PCEP Extensions for RSVP-TE Local-Protection with PCE-Stateful
draft-cbrt-pce-stateful-local-protection-00

Abstract

Stateful PCE [ietf-pce-stateful-pce] can apply global concurrent optimizations to optimize LSP placement. In a deployment where a PCE is used to compute all the paths, it may be beneficial for the local protection paths to also be computed by the PCE. This document defines extensions needed for the setup and management of RSVP-TE protection paths by the PCE.

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1. Introduction

[RFC5440] describes the Path Computation Element Protocol PCEP. PCEP defines the communication between a Path Computation Client (PCC) and a Path Control Element (PCE), or between PCE and PCE, enabling computation of Multi-protocol Label Switching (MPLS) for Traffic Engineering Label Switched Path (TE LSP) characteristics.

Stateful PCE [ietf-pce-stateful-pce] specifies a set of extensions to PCEP to enable stateful control of paths such as MPLS TE LSPs between and across PCEP sessions in compliance with [RFC4657]. It includes mechanisms to effect LSP state synchronization between PCCs and PCEs and allow delegation of control of LSPs to PCEs.

In a network where all LSPs have control delegated to a PCE, the PCE can apply global concurrent optimization to optimize LSP placement. The PCE can also control the timing and sequence of path computation and applying path changes. In a deployment where a PCE is used to compute all the paths, it may be beneficial for the protection paths to also be controlled through the PCE. This document defines extensions needed for the setup and management of protection paths by the PCE.
Benefits of stateful synchronization and control of the protection paths include:

- Better control over traffic after a failure and more deterministic path computation of protection paths. The PCE can optimize the protection path based on data not available to the PCC, for instance the PCE can make sure the protection path will not violate the delay specified by [I-D.ietf-pce-pcep-service-aware].

- Satisfy more complex constraints and diversity requirements, such as maintaining diverse paths for LSPs as well as their local protection paths.

- Given the PCE’s global view of network resources, act as a form of LSP admission control into a protection path to ensure links are not overloaded during failure events.

- On a PLR with multiple available protection routes, allows the PCE to map LSPs to all available protection routes versus a single best protection route.

- Most of the benefits stated in the stateful PCE applicability draft [I-D.ietf-pce-stateful-pce-app-04] apply equally to protection paths.

2. Terminology

This document uses the following terms defined in [RFC5440] PCC PCE, PCEP Peer.

This document uses the following terms defined in Stateful PCE [ietf-pce-stateful-pce] : Stateful PCE, Delegation, Delegation Timeout Interval, LSP State Report, LSP Update Request.

The message formats in this document are specified using Routing Backus-Naur Format (RBNF) encoding as specified in RFC5511.

3. Architectural Overview

3.1. Local Protection Overview

Local protection refers to the ability to locally route around failure of an LSP. Two types of local protection are possible:

1. 1:1 protection – the protection path protects a single LSP.

2. N:1 protection – the protection path protects multiple LSPs traversing the protected resource.
It is assumed that the PCE knows what resources require protection through mechanisms outside the scope of this document. In a PCE controlled deployment, support of 1:1 protection has limited applicability, and can be achieved as a degenerate case of 1:N protection. For this reason, local protection will be discussed only for the N:1 case.

Local protection requires the setup of a bypass at the PLR. This bypass can be PCC-initiated and delegated, or PCE-initiated. In either case, the PLR MUST maintain a PCEP session to the PCE. A bypass identifier (the name of the bypass) is required for disambiguation as multiple bypasses are possible at the PLR. There are two types of bypass LSP mappings:

(1) Independent Bypass LSP Mapping: In this case, bypass LSP mapping is handled by a local policy on PCC and the PCC reports all mappings to the PCE. In other words, bypass LSP(s) are mapped to any protected LSP(s) that satisfy PCC local policy.

(2) Dependent Bypass LSP mapping: Mapping of LSPs to bypass is done through a new TLV, the LOCALLY-PROTECTED-LSPS TLV in the LSP Update message from PCE to PLR. See section Section 4.3. When an LSP requiring protection is set up through the PLR, the PLR checks if it has a mapping to a bypass and only provides protection if such a mapping exists. The status of bypasses and what LSPs are protected by them is communicated to the PCE via LSP Status Report messages.

4. Extensions for the LSPA object

4.1. The Weight TLV

This TLV will be discussed in a future version of this document.

4.2. The Bypass TLV

The facility backup method creates a bypass tunnel to protect a potential failure point. The bypass tunnel protects a set of LSPs with similar backup constraints [RFC4090].

A PCC can delegate a bypass tunnel to PCE control or a PCE can provision the bypass tunnel via a PCC. The procedures for bypass instantiation rely on the extensions defined in PCE-Initiated LSP [ietf-pce-pce-initiated-lsp] and will be detailed in a future version of this document.

The Bypass TLV carries information about the bypass tunnel. It is included in the LSPA Object in LSP State Report and LSP Update Request messages.
The format of the IPv4 Bypass TLV is shown in the following figure:

```
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 2 3 4 5 6 7 8 9 0 1 2
+-------------------------------+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=[TBD]          |           Length=8            |
+-------------------------------+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          MUST be zero         |           Flags           |I|N|
+-------------------------------+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Bypass IPv4 Address                      |
+----------------------------------------------------------------
```

Figure 1: IPv4 Bypass TLV format

The type of the TLV is [TBD] and it has a fixed length of 8 octets. The value contains the following fields:

Flags (16 bit)

N (Node Protection - 1 bit): The N flag indicates whether the Bypass is used for node-protection. If the N flag is set to 1, the Bypass is used for node-protection. If the N flag is 0, the Bypass is used for link-protection.

I (Local Protection In Use - 1 bit): The I Flag indicates that local repair mechanism is in use.

