PCEP Procedures and Protocol Extensions for Using PCE as a Central
Controller (PCECC) for P2MP LSPs
draft-dhody-pce-pcep-extension-pce-controller-p2mp-00

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.

   The PCE has been identified as an appropriate technology for the
   determination of the paths of point- to-multipoint (P2MP) TE Label
   Switched Paths (LSPs).

   PCE was developed to derive paths for MPLS P2MP LSPs, which are
   supplied to the head end (root) of the LSP using PCEP. PCEP has been
   proposed as a control protocol 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 P2MP 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 P2MP path while leveraging the existing PCE
   technologies as much as possible.

   This document specifies the procedures and PCEP protocol extensions
   for using the PCE as the central controller for P2MP TE LSP.

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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.

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.

[I-D.zhao-pce-pcep-extension-for-pce-controller] specify the
procedures and PCEP protocol extensions for using the PCE as the
central controller for static P2P LSPs, where LSPs can be provisioned
as explicit label instructions at each hop on the end-to-end path.
Each router along the path must be told what label-forwarding
instructions to program and what resources to reserve. The PCE-based
controller keeps a view of the network and determines the paths of
the end-to-end LSPs, and the controller uses PCEP to communicate with
each router along the path of the end-to-end LSP.

[RFC4857] describes how to set up point-to-multipoint (P2MP) Traffic
Engineering Label Switched Paths (TE LSPs) for use in Multiprotocol
Label Switching (MPLS) and Generalized MPLS (GMPLS) networks. The
PCE has been identified as a suitable application for the computation
of paths for P2MP TE LSPs ([RFC5671]). The extensions of PCEP to
request path computation for P2MP TE LSPs are described in [RFC8306].
Further [I-D.ietf-pce-stateful-pce-p2mp] specify the extensions that
are necessary in order for the deployment of stateful PCEs to support
P2MP TE LSPs as well as the setup, maintenance and teardown of PCE-
initiated P2MP LSPs under the stateful PCE model.

This document extends
[I-D.zhao-pce-pcep-extension-for-pce-controller] to specify the
procedures and PCEP protocol extensions for using the PCE as the
central controller for static P2MP LSPs, where LSPs can be
provisioned as explicit label instructions at each hop on the end-to-
end path with an added functionality of a P2MP branch node. As per
[RFC4875], a branch node is an LSR that replicates the incoming data
on to one or more outgoing interfaces.
[I-D.ietf-teas-pcecc-use-cases] describes the use cases for P2MP in
PCECC architecture.

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. Basic PCECC Mode

As described in [I-D.zhao-pce-pcep-extension-for-pce-controller], in
this mode LSPs are provisioned as explicit label instructions at each
hop on the end-to-end path. Each router along the path must be told
what label forwarding instructions to program and what resources to
reserve. The controller uses PCEP to communicate with each router
along the path of the end-to-end LSP. Note that the PCE-based
controller will take responsibility for managing some part of the
MPLS label space for each of the routers that it controls, and may
taker wider responsibility for partitioning the label space for each
router and allocating different parts for different uses. This is
also described in section 3.1.2. of [RFC8283]. For the purpose of
this document, it is assumed that label range to be used by a PCE is
known and set on both PCEP peers. A future extension could add this
capability to advertise the range via possible PCEP extensions as
well.

This document extends the functionality to include support for
central control instruction for replication at the branch nodes.

The rest of processing is similar to the existing stateful PCE
mechanism for P2MP.

4. Procedures for Using the PCE as the Central Controller (PCECC) for P2MP

4.1. Stateful PCE Model

Active stateful PCE is described in [RFC8231] and extended for P2MP
[I-D.ietf-pce-stateful-pce-p2mp]. PCE as a central controller
(PCECC) reuses existing Active stateful PCE mechanism as much as
possible to control the LSP.

[I-D.zhao-pce-pcep-extension-for-pce-controller] extends PCEP
messages - PCRpt, PCInitiate, PCUpd message for the Central
Controller's Instructions (CCI) (label forwarding instructions in the
context of this document). This documents specify the procedure for
aditional instruction for branch node needed for P2MP.

4.2. PCECC Capability Advertisement

As per [I-D.zhao-pce-pcep-extension-for-pce-controller], during PCEP
Initialization Phase, PCEP Speakers (PCE or PCC) advertise their
support of PCECC extensions by sending a PATH-SETUP-TYPE-CAPABILITY
TLV in the OPEN object with this PST=PCECC included in the PST list.

