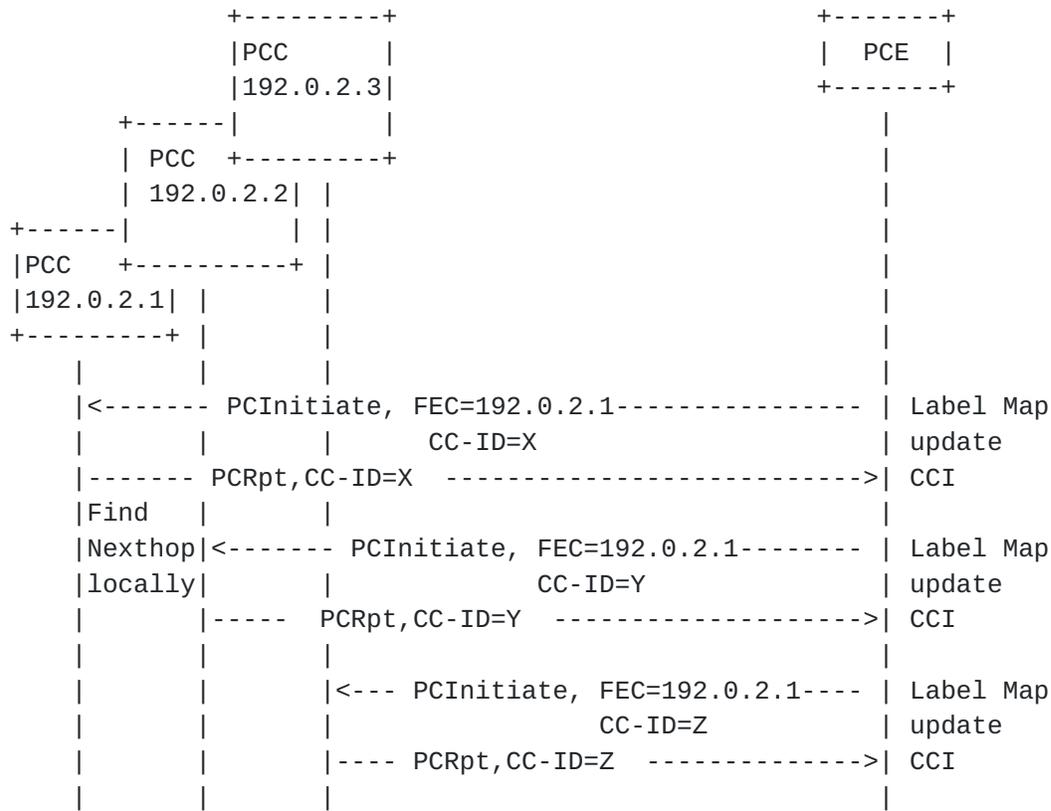
5.5.1.1. PCECC SR Node/Prefix SID allocation

Each node (PCC) is allocated a node-SID by the PCECC. The PCECC sends PCInitiate message to update the label map of each node to all the nodes in the domain. The TE router ID is determined from the TEDB or from "IPv4/IPv6 Router-ID" Sub-TLV [[I-D.dhodylee-pce-pcep-ls](#)], in the OPEN Object [Section 5.4](#).

It is RECOMMENDED that PCEP session with PCECC SR capability to 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 maps ([Section 5.4](#)).

If a node (PCC) receives a PCInitiate message with a CCI encoding a SID, out of the range set aside for the SRGB, it MUST send a PCErr message with Error-type=TBD (PCECC failure) and Error-value=TBD (SID out of range) and MUST include the SRP object to specify the error is for the corresponding label update via PCInitiate message.

On receiving the label map, each node (PCC) uses the local information to determine the next-hop and download the label forwarding instructions accordingly. The PCInitiate message in this case MUST NOT have LSP object but uses the new FEC object defined in this document.