Bypass IPv4 address: For link protection, the Bypass IPv4 Address is the nexthop address of the protected link in the paths of the protected LSPs. For node protection, the Bypass IPv4 Address is the node addresses of the protected node.

If the Bypass TLV is included, then the LSPA object MUST also carry the SYMBOLIC-PATH-NAME TLV as one of the optional TLVs. Failure to include the mandatory SYMBOLIC-PATH-NAME TLV MUST trigger PCErr of type 6 (Mandatory Object missing) and value TBD (SYMBOLIC-PATH-NAME TLV missing for bypass LSP)

4.3. The LOCALLY-PROTECTED-LSPS TLV

The IPv4-LOCALLY-PROTECTED-LSPS TLV in the LSPA Object contains a list of LSPs protected by the bypass tunnel.

The format of the Locally protected LSPs TLV is shown in the following figure:
Figure 2: IPv4 Locally protected LSPs TLV format

The type of the TLV is [TBD] and it is of variable length. The value contains one or more LSP descriptors including the following fields filled per [RFC3209]

IPv4 Tunnel end point address: As defined in [RFC3209], Section 4.6.1.1

Flags (16 bit)

R(Remove - 1 bit): The R flag indicates that the LSP has been removed from the list of LSPs protected by the bypass tunnel.

Tunnel ID: As defined in [RFC3209], Section 4.6.1.1

Extended Tunnel ID: As defined in [RFC3209], Section 4.6.2.1

IPv4 Tunnel Sender address: As defined in [RFC3209], Section 4.6.2.1
5. IANA considerations

5.1. PCEP-Error Object

This document defines new Error-Type and Error-Value for the following new error conditions:

Error-Type Meaning 6 Mandatory Object missing Error-value=TBD: SYMBOLIC-PATH-NAME TLV missing for a path where the S-bit is set in the LSPA object. Error-value=TBD: SYMBOLIC-PATH-NAME TLV missing for a bypass path.

5.2. PCEP TLV Type Indicators

This document defines the following new PCEP TLVs:

<table>
<thead>
<tr>
<th>Value #</th>
<th>Meaning</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>???</td>
<td>Bypass</td>
<td>This Document</td>
</tr>
<tr>
<td>???</td>
<td>Weight</td>
<td>This Document</td>
</tr>
<tr>
<td>???</td>
<td>LOCALLY-PROTECTED-LSPS</td>
<td>This Document</td>
</tr>
</tbody>
</table>

Table 1: New PCEP TLVs

6. Security Considerations

The same security considerations apply at the PLR as those describe for the head end in PCE Initiated LSPs [ietf-pce-pce-initiated-lsp].

7. Acknowledgements

We would like to thank Ambrose Kwong for his contributions to this document.

8. References

8.1. Normative References

[ietf-pce-pce-initiated-lsp]

Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.


8.2. Informative References


Appendix A. Additional Stuff

This becomes an Appendix.

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PCE-initiated IP Tunnel

draft-chen-pce-pce-initiated-ip-tunnel-00

Abstract

This document specifies a set of extensions to PCEP to support PCE-initiated IP Tunnel to satisfy the requirement which is introduced in [I-D.li-spring-tunnel-segment]. The extensions include the setup, maintenance and teardown of PCE-initiated IP Tunnels, without the need for local configuration on the PCC.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

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1. Introduction

[I-D.li-spring-tunnel-segment] introduces a new type of segment, Tunnel Segment, for the segment routing. Tunnel segment can be used to reduce SID stack depth of SR path, span the non-SR domain or provide differentiated services. The tunnel segment can be allocated for MPLS RSVP-TE tunnel, SR-TE tunnel or IP Tunnel.
[I-D.li-spring-tunnel-segment] introduces two ways to set up the tunnel which is used as tunnel segment: one is to configure tunnel on the device, the other is PCE-initiated tunnel.

[I-D.ietf-pce-stateful-pce], [I-D.ietf-pce-pce-initiated-lsp] and [I-D.ietf-pce-segment-routing] has defined how to set up the PCE initiated RSVP-TE LSP and SR-TE LSP. This document specifies a set of extensions to PCEP to support PCE-initiated IP Tunnel. The extensions include the setup, maintenance and teardown of PCE-initiated IP Tunnels, without the need for local configuration on the PCC.

2. Terminology

SR: Segment Routing
SR-TE: Segment Routing Traffic Engineering

This document uses the terms defined in [RFC5440]: PCC, PCE, PCEP Peer.

The following terms are defined in [I-D.ietf-pce-pce-initiated-lsp]:

PCE-initiated LSP: LSP that is instantiated as a result of a request from the PCE.

The following terms are defined in this document:

IP Tunnel: Tunnel that uses IP encapsulation.

PCE-initiated IP Tunnel: IP Tunnel that is instantiated as a result of a request from the PCE.

The message formats in this document are specified using Routing Backus-Naur Format (RBNF) encoding as specified in [RFC5511].

3. Procedures for PCE-initiated IP Tunnel

3.1. Overview of Procedures

A PCC or PCE indicates its ability to support PCE Initiated dynamic tunnel during the PCEP Initialization Phase via "PCE Initiated Tunnel Capability" TLV (see details in Section 5.1).

In this document the procedure is only about PCE Initiated dynamic IP Tunnel. The decision when to instantiate or delete a PCE-initiated IP Tunnel is out of the scope of this document.
This section introduces the procedure to support PCE provisioned IP Tunnel as follows:

Firstly both the PCC and the PCE negotiate the PCE Initiated Tunnel Capability for tunnel types during the PCE session initiation phase. On the PCEP session with PCE Initiated Tunnel Capability PCE communicates with PCC to set up, maintain and tear down PCE-initiated IP Tunnels.

The procedure about tunnel state synchronization, PCC local policy and timeout process, the session failure process, etc. will be specified in the future version.