[I-D.zhao-pce-pcep-extension-for-pce-controller] also defines the
PCECC Capability sub-TLV. A new M-bit is added in PCECC-CAPABILITY
TLV to indicate support for PCECC-P2MP. A PCC MUST set M-bit in
PCECC-CAPABILITY TLV and include STATEFUL-PCE-CAPABILITY TLV with
P2MP bits set ([I-D.ietf-pce-stateful-pce-p2mp]) in OPEN Object to
support the PCECC P2MP extensions defined in this document. If M-bit
is set in PCECC-CAPABILITY TLV and N-bit in STATEFUL-PCE-CAPABILITY
TLV is not set in OPEN Object, PCE SHOULD send a PCErr message with
Error-Type=19 (Invalid Operation) and Error-value=TBD (P2MP
capability was not advertised) and terminate the session.

4.3. LSP Operations

The PCEP messages pertaining to PCECC MUST include PATH-SETUP-TYPE
TLV [RFC8408] with PST=PCECC
[I-D.zhao-pce-pcep-extension-for-pce-controller] in the SRP object to
clearly identify the PCECC LSP is intended.

4.3.1. Basic PCECC LSP Setup

In order to setup a P2MP LSP based on PCECC mechanism, a PCC MUST
delegate the P2MP LSP by sending a PCRpt message with PST set for
PCECC and D (Delegate) flag (see [I-D.ietf-pce-stateful-pce-p2mp])
set in the LSP object.

P2MP-LSP-IDENTIFIER TLV [I-D.ietf-pce-stateful-pce-p2mp] MUST be
included for PCECC LSP, the tuple uniquely identifies the P2MP LSP in
the network. As per
[I-D.zhao-pce-pcep-extension-for-pce-controller], the LSP object is
included in central controller's instructions (label download) to
identify the PCECC LSP for this instruction.

When a PCE receives PCRpt message with D flags and PST Type set, it
calculates the P2MP tree and assigns labels along the path; and set
up the path by sending PCInitiate message to each node along the path

of the LSP, similar to
[I-D.zhao-pce-pcep-extension-for-pce-controller]. The new extention
required is the instructions on the branch nodes for replications to
more than one outgoing interfaces with respective labels. The rest
of the operations remains same as
[I-D.zhao-pce-pcep-extension-for-pce-controller] and
[I-D.ietf-pce-stateful-pce-p2mp].

4.3.2. Central Control Instructions

The new central controller's instructions (CCI) for the label
operations in PCEP is done via the PCInitiate message, by defining a
new PCEP Objects for CCI operations. Local label range of each PCC
is assumed to be known at both the PCC and the PCE.

4.3.2.1. Label Download

In order to setup an LSP based on PCECC, the PCE sends a PCInitiate
message to each node along the path to download the Label instruction
as described in Section 4.3.1.

The CCI object MUST be included, along with the LSP object in the
PCInitiate message. The LSP-IDENTIFIER TLV MUST be included in LSP
object. The SPEAKER-ENTITY-ID TLV SHOULD be included in LSP object.

As described in [I-D.zhao-pce-pcep-extension-for-pce-controller], if
a node (PCC) receives a PCInitiate message which includes a Label to
download as part of CCI, that is out of the range set aside for the
PCE, it send a PCErr message with Error-type=TBD (PCECC failure) and
Error-value=TBD (Label out of range). If a PCC receives a PCInitiate
message but failed to download the Label entry, it sends a PCErr
message with Error-type=TBD (PCECC failure) and Error-value=TBD
(instruction failed).

