       **PCEP Procedures and Protocol Extensions for Using PCE as a Central
                       Controller (PCECC) for SRv6**
         draft-dhody-pce-pcep-extension-pce-controller-srv6-04

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. 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 for Segment Routing in IPv6 (SRv6), in addition to
   computing the SRv6 paths for packet flows and telling the edge
   routers what instructions to attach to packets as they enter the
   network.

Status of This Memo

   This Internet-Draft is submitted in full conformance with the
   provisions of BCP 78 and BCP 79.

   Internet-Drafts are working documents of the Internet Engineering
   Task Force (IETF). Note that other groups may also distribute
   working documents as Internet-Drafts. The list of current Internet-
   Drafts is at https://datatracker.ietf.org/drafts/current/.

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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 list of segment forming the path is called the Segment
List and is encoded in the packet header. Segment Routing can be
applied to the IPv6 architecture with the Segment Routing Header
(SRH) [RFC8754]. A segment is encoded as an IPv6 address. An
ordered list of segments is encoded as an ordered list of IPv6
addresses in the routing header. The active segment is indicated by
the Destination Address of the packet. Upon completion of a segment,
a pointer in the new routing header is incremented and indicates the
next segment. 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] and
[I-D.ietf-pce-segment-routing-ipv6] 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.
[I-D.zhao-pce-pcep-extension-pce-controller-sr] 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. This document extends this to include SRv6 SID
distribution as well.

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 SRv6

[RFC8664] specifies extensions to PCEP that allow a stateful PCE to
compute, update or initiate SR-TE paths for MPLS dataplane. 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). [I-D.ietf-pce-segment-routing-ipv6]
extends the procedure to include support for SRv6 paths.

As per [RFC8754], an SRv6 Segment is a 128-bit value. "SRv6 SID" or
simply "SID" are often used as a shorter reference for "SRv6
Segment". Further details are in an illustration provided in
[I-D.ietf-spring-srv6-network-programming]. The SR is applied to
IPV6 forwarding plane using SRH. A SR path can be derived from an
IGP Shortest Path Tree (SPT), but SR-TE paths may not follow IGP SPT.
Such paths may be chosen by a suitable network planning tool, or a
PCE and provisioned on the ingress node.
[I-D.ietf-pce-segment-routing-ipv6] extended SR-ERO subobject capable
of carrying an SRv6 SID as well as the identity of the node/adjacency
represented by the SID.

As per [RFC8283], PCE as a central controller can allocate and
provision the node/prefix/adjacency label (SID) via PCEP. As per
[I-D.ietf-teas-pcecc-use-cases] this is also applicable to SRv6 SIDs.

Rest of the processing is similar to existing stateful PCE with SRv6
mechanism.

4. PCEP Requirements

Following key requirements for PCECC-SRv6 should be considered when`
designing the PCECC based solution:

o PCEP speaker supporting this draft needs to have the capability to
   advertise its PCECC-SRv6 capability to its peers.

o PCEP speaker not supporting this draft needs to be able to reject
   PCECC-SRv6 related message with a reason code that indicates no
   support for it.

o PCEP procedures needs to provide a means to update (or cleanup)
   the SRv6 SID to the PCC.

o PCEP procedures needs to provide a means to synchronize the SRv6
   SID allocations between PCE to PCC in the PCEP messages.

5. Procedures for Using the PCE as the Central Controller (PCECC) in SRv6

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 Functions

This document uses the same PCEP messages and its extensions which
are described in [I-D.ietf-pce-pcep-extension-for-pce-controller] and
[I-D.zhao-pce-pcep-extension-pce-controller-sr] for PCECC-SRv6 as
well.

PCEP messages PCRpt, PCInitiate, PCUpd are also 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) (SRv6 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 (SRv6 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.
[I-D.zhao-pce-pcep-extension-pce-controller-sr] extends the CCI by
defining a object-type for segment routing. This document further
extends the CCI by defining another object-type for SRv6.