3.2. Capability Advertisement

During PCEP session establishment, both the PCC and the PCE must announce their support of PCEP extensions defined in this document. A PCEP Speaker (PCE or PCC) includes the "PCE Initiated Tunnel Capability" TLV, described in Section 5.1, in the OPEN Object to advertise its support for PCEP extensions for PCE Initiated IP Tunnel Capability.

The PCE Initiated Tunnel Capability TLV includes the tunnel types that are supported by PCEP Speaker. Each tunnel type is indicated by one bit.

The presence of the PCE Initiated Tunnel Capability TLV in PCE’s OPEN message indicates that the PCE can support the instantiation of PCE-initiated Tunnels and the types of the tunnels which PCE can initiate.

The presence of such Capability TLV in PCC’s OPEN Object indicates that the PCC can support to instantiate the tunnel according to the PCE’s indication and the types of the tunnels which PCC can setup automatically according to the PCE’s request.

If PCE has such capability TLV and PCC has no such capability TLV PCE MUST NOT send the PCE messages for procedure of PCE initiated IP Tunnel. And if PCC receives such messages it should send PCErr message to PCE.

If both PCE and PCC have such capability TLV they only negotiate the types of the tunnels both PCE and PCC can support. PCE MUST only initiate the specific tunnel which both PCE and PCC can support. Otherwise PCC MUST send the PCErr message.
3.3. Tunnel Operations

3.3.1. PCE IP Tunnel Instantiation

To instantiate a tunnel, the PCE sends a Path Computation Tunnel Initiate (PCTunnelInitiate) message to the PCC. The PCTunnelInitiate message MUST include the SRP object (see details in Section 5.2) and TUNNEL object (see details in Section 5.3). The TUNNEL object MUST have a PTUNNEL-ID of 0 and MUST include the Tunnel Identifier TLV with the TUNNEL-ID 0 and the Tunnel Name TLV. The TUNNEL object MAY have the Tunnel Parameter TLV.

The PCC creates the different type of tunnel using the end point address carried in Tunnel Identifier TLV and sends the Path Computation Tunnel State Report (PCTunneRpt) message to PCE. The PCTunneRpt message MUST include the SRP object and TUNNEL object. PCC assigns a unique PTUNNEL-ID carried via TUNNEL object and a unique TUNNEL-ID carried via Tunnel Identifier TLV (see details in Section 5.3) in TUNNEL object for the tunnel. PCC indicates the operational state in the TUNNEL object.

The PCTunneRpt message MUST include the SRP object, with the SRP-ID-NUMBER used in the SRP object of the PCTunnelInitiate message.

```
1) add new tunnel   |-- PCTunnelInitiate --> |
     PTUNNEL-ID=0,   |
     TUNNEL-ID=0    |
     R=0            |
     .              |
     <---- PCTunneRpt ------ 2) Tunnel Status Report sent
     PTUNNEL-ID=1,   |
     TUNNEL-ID=1    |
     Up             |
```

3.3.2. PCE IP Tunnel Update

To update the parameters used to create a tunnel, the PCE sends a Path Computation Tunnel Update (PCTunnelUpd) message to the PCC. The PCTunnelUpd message MUST include the SRP object and TUNNEL object. The TUNNEL object MUST have specific PTUNNEL-ID and MUST have specific Tunnel Identifier TLV. The TUNNEL object MUST carry any of the Tunnel Parameter TLV and Tunnel Attribute TLV.
The PCC updates the encapsulation parameters and/or attributes of the
tunnel and PCC sends the PCTunneRpt message to PCE to report updated
state.

The PCTunneRpt message MUST include the SRP object, with the SRP-ID-
NUMBER used in the SRP object of the PCTunnelUpd message.

1) update tunnel
    parameter
    ---- PCTunnelUpd ---->
       PTUNNEL-ID=1,
       TUNNEL-ID=1
       .
<---- PCTunneRpt -----
       PTUNNEL-ID=1,
       TUNNEL-ID=1
       Up

2) Tunnel Status Report sent

3.3.3. PCE IP Tunnel Deletion

To delete a tunnel, the PCE sends a Path Computation Tunnel Initiate
(PCTunnelInitiate) message to the PCC. The PCTunnelInitiate message
MUST include the SRP object and TUNNEL object and the ‘R’ flag in SRP
object SHOULD be set. The TUNNEL object MUST have specific PTUNNEL-
ID and MUST have specific Tunnel Identifier TLV.

The PCC delete the tunnel specified by PTUNNEL-ID and PCC sends the
PCTunneRpt message to PCE to report updated state.

The PCTunneRpt message MUST include the SRP object, with the SRP-ID-
NUMBER used in the SRP object of the PCTunnelInitiate message.
4. PCEP Messages

To initiate a tunnel, a PCE sends a PCTunnelInitiate message to a PCC.

To report the state of a tunnel, a PCC sends a PCTunnelRpt message to a PCE.

To modify the parameters of a tunnel, a PCE sends a PCTunnelUpd message to a PCC.

The message format, objects and TLVs are discussed separately below for the creation and the deletion cases.

4.1. PCTunnelInitiate Message

A Path Computation Tunnel Initiate message which is also referred to as PCTunnelInitiate message is a PCEP message sent by a PCE to a PCC to trigger tunnel instantiation or deletion.

The Message-Type field of the PCEP common header for the PCTunnelInitiate message is to be assigned by IANA. The PCTunnelInitiate message MUST include the SRP and the TUNNEL objects. If the SRP object is missing, the PCC MUST send a PCErr with error-type 6 (Mandatory Object missing) and error-value=10 (SRP Object missing) (per [I-D.ietf-pce-stateful-pce]). If the TUNNEL object is missing, the PCC MUST send a PCErr with error-type 6 (Mandatory Object missing) and error-value which means TUNNEL Object missing.