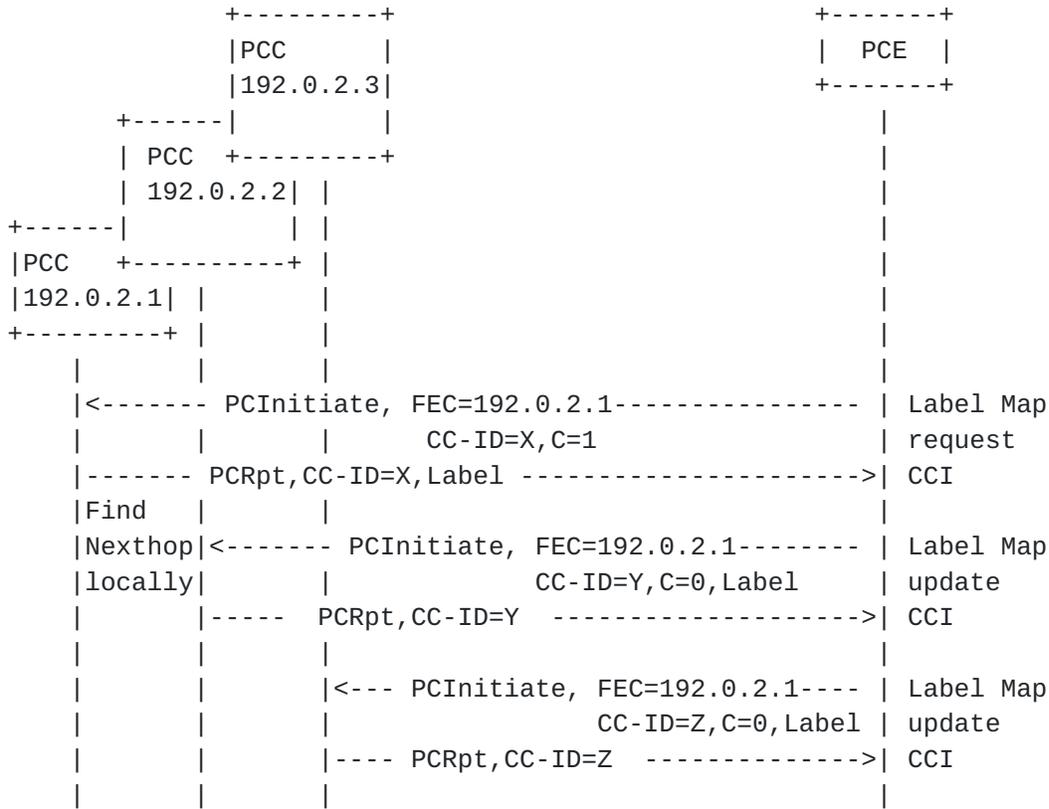


The forwarding behavior and the end result is similar to IGP based "Node-SID" in SR. Thus, from anywhere in the domain, it enforces the ECMP-aware shortest-path forwarding of the packet towards the related node.

PCE relies on the Node/Prefix Label cleanup using the same PCInitiate message.

The above example Figure 1 depict FEC and PCEP speakers that uses IPv4 address. Similarly IPv6 address (such as 2001:DB8::1) can be used during PCEP session establishment as well in FEC object as described in this specification.

In case where the label allocation are made by the PCC itself (see [Section 5.5.1.6](#)), the PCE could still request an allocation to be made by the PCC, and where the PCC would send a PCRpt with the allocated label encoded in the CC-ID object as shown below -