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 S-bit is added in PCECC-CAPABILITY sub-TLV to indicate support for
   PCECC-SR in [I-D.zhao-pce-pcep-extension-pce-controller-sr]. This
   document adds another I-bit to indicate support for SR in IPv6. A
   PCC MUST set I-bit in PCECC-CAPABILITY sub-TLV and include SRv6-PCE-
   CAPABILITY sub-TLV ([I-D.ietf-pce-segment-routing-ipv6]) in OPEN
   Object (inside the the PATH-SETUP-TYPE-CAPABILITY TLV) to support the
   PCECC SRv6 extensions defined in this document. If I-bit is set in
   PCECC-CAPABILITY sub-TLV and SRv6-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=TBD4 (SRv6
   capability was not advertised) and terminate the session.

5.4. PCEP session IP address and TEDB Router ID

   As described in [I-D.zhao-pce-pcep-extension-pce-controller-sr], it
   is important to link the session IP address with the Router ID in
   TEDB for successful PCECC operations.

5.5. SRv6 Path Operations

   The PCEP messages pertaining to PCECC-SRv6 MUST include PATH-SETUP-
   TYPE TLV [RFC8408] with PST=TBD2 in the SRP object to clearly
   identify the PCECC-SRv6 setup is intended.

5.5.1. PCECC Segment Routing in IPv6 (SRv6)

   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 SRv6 SID centrally and uses PCEP to advertise the SRv6 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 SRv6 Node/Prefix SID allocation

   Each node (PCC) is allocated a node SRv6 SID by the PCECC. The PCECC
   sends PCInitiate message to update the SID table of each node. 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.

On receiving the SRv6 node SID allocation, each node (PCC) uses the
local routing information to determine the next-hop and download the
forwarding instructions accordingly. The PCInitiate message in this
case MUST have FEC object.

On receiving the SRv6 node SID allocation:

   For the local SID, node (PCC) needs to update SID with associated
   function (END function in this case) in "My Local SID Table"
   ([I-D.ietf-spring-srv6-network-programming]).

   For the non-local SID, node (PCC) uses the local routing
   information to determine the next-hop and download the forwarding
   instructions accordingly.

The PCInitiate message in this case MUST have FEC object.

The forwarding behavior and the end result is similar to IGP based
"Node-SID" in SRv6. 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 SRv6 SID cleanup using the same
PCInitiate message.

5.5.1.2. PCECC SRv6 Adjacency SID 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 SRv6
SID instructions accordingly. Similar to SRv6 Node/Prefix Label
allocation, the PCInitiate message in this case uses the FEC object.

The forwarding behavior and the end result is similar to IGP based
"Adj-SID" in SRv6.

The Path Setup Type for segment routing MUST be set for PCECC SRv6 =
TBD2 (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.

[5.5.1.3](#). Redundant PCEs

[I-D.litkowski-pce-state-sync] describes synchronization mechanism
between the stateful PCEs. The SRv6 SIDs allocated by a PCE MUST
also be synchronized among PCEs for PCECC SRv6 state synchronization.
Note that the SRv6 SIDs are independent to the PCECC-SRv6 paths, and
remains intact till any topology change. The redundant PCEs MUST
have a common view of all SRv6 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 SRv6 SID as well.

[5.5.1.5](#). Synchronization of SRv6 SID 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 SRv6 SIDs as well.

[6](#). PCEP messages

The PCEP messages are as per
[[I-D.zhao-pce-pcep-extension-pce-controller-sr](#)].

[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 I-bit is defined in PCECC-CAPABILITY sub-TLV for PCECC-SRv6:

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |           Type=TBD            |            Length=4           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                          Flags                         |I|S|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

[Editor's Note - The above figure is included for ease of the reader but should be removed before publication.]

I (PCECC-SRv6-CAPABILITY - 1 bit - TBD1): If set to 1 by a PCEP speaker, it indicates that the PCEP speaker is capable for PCECC-SRv6 capability and PCE would allocate node and Adj SRv6 SID on this session.

7.2. PATH-SETUP-TYPE TLV

The PATH-SETUP-TYPE TLV is defined in [RFC8408]. PST = TBD2 is used when Path is setup via PCECC SRv6 mode.

On a PCRpt/PCUpd/PCInitiate message, the PST=TBD2 indicates that this path was setup via a PCECC-SRv6 based mechanism where either the SIDs were allocated/instructed by PCE via PCECC mechanism.