Tunnel instantiation is done by sending an Tunnel Initiate Message with an TUNNEL object with the reserved PTUNNEL-ID 0. Tunnel deletion is done by sending an Tunnel Initiate Message with an TUNNEL
The format of a PCTunnelInitiate message for tunnel instantiation is as follows:

\[
\text{<PCTunnelInitiate Message> ::= <Common Header>}
\]
\[
\quad \text{<PCE-initiated-tunnel-list>}
\]

Where:

\[
\text{<PCE-initiated-tunnel-list> ::= <PCE-initiated-tunnel-request>}
\]
\[
\quad [\text{<PCE-initiated-tunnel-request>}
\]
\[
\text{<PCE-initiated-tunnel-request> ::= (<PCE-initiated-tunnel-instantiation>}
\]
\[
\quad |\text{<PCE-initiated-tunnel-deletion>})
\]
\[
\text{<PCE-initiated-tunnel-instantiation> ::= <SRP>}
\]
\[
\quad \text{TUNNEL}
\]
\[
\text{<PCE-initiated-tunnel-deletion> ::= <SRP>}
\]
\[
\quad \text{TUNNEL}
\]

The SRP object defined in [I-D.ietf-pce-stateful-pce] can be used in this document to correlate tunnel initiate requests and update requests sent by the PCE with the error reports and tunnel state reports sent by the PCC. Every request from the PCE sends a new SRP-ID-NUMBER. This number is unique per PCEP session and is incremented each time an operation (initiation, update, etc) is requested from the PCE. The value of the SRP-ID-NUMBER MUST be echoed back by the PCC in PCErr and PCTunnelRpt messages to allow for correlation between requests made by the PCE and errors or state reports generated by the PCC. Procedure of PCE-initiated IP Tunnel share the same number space of the SRP-ID-NUMBER with procedure of stateful PCE.

The <TUNNEL> object is an new object introduced in this document. <TUNNEL> object in PCTunnelInitiate message MUST include Tunnel Identifier TLV and Tunnel Name TLV. Tunnel Parameter TLV is optionally included.

The Tunnel Initiate message for tunnel instantiation has the TUNNEL object with the TUNNEL-ID in Tunnel Identifier TLV 0. The Tunnel Initiate message for tunnel deletion has the TUNNEL object carrying the TUNNEL-ID of the TUNNEL to be removed.

4.2. PCTunnelUpd Message

A Path Computation Tunnel Update Request message (also referred to as PCTunnelUpd message) is a PCEP message sent by a PCE to a PCC to update the encapsulation parameters and/or attributes of a tunnel. A PCTunnelUpd message can carry more than one Tunnel Update Request.
The Message-Type field of the PCEP common header for the PCUpd message is to be assigned by IANA.

The PCTunnelUpd message MUST include the SRP and the TUNNEL objects. If the SRP object is missing, the PCC MUST send a PCErr with error-type 6 (Mandatory Object missing) and error-value=10 (SRP Object missing) (per [I-D.ietf-pce-stateful-pce]). If the TUNNEL object is missing, the PCC MUST send a PCErr with error-type 6 (Mandatory Object missing) and error-value which means TUNNEL Object missing.

The format of a PCTunnelUpd message for tunnel parameter update is as follows:

<PCETunnelUpd Message> ::= <Common Header> <tunnel-update-request-list>

Where:
	<tunnel-update-request-list> ::= <tunnel-update-request> [<tunnel-update-request-list>]
	<tunnel-update-request> ::= <SRP> <TUNNEL>

<TUNNEL> object in PCTunnelUpd message MUST include Tunnel Identifier TLV and any of Tunnel Parameter TLV and Tunnel Attribute TLV. Tunnel Name TLV is not included.

4.3. PCTunnelRpt Message

A Path Computation Tunnel State Report message which is also referred to as PCTunnelRpt message is a PCEP message sent by a PCC to a PCE to report the current state of a tunnel. A PCTunnelRpt message can carry more than one Tunnel State Reports. A PCC sends an Tunnel State Report in response to a Tunnel Initiate Request for creation or a Tunnel Update Request from a PCE.

The Message-Type field of the PCEP common header for the PCTunnelRpt message is to be assigned by IANA. The PCTunnelRpt message MUST include the SRP and the TUNNEL objects. If the SRP object is missing, the PCE MUST send a PCErr with error-type 6 (Mandatory Object missing) and error-value=10 (SRP Object missing) (per [I-D.ietf-pce-stateful-pce]). If the TUNNEL object is missing, the PCE MUST send a PCErr with error-type 6 (Mandatory Object missing) and error-value which means TUNNEL Object missing.

The format of a PCTunnelRpt message for tunnel instantiation is as follows:
<PCTunnelRpt Message> ::= <Common Header>  
    <tunnel-state-report-list>

Where:
<tunnel-state-report-list> ::= <tunnel-state-report>  
    [<tunnel-state-report-list>]
<tunnel-state-report> ::= <SRP>
    <TUNNEL>

<TUNNEL> object in PCTunnelRpt message MUST include Tunnel Identifier TLV.

Tunnel Parameter TLV and Tunnel Attribute TLV is optionally included in PCTunnelRpt message. In the first PCTunnelRpt message in response to the PCTunnelInitiate message Tunnel Name TLV MUST be included. And in the subsequent PCTunnelRpt message Tunnel Name TLV is optionally included.

5. PCEP Objects

5.1. OPEN Object

5.1.1. PCE Initiated Tunnel Capability TLV

The PCE-INITIATE-TUNNEL-CAPABILITY TLV is an optional TLV associated with the OPEN Object [RFC5440] to exchange PCE-initiated tunnel capability of PCEP speakers.

Its format is shown in the following figure:

<table>
<thead>
<tr>
<th>0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type=[TBD]</td>
</tr>
</tbody>
</table>
| +-------------------------------------------------
| Tunnel Types |
| +-------------------------------------------------

Figure 1: PCE-INITIATE-TUNNEL-CAPABILITY TLV

The type of the TLV is to be assigned by IANA and it has a fixed length of 4 octets.