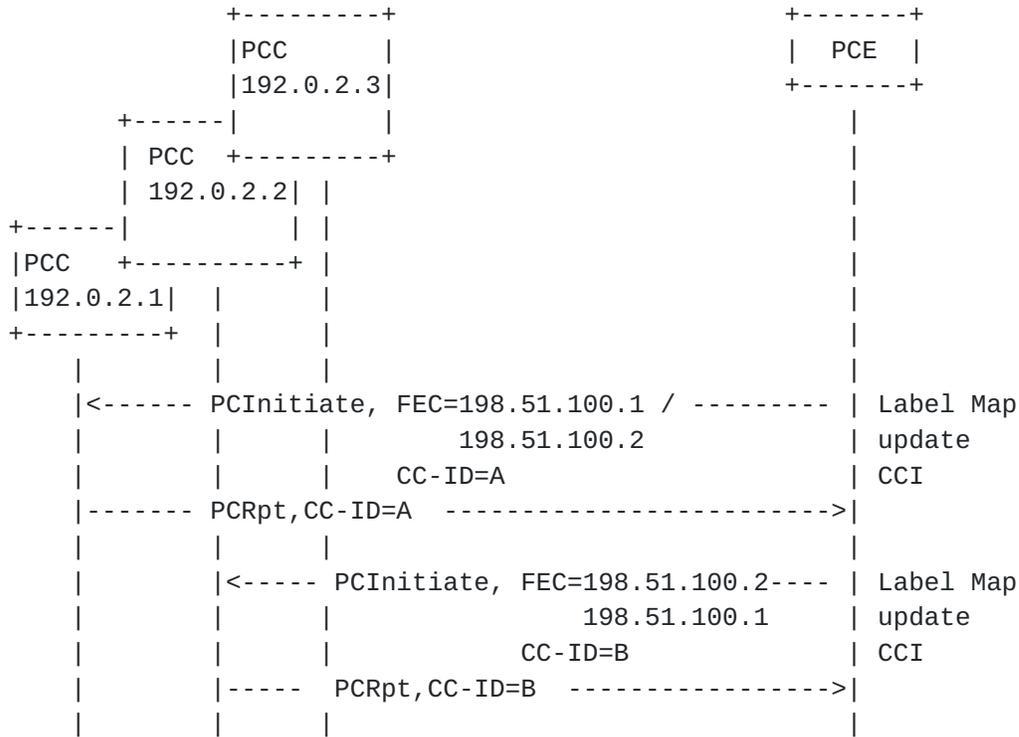


It should be noted that in this example, the request is made to the node 192.0.2.1 with C bit set in the CCI object to indicate that the allocation needs to be done by this PCC and it responds with the allocated label/SID to the PCE. The PCE would further inform the other PCCs in the network about the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

5.5.1.2. PCECC SR Adjacency Label allocation

[RFC8664] extends PCEP 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.

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 PCInitiate message to update the label map of each Adj to the corresponding nodes in the domain. Each node (PCC) download the label forwarding instructions accordingly. Similar to SR Node/Prefix Label allocation, the PCInitiate message in this case MUST NOT have LSP object but uses the new FEC object defined in this document.



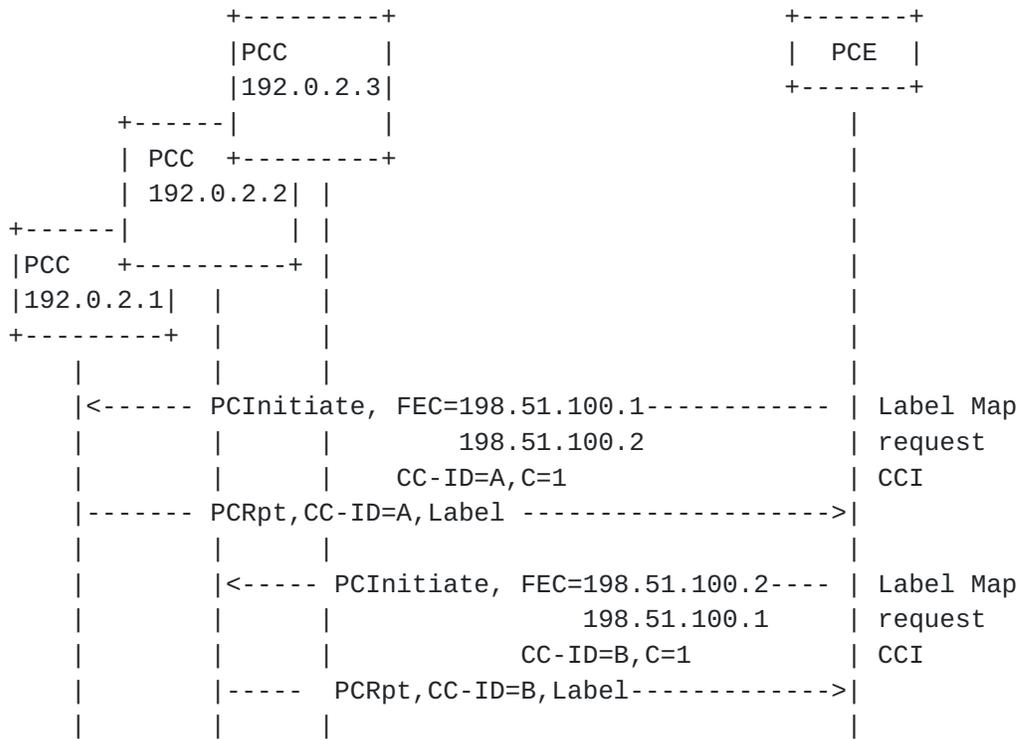
The forwarding behavior and the end result is similar to IGP based "Adj-SID" in SR.