Consider the example in the [I-D.ietf-teas-pcecc-use-cases] -

```
                        +----------+
                        |    R1    | Root node of the multicast LSP
                        +----------+
                            |6000
                        +----------+
        Transit Node    |    R2    |
        branch          +----------+
                        *  |   *   *
                  9001* |   *   *9002
                      *  |   *    *
        +-----------+    |   *      +-----------+
        |    R4     |    |   *      |    R5     | Transit Nodes
        +-----------+    |   *      +-----------+
              *       |   *     *      +
          9003*       |   *     *      +9004
              *       |   *     *      +
        +-----------+  +-----------+
        |    R3     |  |    R6     | Leaf Node
        +-----------+  +-----------+
         9005|
        +-----------+
        |    R8     | Leaf Node
        +-----------+
```
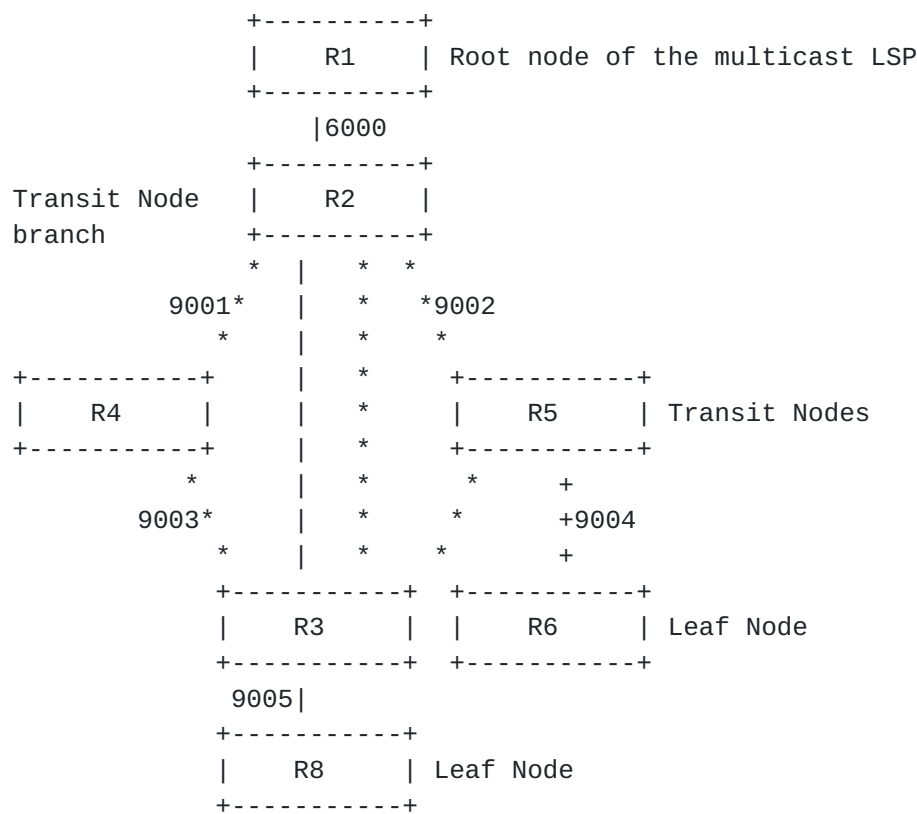
PCECC would provision each node along the path and assign incoming
and outgoing labels from R1 to {R6, R8} with the path: {R1, 6000},
{6000, R2, {9001,9002}}, {9001, R4, 9003}, {9002, R5, 9004} {9003,
R3, 9005}, {9004, R6}, {9005, R8}. The operations on all nodes except
R2 are same as [I-D.zhao-pce-pcep-extension-for-pce-controller]. The
branch node (R2) needs to be instructed to replicate two copies of
the incoming packet, and sent towards R4 and R5 with 9001 and 9002
labels respectively). This done via including 3 instances of CCI
objects in the PCEP messages, one for each label in the example, 6000
for incoming and 9001/9002 for outgoing (along with remote nexthop).
The message and procedure remains exactly as
[I-D.zhao-pce-pcep-extension-for-pce-controller] with only
distinction that more than one outgoing CCI MAY be present for the
P2MP LSP.

4.3.2.2. Label Cleanup

In order to delete an P2MP LSP based on PCECC, the PCE sends a
central controller instructions via a PCInitiate message to each node
along the path of the LSP to cleanup the Label forwarding instruction
as per [I-D.zhao-pce-pcep-extension-for-pce-controller]. In case of
branch nodes all instances of CCIs needs to be present in the PCEP
message.

4.3.3. PCE Initiated PCECC LSP

The LSP Instantiation operation is same as defined in [RFC8281] and
[I-D.ietf-pce-stateful-pce-p2mp].

In order to setup a P2MP PCE Initiated LSP based on the PCECC
mechanism, a PCE sends PCInitiate message with Path Setup Type set
for PCECC (see Section 5.2) to the Ingress PCC (root).

The Ingress PCC MUST also set D (Delegate) flag (see [RFC8231]) and C
(Create) flag (see [RFC8281]) in LSP object of PCRpt message. The
PCC responds with first PCRpt message with the status as "GOING-UP"
and assigned PLSP-ID.

As described in [I-D.zhao-pce-pcep-extension-for-pce-controller], the
label forwarding instructions from PCECC are send after the initial
PCInitiate and PCRpt exchange. This is done so that the PLSP-ID and
other LSP identifiers can be obtained from the ingress and can be
included in the label forwarding instruction in the next PCInitiate
message. The rest of the PCECC LSP setup operations are same as
those described in Section 4.3.1.