The value comprises a single field – Tunnel Types (32 bits):

Each bit indicates one kind of tunnel. Each bit from right to left successively represents the value of tunnel type which is 0 to 31. The value of tunnel types refer to the registry for "BGP Tunnel
Encapsulation Attribute Tunnel Types" [RFC5512] assigned by IANA. This document only use the IP tunnel type.

The assignments used by this document are as follows:

<table>
<thead>
<tr>
<th>Tunnel Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>0</td>
</tr>
<tr>
<td>GRE</td>
<td>2</td>
</tr>
<tr>
<td>VXLAN</td>
<td>8</td>
</tr>
<tr>
<td>NVGRE</td>
<td>9</td>
</tr>
<tr>
<td>MPLS in GRE</td>
<td>11</td>
</tr>
<tr>
<td>VxLAN GPE</td>
<td>12</td>
</tr>
<tr>
<td>MPLS in UDP</td>
<td>13</td>
</tr>
</tbody>
</table>

Unassigned bits are considered reserved. They MUST be set to 0 on transmission and MUST be ignored on receipt.

5.2. SRP Object

<SRP> object is defined in [I-D.ietf-pce-stateful-pce]. In this document <SRP> is used to correlate PCTunnelInitiate and PCTunnelRpt or PCErr message.

‘R’ Flag in <SRP> object is defined in [I-D.ietf-pce-pce-initiated-lsp]. When PCE requests PCC to create the IP tunnel ‘R’ Flag in <SRP> is set to 0. When PCE requests PCC to delete the IP tunnel ‘R’ Flag in <SRP> is set to 1.

Other flags must be set to 0 and if PCC receive the PCTunnelInitiate message with other reserved flags in <SRP> set to 1 PCC will send the PCErr message.

In procedure of PCE-initiated IP tunnel <SRP> object carries no optional TLVs.

5.3. TUNNEL Object

The TUNNEL object MUST be present within PCTunnelInitiate, PCTunnelRpt and PCTunnelUpd messages. The TUNNEL object contains a set of fields used to specify the target tunnel, the flags to indicate the state of the tunnel or operation to be performed on the tunnel and TLVs.

TUNNEL Object-Class is to be assigned by IANA.

TUNNEL Object-Type is 1.
The format of the TUNNEL object body is shown in following Figure:

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                PTUNNEL-ID                     |  Flag   |    O|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                        TLVs                                 //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
Figure 2: TUNNEL Object
```

PTUNNEL-ID (24 bits): A PCEP-specific identifier for the tunnel. A PCC creates a unique PTUNNEL-ID for each tunnel that is constant for the lifetime of a PCEP session. The PCC will advertise the same PTUNNEL-ID on all PCEP sessions. The mapping of the Tunnel Name to PTUNNEL-ID is communicated to the PCE by sending a PCTunnelRpt message containing the TUNNEL-NAME TLV. All subsequent PCEP messages then address the tunnel by the PTUNNEL-ID. The values of 0 and 0xFFFFFFFF are reserved.

Flags (8 bits):

O(Operational - 3 bits): On PCTunnelRpt messages, the O Field represents the operational status of the tunnel.

The following values are defined:

0 - DOWN: The tunnel can’t carry the traffic.

1 - UP: The tunnel can carry the traffic.

2-7 - Reserved: these values are reserved for future use.

Unassigned bits are considered reserved. They MUST be set to 0 on transmission and MUST be ignored on receipt.

TLVs that may be included in the TUNNEL Object are described in the following sections.

5.3.1. Tunnel Identifier TLV

The Tunnel Identifier TLV MUST be included in the TUNNEL object in PCTunnelInitiate, PCTunnelRpt and PCTunnelUpd messages for PCE-initiated IP Tunnels. If the TLV is missing, the PCE will generate an error with error-type 6 (mandatory object missing) and error-value
which means Tunnel Identifier TLV missing and close the session.
There are two Tunnel Identifier TLVs, one for IPv4 and one for IPv6.

The format of the IPV4-TUNNEL-Identifier TLV is shown in the
following figure:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=[TBD]          |           Length=12           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   IPv4 Tunnel Source Address                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   IPv4 Tunnel Destination Address             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Tunnel Type         |           Tunnel ID           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

Figure 3: IPV4-TUNNEL-Identifier TLV
```

The type of the TLV is to be assigned by IANA and it has a fixed
length of 12 octets. The value contains the following fields:

IPv4 Tunnel Source Address: contains the source IPv4 address of the
ingress node of the tunnel.

IPv4 Tunnel Destination Address: contains the destination IPv4
address of the egress node of the tunnel.

Tunnel Type: contains the type of tunnel. The value of tunnel types
refer to the registry for "BGP Tunnel Encapsulation Attribute Tunnel
Types" [RFC5512] IANA set up. This document only use the IP tunnel
type.

The assignments used by this document are as follows:

<table>
<thead>
<tr>
<th>Tunnel Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>0</td>
</tr>
<tr>
<td>GRE</td>
<td>2</td>
</tr>
<tr>
<td>VXLAN</td>
<td>8</td>
</tr>
<tr>
<td>NVGRE</td>
<td>9</td>
</tr>
<tr>
<td>MPLS in GRE</td>
<td>11</td>
</tr>
<tr>
<td>VxLAN GPE</td>
<td>12</td>
</tr>
<tr>
<td>MPLS in UDP</td>
<td>13</td>
</tr>
</tbody>
</table>

Tunnel ID: Tunnel ID remains constant over the life time of a tunnel.
A PCC creates a unique Tunnel ID for each tunnel. Each tunnel type
has individual identifier space. The Tunnel ID is allocated on id space of the tunnel type and is unique in the same id space.