The Path Setup Type for segment routing MUST be set for PCECC SR = TBD (see [Section 7.2](#)). All PCEP procedures and mechanism are similar to [\[RFC8664\]](#).

PCE relies on the Adj label cleanup using the same PCInitiate message.

The above example Figure 3 depict FEC and PCEP speakers that uses IPv4 address. Similarly IPv6 address (such as 2001:DB8::1, 2001:DB8::2) can be used during PCEP session establishment as well in FEC object as described in this specification.

In case where the label allocation are made by the PCC itself (see [Section 5.5.1.6](#)), the PCE could still request an allocation to be made by the PCC, and where the PCC would send a PCRpt with the allocated label encoded in the CC-ID object as shown below -



In this example 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 for the adjacency (198.51.100.1 - 198.51.100.2) and it responds with the allocated label/SID to the PCE. Similarly, another request is made to the node 192.0.2.2 with C bit set in the CCI object to indicate that the allocation needs to be done by this PCC for the adjacency (198.51.100.2 - 198.51.100.1).

5.5.1.3. Redundant PCEs

[I-D.litkowski-pce-state-sync] describes synchronization mechanism between the stateful PCEs. 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 to the PCECC-SR LSP, and remains intact till any topology change. The redundant PCEs MUST have a common view of all SR SIDs allocated in the domain.

5.5.1.4. Re Delegation and Cleanup

[I-D.ietf-pce-pcep-extension-for-pce-controller] describes the action needed for CCIs for the Basic PCECC LSP on this terminated session. Similarly actions should be applied for the SR SID as well.

5.5.1.5. Synchronization of Label Allocations

[I-D.ietf-pce-pcep-extension-for-pce-controller] describes the synchronization of Central Controller's Instructions (CCI) via LSP state synchronization as described in [[RFC8231](#)] and [[RFC8232](#)]. Same procedures should be applied for SR SIDs 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, 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 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. Else, it MUST send a PCErr message with Error-Type = TBD ("PCECC failure") and Error Value = TBD ("Invalid CCI"). If the value of the 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 = TBD ("PCECC failure") and Error Value = TBD ("Unable to allocate the specified CCI").

If the PCC wishes to withdrawn 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 PCE as a central controller can allocate and provision the node/prefix/adjacency label (SID) via PCEP. One such SID is binding SID as described in [[I-D.ietf-pce-binding-label-sid](#)], the PCECC mechanism can also be used to allocate the binding SID as described in this section.

A procedure for binding label/SID allocation is described in [[I-D.ietf-pce-pcep-extension-for-pce-controller](#)] and is applicable for all path setup types (including SR paths).

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.

6.1. Central Control Instructions

6.1.1. The PCInitiate message

The PCInitiate Message defined in [[RFC8281](#)] and extended in [[I-D.ietf-pce-pcep-extension-for-pce-controller](#)] 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](#)].

When PCInitiate message is used to distribute SR SIDs, the SRP, FEC and CCI objects MUST be present. The error handling for missing SRP or CCI object is as per [\[I-D.ietf-pce-pcep-extension-for-pce-controller\]](#). If the FEC object is missing, the receiving PCC MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=TBD (FEC object missing).

To cleanup the SRP object must set the R (remove) bit and include the FEC and the CCI object.

[6.1.2.](#) The PCRpt message

The PCRpt message can be used to report the SR instructions received from the central controller (PCE) during the state synchronization phase.

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 object are also defined in [\[RFC8231\]](#).

When PCRpt message is used to report the label map allocations, the FEC and CCI objects MUST be present. The error handling for CCI object is as per [\[I-D.ietf-pce-pcep-extension-for-pce-controller\]](#). If the FEC object is missing, the receiving PCC MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=TBD (FEC object missing).

[7. PCEP Objects](#)

[7.1. OPEN Object](#)

[7.1.1. PCECC Capability sub-TLV](#)

[I-D.ietf-pce-pcep-extension-for-pce-controller] defined the PCECC-CAPABILITY TLV.