4.3.4. PCECC LSP Update

In case of a modification of PCECC P2MP LSP with a new path, the
procedure and instructions as described in
[I-D.zhao-pce-pcep-extension-for-pce-controller] apply.

4.3.5. Re Delegation and Cleanup

In case of a redelgation and cleanup of PCECC P2MP LSP, the procedure
and instructions as described in
[I-D.zhao-pce-pcep-extension-for-pce-controller] apply.

4.3.6. Synchronization of Central Controllers Instructions

The procedure and instructions are as per
[I-D.zhao-pce-pcep-extension-for-pce-controller].

4.3.7. PCECC LSP State Report

An Ingress PCC MAY choose to apply any OAM mechanism to check the
status of LSP in the Data plane and MAY further send its status in
PCRpt message (as per [I-D.ietf-pce-stateful-pce-p2mp]) to the PCE.

5. PCEP Objects

5.1. OPEN Object

5.1.1. PCECC Capability sub-TLV

   The PCECC-CAPABILITY sub-TLV is an optional TLV for use in the OPEN
   Object for PCECC capability advertisement in PATH-SETUP-TYPE-
   CAPABILITY TLV as specified in
   [I-D.zhao-pce-pcep-extension-for-pce-controller].

   This document adds a new flag (M-bit) in PCECC-CAPABILITY sub-TLV to
   indicate the support for P2MP in PCECC. A PCC MUST set M-bit in
   PCECC-CAPABILITY sub-TLV and set the N (P2MP-CAPABILITY), M (P2MP-
   LSP-UPDATE-CAPABILITY), and P (P2MP-LSP-INSTANTIATION-CAPABILITY) (as
   per [I-D.ietf-pce-stateful-pce-p2mp]) in STATEFUL-PCE-CAPABILITY TLV
   [RFC8231] to support the PCECC P2MP extensions defined in this
   document. If M-bit is set in PCECC-CAPABILITY sub-TLV and the P2MP
   bits in STATEFUL-PCE-CAPABILITY TLV are not set in OPEN Object, PCE
   SHOULD send a PCErr message with Error-Type=19 (Invalid Operation)
   and Error-value=TBD(P2MP capability was not advertised) and terminate
   the session.

5.2. PATH-SETUP-TYPE TLV

   The PATH-SETUP-TYPE TLV is defined in [RFC8408];
   [I-D.zhao-pce-pcep-extension-for-pce-controller] defines a PST value
   for PCECC, which is also used for P2MP.

5.3. CCI Object

   The Central Control Instructions (CCI) Object
   [I-D.zhao-pce-pcep-extension-for-pce-controller] is used by the PCE
   to specify the forwarding instructions (Label information in the
   context of this document) to the PCC, and MAY be carried within
   PCInitiate or PCRpt message for label download which defined Object
   Type 1 for MPLS Label, which is also used for P2MP. The address TLVs
   [I-D.zhao-pce-pcep-extension-for-pce-controller] associates the next-
   hop information in case of an outgoing label.

   If a node (PCC) receives a PCInitiate/PCUpd message with more than
   one CCI with O-bit set for outgoing label and the node does not
   support the P2MP branch/replication capability, it MUST respond with
   PCErr message with Error-Type=2(Capability not supported).

6. Security Considerations

The security considerations described in [RFC8231], [RFC8281],
[I-D.ietf-pce-stateful-pce-p2mp], and
[I-D.zhao-pce-pcep-extension-for-pce-controller] apply to the
extensions described in this document.

7. Manageability Considerations

7.1. Control of Function and Policy

A PCE or PCC implementation SHOULD allow to configure to enable/
disable PCECC P2MP capability as a global configuration.

7.2. Information and Data Models

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

The PCEP YANG module [I-D.ietf-pce-pcep-yang] could be extended to
enable/disable PCECC P2MP capability.

7.3. 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].

7.4. 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].

7.5. Requirements On Other Protocols

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

7.6. Impact On Network Operations

PCEP extensions defined in this document do not put new requirements
on network operations.

8. IANA Considerations

8.1. PCECC-CAPABILITY TLV

[I-D.zhao-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
     TBD             M((PCECC-P2MP-CAPABILITY)) This document
```

8.2. 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 = TBD :             P2MP capability was
                                             not advertised
```

9. Acknowledgments

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