The PCC will advertise the same Tunnel ID on all PCEP sessions. The mapping of the Tunnel Name to Tunnel ID is communicated to the PCE by sending a PCTunnelRpt message containing the TUNNEL-NAME TLV. The values of 0 and 0xFFFF are reserved.

The format of the IPV6-TUNNEL-Identifier TLV is shown in following figure:

```
   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=36                    |
  +-----------------------------------------------+
  |                                                  |
  |                                     IPv6 tunnel source address |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
  +-----------------------------------------------+
  |                Tunnel Type                   |
  |                Tunnel ID                    |

Figure 4: IPV6-TUNNEL-Identifier TLV
```

The type of the TLV is to be assigned by IANA and it has a fixed length of 36 octets. The value contains the following fields:

IPv6 Tunnel Source Address: contains the source IPv6 address of the ingress node of the tunnel.

IPv6 Tunnel Destination Address: contains the destination IPv6 address of the egress node of the tunnel.
Tunnel Type: contains the type of tunnel. The value of tunnel types refer to the registry for "BGP Tunnel Encapsulation Attribute Tunnel Types" [RFC5512] IANA set up.

This document only use the IP tunnel type. The assignments used by this document are as follows:

<table>
<thead>
<tr>
<th>Tunnel Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>0</td>
</tr>
<tr>
<td>GRE</td>
<td>2</td>
</tr>
<tr>
<td>VXLAN</td>
<td>8</td>
</tr>
<tr>
<td>NVGRE</td>
<td>9</td>
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</tr>
<tr>
<td>VxLAN GPE</td>
<td>12</td>
</tr>
<tr>
<td>MPLS in UDP</td>
<td>13</td>
</tr>
</tbody>
</table>

Tunnel ID: Tunnel ID remains constant over the life time of a tunnel. A PCC creates a unique Tunnel ID for each TUNNEL. Each tunnel type has individual identifier space. The tunnel ID is allocated on id space of the tunnel type and is unique in the same id space.

The PCC will advertise the same Tunnel ID on all PCEP sessions. The mapping of the Tunnel Name to Tunnel ID is communicated to the PCE by sending a PCTunnelRpt message containing the TUNNEL-NAME TLV. The values of 0 and 0xFFFF are reserved.

5.3.2. Tunnel Name TLV

The Tunnel Name TLV MUST be included in the TUNNEL object in PCTunnelInitiate messages for PCE-initiated IP Tunnels. If the TLV is missing, the PCE will generate an error with error-type 6 (mandatory object missing) and error-value which means Tunnel Name TLV missing and close the session.

Each tunnel MUST have a tunnel name that is unique in the PCC. This tunnel name MUST remain constant throughout a tunnel’s lifetime.

The TUNNEL-NAME TLV MUST be included in the PCTunnelRpt message when a tunnel is first reported to a PCE in response to the PCTunnelInitiate message to create the tunnel. The tunnel name MAY be included in subsequent PCTunnelRpt messages for the tunnel.

The format of the TUNNEL-NAME TLV is shown in the following figure:
The type of the TLV is to be assigned by IANA and it has a variable length, which MUST be greater than 0.

5.3.3. Tunnel Parameter TLV

The Tunnel Parameter TLV and/or Tunnel Attribute TLV (see details in following section) MUST be included in the TUNNEL object in PCTunnelUpd messages for PCE-initiated IP Tunnels. If both of the TLVs are missing, the PCE will generate an error with error-type 6 (mandatory object missing) and error-value which means Tunnel Parameter TLV and Tunnel Attribute TLV missing and close the session.

The Tunnel Parameter TLV MAY be included in the TUNNEL object in PCTunnelInitiate and PCTunnelRpt messages for PCE-initiated IP Tunnels.

Tunnel Parameter TLV specifies information needed to construct the encapsulation header when sending packets through that tunnel.

The tunnel with different type has different encapsulation mode and each tunnel with same type MAY has different encapsulation parameters. When PCE initiate setup of the tunnel PCE can specify the encapsulation parameter of the tunnel and PCC will setup the tunnel and encapsulate the packet according to the parameters.

After the tunnel has been triggered to instantiate PCE can send PCTunnelUpd message to modify the encapsulation parameter.

The format of the TUNNEL-PARAMETER TLV is shown in following figure:
The type of the TLV is to be assigned by IANA and it has a variable length, which MUST be greater than 0. The minimum value of length is 4 without any parameter. The value contains the following fields:

Tunnel Type: contains the type of tunnel. The value of tunnel types refer to the registry for "BGP Tunnel Encapsulation Attribute Tunnel Types" [RFC5512] IANA set up. This document only use the IP tunnel type.

The assignments used by this document are as follows:

<table>
<thead>
<tr>
<th>Tunnel Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>0</td>
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<tr>
<td>GRE</td>
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<td>8</td>
</tr>
<tr>
<td>NVGRE</td>
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<td>MPLS in GRE</td>
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</tr>
<tr>
<td>VXLAN GPE</td>
<td>12</td>
</tr>
<tr>
<td>MPLS in UDP</td>
<td>13</td>
</tr>
</tbody>
</table>

MPLS in GRE has the same encapsulation with GRE.

5.3.3.1. GRE

When the tunnel type of the TLV is GRE, the following is the structure of the value field of Tunnel Encapsulation Parameter:
Figure 7: GRE Encapsulation TLV

* GRE Key: 4-octet field [RFC2890]. The actual method by which the key is obtained by PCE is beyond the scope of this document. The key is inserted into the GRE encapsulation header of the payload packets sent by ingress router to the egress router. It is intended to be used for identifying extra context information about the received payload.

Note that the key is optional. Unless a key value is being used, the GRE encapsulation MUST NOT be present. If GRE tunnel didn’t use the GRE key the PCTunnelInitiate message needn’t carry the TUNNEL-PARAMETER TLV. If GRE tunnel firstly use the GRE key the PCTunnelInitiate message need carry the TUNNEL-PARAMETER TLV. Then if the GRE tunnel quit using the GRE key the PCTunnelUpd message can carry the TUNNEL-PARAMETER TLV without GRE key to delete the parameter previously set.