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

The field CC-ID is as described in [\[I-D.ietf-pce-pcep-extension-for-pce-controller\]](#). Following new fields are defined for CCI Object-Type TBD -

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 0 bit was defined in [\[I-D.ietf-pce-pcep-extension-for-pce-controller\]](#), this document further defines following bits-

- * 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 global significance.
- * V-Bit (Value/Index): If set, then the CCI carries an absolute value. If not set, then the CCI carries an 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 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 CC-ID and report it to the PCE.
- * 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 \[RFC8402\]](#).

SID/Label/Index: According to the V and L flags, it contains either:

A 32-bit index defining the offset in the SID/Label space advertised by this router.

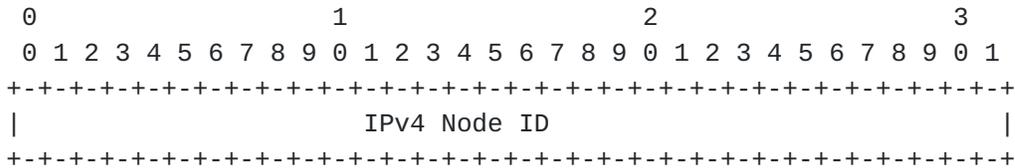
A 24-bit label where the 20 rightmost bits are used for encoding the label value.

7.4. FEC Object

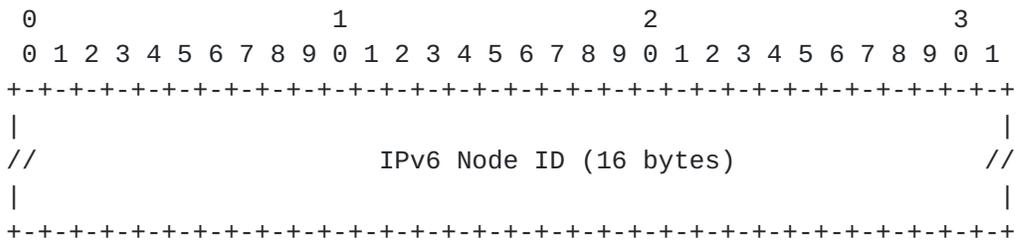
The FEC Object is used to specify the FEC information and MAY be carried within PCInitiate or PCRpt message.

FEC Object-Class is TBD.

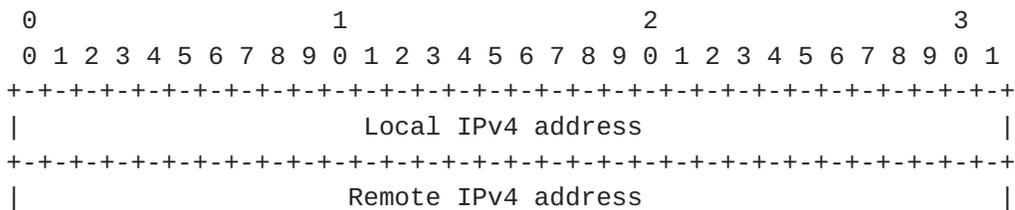
FEC Object-Type is 1 'IPv4 Node ID'.



FEC Object-Type is 2 'IPv6 Node ID'.



FEC Object-Type is 3 'IPv4 Adjacency'.



+-----+

FEC Object-Type is 4 'IPv6 Adjacency'.

```

0                               1                               2                               3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+
|
//                Local IPv6 address (16 bytes)                //
|
+-----+
|
//                Remote IPv6 address (16 bytes)                //
|
+-----+
```

FEC Object-Type is 5 'Unnumbered Adjacency with IPv4 NodeIDs'.

```

0                               1                               2                               3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+
|                Local Node-ID                |
+-----+
|                Local Interface ID            |
+-----+
|                Remote Node-ID                |
+-----+
|                Remote Interface ID            |
+-----+
```

FEC Object-Type is 6 'Linklocal IPv6 Adjacency'.

```

0                               1                               2                               3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+
//                Local IPv6 address (16 octets)                //
+-----+
|                Local Interface ID            |
+-----+
//                Remote IPv6 address (16 octets)                //
+-----+
|                Remote Interface ID            |
+-----+
```

The FEC objects are as follows:

IPv4 Node ID: where IPv4 Node ID is specified as an IPv4 address of the Node. FEC Object-type is 1, and the Object-Length is 4 in this case.

IPv6 Node ID: where IPv6 Node ID is specified as an IPv6 address of the Node. FEC Object-type is 2, and the Object-Length is 16 in this case.