7.3. CCI Object

The Central Control Instructions (CCI) Object is used by the PCE to specify the forwarding instructions is defined in [I-D.ietf-pce-pcep-extension-for-pce-controller]. This document defines another object-type for SRv6 purpose.

CCI Object-Type is TBD3 for SRv6 as below -

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            CC-ID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    MT-ID     |   Algorithm   |     Flags     |B|P|G|C|N|E|V|L|O|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Reserved             |     SRv6 Endpoint Function    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                      SRv6 Identifier                          |
|                        (128-bit)                              |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                     Optional TLV                            //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The field CC-ID is as described in
[I-D.ietf-pce-pcep-extension-for-pce-controller]. The field MT-ID,
Algorithm, Flags are defined in
[I-D.zhao-pce-pcep-extension-pce-controller-sr].

Reserved: MUST be set to 0 while sending and ignored on receipt.

SRv6 Endpoint Function: 16 bit field representing supported functions
associated with SRv6 SIDs.

SRv6 Identifier: 128 bit IPv6 addresses representing SRv6 segment.

[Editor's Note - It might be useful to seperate the LOC:FUNC part in
the SRv6 SID (future study)]

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 (and various Object-Types) are described in
[I-D.zhao-pce-pcep-extension-pce-controller-sr]. SRv6 Node SID MUST
includes the FEC Object-Type 2 for IPv6 Node. SRv6 Adjacency SID
MUST include the FEC Object-Type=4 for IPv6 adjacency. Further FEC
object types would be added in future revisions.

8. Security Considerations

The security considerations described in
[I-D.ietf-pce-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]).

9. Manageability Considerations

9.1. Control of Function and Policy

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

9.2. 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-pce-pcep-yang] could be extended to enable/disable PCECC SR capability.

9.3. 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].

9.4. 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].

9.5. Requirements On Other Protocols

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

9.6. Impact On Network Operations

PCEP implementation SHOULD allow a limit to be placed on the rate of PCInitiate/PCUpd messages (as per [RFC8231]) sent by PCE and processed by PCC. It SHOULD also allow sending a notification when a rate threshold is reached.

10. IANA Considerations

10.1. PCECC-CAPABILITY TLV

[I-D.ietf-pce-pcep-extension-for-pce-controller] defines the PCECC-CAPABILITY TLV and requests that IANA creates a registry to manage the value of the PCECC-CAPABILITY TLV's Flag field. IANA is requested to allocate a new bit in the PCECC-CAPABILITY TLV Flag Field registry, as follows:

```
      Bit             Description                Reference
      TBD1            I((PCECC-SRv6-CAPABILITY)) This document
```

10.2. New Path Setup Type Registry

   IANA is requested to allocate new PST Field in PATH- SETUP-TYPE TLV.
   The allocation policy for this new registry should be by IETF
   Consensus. The new registry should contain the following value:

Value	Description	Reference
TBD2	Path is setup using PCECC-SRv6 mode	This document

10.3. PCEP Object

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

Object-Class Value	Name	Object-Type	Reference
TBD	CCI		
		TBD3: SRv6	This document

10.4. 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
19	Invalid operation.
	Error-value = TBD4 : SRv6 capability was not advertised

11. Acknowledgments

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12.2. Informative References

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Appendix A. Contributor Addresses

      Dhruv Dhody
      Huawei Technologies
      Divyashree Techno Park, Whitefield
      Bangalore, Karnataka 560066
      India

      EMail: dhruv.ietf@gmail.com

Authors' Addresses

      Zhenbin Li
      Huawei Technologies
      Huawei Bld., No.156 Beiqing Rd.
      Beijing   100095
      China

      EMail: lizhenbin@huawei.com

      Shuping Peng
      Huawei Technologies
      Huawei Bld., No.156 Beiqing Rd.
      Beijing 100095
      China

      EMail: pengshuping@huawei.com

      Xuesong Geng
      Huawei Technologies
      China

      EMail: gengxuesong@huawei.com

      Mahendra Singh Negi
      RtBrick India
      N-17L, Floor-1, 18th Cross Rd, HSR Layout Sector-3
      Bangalore, Karnataka 560102
      India

      EMail: mahend.ietf@gmail.com