5.3.3.2. VXLAN

When the tunnel type of the TLV is VXLAN, the following is the structure of the value field of Tunnel Encapsulation Parameter:

Figure 8: VXLAN Encapsulation TLV

The definition of the fields refer to [I-D.rosen-idr-tunnel-encaps].

5.3.3.3. VXLAN-GPE

When the tunnel type of the TLV is VXLAN-GPE, the following is the structure of the value field of Tunnel Encapsulation Parameter:
5.3.3.4. NVGRE

When the tunnel type of the TLV is NVGRE, the following is the structure of the value field of Tunnel Encapsulation Parameter:

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|V|M|R|R|R|R|R|          VN-ID (3 Octets)                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 MAC Address (4 Octets)                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  MAC Address (2 Octets)     |   Reserved                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 10: NVGRE Encapsulation TLV

The definition of the fields refer to [I-D.rosen-idr-tunnel-encaps].

5.3.3.5. MPLS-in-UDP

When the tunnel type of the TLV is MPLS-in-UDP, the following is the structure of the value field of Tunnel Encapsulation Parameter:

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Source Port (2 Octets)      |  Destination Port (2 Octets) |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 11: MPLS-in-UDP Encapsulation TLV

Source Port: UDP source port.

Destination Port: UDP destination port.
5.3.4. Tunnel Attribute TLV

The Tunnel Attribute TLV MAY be included in the TUNNEL object in PCTunnelInitiate, PCTunnelUpd, PCTunnelRpt messages for PCE-initiated IP Tunnels.

Tunnel Attribute TLV specifies some of the information of the tunnel such as metric or TE metric which are carried in sub-TLVs.

The format of the TUNNEL-ATTRIBUTE TLV is shown in following figure:

```
+-----------------+-----------------+-----------------+-----------------+
| Type=[TBD]       | Length           |
| sub-TLVs         |                 |
|                  |                 |
+-----------------+-----------------+-----------------+-----------------+
```

Figure 12: Tunnel Attribute TLV Format

The type of the TLV is to be assigned by IANA and it has a variable length. The minimum value of length is 0 without any parameter. The value contains the following fields:

- sub-TLVs: Each sub-TLV has the Type (two octets), Length (two octets), Value. The length is the length of the value of the sub-TLV. Unknown sub-TLVs are to be ignored and skipped upon receipt.

This document defines the following sub-TLVs.

5.3.4.1. Metric Sub-TLV

The following is the structure of the sub-TLV of metric:

```
+-----------------+-----------------+-----------------+-----------------+
| Type=[TBD]       | Length           |
| Metric Value     |                 |
+-----------------+-----------------+-----------------+-----------------+
```

Figure 13: Metric Sub-TLV

The type of the sub-TLV is to be assigned by IANA and it has a fixed length of 4 octets.
The value comprises a single field - Metric Value (32 bits): value of metric.