IPv4 Adjacency: where Local and Remote IPv4 address is specified as pair of IPv4 address of the adjacency. FEC Object-type is 3, and the Object-Length is 8 in this case.

IPv6 Adjacency: where Local and Remote IPv6 address is specified as pair of IPv6 address of the adjacency. FEC Object-type is 4, and the Object-Length is 32 in this case.

Unnumbered Adjacency with IPv4 NodeID: where a pair of Node ID / Interface ID tuples is used. FEC Object-type is 5, and the Object-Length is 16 in this case.

Linklocal IPv6 Adjacency: where a pair of (global IPv6 address, interface ID) tuples is used. FEC object-type is 6, and the Object-Length is 40 in this case.

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.

- o Organization: Huawei
- o Implementation: Huawei's PoC based on ONOS
- o 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>
- o Maturity Level: Prototype
- o Coverage: Partial
- o Contact: satishk@huawei.com

9. Security Considerations

The security considerations described in [[I-D.ietf-pcep-extension-for-pce-controller](#)] apply to the extensions described in this document.

As per [[RFC8231](#)], it is RECOMMENDED that these PCEP extensions only be activated on authenticated and encrypted sessions across PCEs and PCCs belonging to the same administrative authority, using Transport Layer Security (TLS) [[RFC8253](#)] as per the recommendations and best current practices in [[RFC7525](#)] (unless explicitly set aside in [[RFC8253](#)]).

10. Manageability Considerations

10.1. Control of Function and Policy

A PCE or PCC implementation SHOULD allow to configure to enable/disable PCECC SR capability as a global configuration.

10.2. Information and Data Models

[[RFC7420](#)] describes the PCEP MIB, this MIB can be extended to get the PCECC SR capability status.

The PCEP YANG module [[I-D.ietf-pcep-pcep-yang](#)] could be extended to enable/disable PCECC SR capability.

10.3. Liveness Detection and Monitoring

Mechanisms defined in this document do not imply any new liveness detection and monitoring requirements 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 in addition to those already listed in [[RFC5440](#)] and [[RFC8231](#)].

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 implementation SHOULD allow a limit to be placed on the rate of PCLabelUpd messages sent by PCE and processed by PCC. It SHOULD also allow sending a notification when a rate threshold is reached.

11. IANA Considerations

11.1. PCECC-CAPABILITY sub-TLV

[I-D.ietf-pce-pcep-extension-for-pce-controller] defines the PCECC-CAPABILITY sub-TLV and requests that IANA creates a registry to manage the value of the PCECC-CAPABILITY sub-TLV's Flag field. New values are to be assigned by Standards Action [[RFC8126](#)]. Each bit should be tracked with the following qualities:

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

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

Bit	Description	Reference
31	S((PCECC-SR-CAPABILITY))	This document

11.2. New Path Setup Type Registry

[RFC8408] created a sub-registry within the "Path Computation Element Protocol (PCEP) Numbers" registry called "PCEP Path Setup Types". IANA is requested to allocate a new code point within this registry, as follows:

Value	Description	Reference
TBD	Traffic engineering path is setup using PCECC-SR mode	This document

11.3. PCEP Object

IANA is requested to allocate new code-point for the new FEC object in "PCEP Objects" sub-registry as follows:

Object-Class	Value	Name	Reference
TBD		FEC	This document
		Object-Type : 1	IPv4 Node ID
		Object-Type : 2	IPv6 Node ID
		Object-Type : 3	IPv4 Adjacency
		Object-Type : 4	IPv6 Adjacency
		Object-Type : 5	Unnumbered Adjacency with IPv4 NodeID
		Object-Type : 6	Linklocal IPv6 Adjacency

11.4. PCEP-Error Object

IANA is requested to allocate new error types and 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
6	Mandatory Object missing.
19	Invalid operation.

Error-value = TBD :	FEC object missing
Error-value = TBD :	SR capability was not advertised

11.5. 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=TBD 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:

- o Bit number (counting from bit 0 as the most significant bit)
- o Capability description
- o 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

12. Acknowledgments

We would like to thank Robert Tao, Changjing Yan, Tieying Huang and Avantika for their useful comments and suggestions.

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[Appendix A](#). Examples

[Editor's Note: Add examples to show how the SID allocation are being done for LAN Adj-SID in a future revision]

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