5.3.4.2. TE Metric Sub-TLV

The following is the structure of the sub-TLV of traffic engineering metric:

```
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              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     TE Metric Value                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 14: TE Metric Sub-TLV

The type of the sub-TLV is to be assigned by IANA and it has a fixed length of 4 octets.

The value comprises a single field - TE Metric Value (32 bits): value of traffic engineering metric.

6. IANA Considerations

TBD.

7. Security Considerations

TBD.

8. References

8.1. Normative References

[I-D.li-spring-tunnel-segment]
Li, Z. and N. Wu, "Tunnel Segment in Segment Routing",
draft-li-spring-tunnel-segment-00 (work in progress),
September 2015.

[I-D.rosen-idr-tunnel-encaps]
Rosen, E., Patel, K., and G. Velde, "Using the BGP Tunnel Encapsulation Attribute without the BGP Encapsulation SAFl",
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8.2. Informative References

[I-D.ietf-pce-pce-initiated-lsp]

[I-D.ietf-pce-segment-routing]

[I-D.ietf-pce-stateful-pce]
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Email: lizhenbin@huawei.com
PCEP Extensions for MPLS-TE LSP Automatic Bandwidth Adjustment with Stateful PCE
draft-dhody-pce-stateful-pce-auto-bandwidth-05

Abstract

The Path Computation Element Communication Protocol (PCEP) provides mechanisms for Path Computation Elements (PCEs) to perform path computations in response to Path Computation Clients (PCCs) requests. The stateful PCE extensions provide stateful control of Multi-Protocol Label Switching (MPLS) Traffic Engineering Label Switched Paths (TE LSPs) via PCEP, for the case where PCC delegates control over one or more locally configured LSPs to the PCE.

This document describes automatic bandwidth adjustment of such LSPs when employing an Active Stateful PCE. In one of the models described, PCC computes the bandwidth to be adjusted and informs the PCE whereas in the second model, PCC reports the real-time traffic to a PCE and the PCE computes the adjustment bandwidth.

This document also describes automatic bandwidth adjustment for stateful PCE-initiated LSPs.

Status of This Memo

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1. Introduction

[RFC5440] describes the Path Computation Element Protocol (PCEP) as a communication mechanism between a Path Computation Client (PCC) and a Path Control Element (PCE), or between PCE and PCE, that enables computation of Multi-Protocol Label Switching (MPLS) Traffic Engineering Label Switched Paths (TE LSPs).

[I-D.ietf-pce-stateful-pce] specifies extensions to PCEP to enable stateful control of MPLS TE LSPs. It describes two modes of operations - Passive Stateful PCE and Active Stateful PCE. In this document, the focus is on Active Stateful PCE where LSPs are configured at the PCC and control over them is delegated to the PCE. Further [I-D.ietf-pce-pce-initiated-lsp] describes the setup, maintenance and teardown of PCE-initiated LSPs under the stateful PCE model.

Over time, based on the varying traffic pattern, an LSP established with certain bandwidth may require to adjust the bandwidth, reserved in the network automatically. Ingress Label Switch Router (LSR) collects the traffic rate at each sample interval to determine the bandwidth demand of the LSP. This bandwidth information is then used to adjust the LSP bandwidth periodically. This feature is commonly referred to as Auto-Bandwidth.

Enabling Auto-Bandwidth feature on an LSP results in the LSP automatically adjusting its bandwidth based on the actual traffic flowing through the LSP. An LSP set-up with some arbitrary
(including zero) bandwidth value, automatically monitors the traffic flow and adjusts its bandwidth every adjustment-interval period. The bandwidth adjustment uses the make-before-break signaling method so that there is no interruption to traffic flow. This is described in detail in Section 4.1. [I-D.ietf-pce-stateful-pce-app] describes the use-case for Auto-Bandwidth adjustment for passive and active stateful PCE.

In this document, following deployment models are considered for employing Auto-Bandwidth feature with active stateful PCE.

- Deployment model 1: PCC to decide adjusted bandwidth:
  - In this model, the PCC (head-end of the LSP) monitors and calculates the new adjusted bandwidth. The PCC reports the calculated bandwidth to be adjusted to the PCE.
  - This approach would be similar to passive stateful PCE model, while the passive stateful PCE uses path request/reply mechanism, the active stateful PCE uses report/update mechanism to adjust the LSP bandwidth.
  - For PCE-initiated LSP, the PCC is requested during the LSP initiation to monitor and calculate the new adjusted bandwidth.

- Deployment model 2: PCE to decide adjusted bandwidth:
  - In this model, the PCE calculates the new adjusted bandwidth for the LSP.
  - Active stateful PCE can use information such as historical trending data, application-specific information about expected demands and central policy information along with real-time actual flow volumes to make smarter bandwidth adjustment to the delegated LSPs. Since the LSP has delegated control to the PCE, it is inherently suited that it should be the stateful PCE that decides the bandwidth adjustments.
  - For PCE-initiated LSP, the PCC is requested during initiation, to monitor and report the real-time bandwidth usage.
  - This model does not exclude use of any other mechanism employed by stateful PCE to learn real-time traffic information. But at the same time, using the same protocol (PCEP in this case) for updating and reporting the adjustment parameters as well as to learn real-time bandwidth usage is operationally beneficial.
This document defines extensions needed to support Auto-Bandwidth feature on the LSPs in a active stateful PCE model using PCEP.

2. Conventions Used in This Document

2.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2.2. Terminology

The following terminology is used in this document.

Active Stateful PCE: PCE that uses tunnel state information learned from PCCs to optimize path computations. Additionally, it actively updates tunnel parameters in those PCCs that delegated control over their tunnels to the PCE.

Delegation: An operation to grant a PCE temporary rights to modify a subset of tunnel parameters on one or more PCC’s tunnels. Tunnels are delegated from a PCC to a PCE.

PCC: Path Computation Client. Any client application requesting a path computation to be performed by a Path Computation Element.

PCE: Path Computation Element. An entity (component, application, or network node) that is capable of computing a network path or route based on a network graph and applying computational constraints.

TE LSP: Traffic Engineering Label Switched Path.

Note the Auto-Bandwidth feature specific terms defined in Section 4.1.

3. Requirements for PCEP Extensions

There are two deployment models considered in this document for automatic bandwidth adjustments in case of active stateful PCE. In the model where PCC decides the adjusted bandwidth, PCC can report the new requested bandwidth and an active stateful PCE can update the bandwidth for a delegated LSP via existing mechanisms defined in [I-D.ietf-pce-stateful-pce]. Additional PCEP extensions required are summarized in the following table.
<table>
<thead>
<tr>
<th>Model</th>
<th>PCC Initiated</th>
<th>PCE Initiated</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC to decide adjusted bandwidth</td>
<td>PCC monitors the traffic and reports the calculated bandwidth to be adjusted to the PCE.</td>
<td>At the time of initiation, PCE request PCC to monitor the traffic and reports the calculated bandwidth to be adjusted to the PCE.</td>
</tr>
<tr>
<td></td>
<td>No new extensions are needed.</td>
<td>Extension is needed for PCE to pass on the adjustment parameters at the time of Initiation.</td>
</tr>
<tr>
<td></td>
<td>Optionally AUTO-BANDWIDTH-ATTRIBUTE TLV can be used to identify the LSP with Auto-Bandwidth Feature enabled.</td>
<td>Refer the AUTO-BANDWIDTH-ATTRIBUTE TLV (and sub-TLVs e.g. Adjustment-Interval, Minimum-Bandwidth) in Section 5.1.</td>
</tr>
<tr>
<td>PCC reports real-time traffic and PCE to decide adjusted bandwidth</td>
<td>PCC monitors the traffic and reports the real-time traffic to the PCE. It is PCE that decides the calculated bandwidth to be adjusted and updates the LSP accordingly.</td>
<td>At the time of initiation, PCE request PCC to monitor the traffic and reports the real-time traffic to the PCE. It is PCE that decides the calculated bandwidth to be adjusted and updates the LSP accordingly.</td>
</tr>
<tr>
<td></td>
<td>Extension is needed for PCC to pass on the adjustment parameters at the time of delegation to PCE.</td>
<td>Extension is needed for PCE to pass on the real-time traffic reporting parameters at the time of Initiation.</td>
</tr>
<tr>
<td></td>
<td>Refer the AUTO-BANDWIDTH-ATTRIBUTE TLV (and sub-TLVs e.g. Adjustment-Threshold, Real-time Traffic-Report-Interval) in Section 5.1.</td>
<td>Refer the Real-time Traffic Reporting (e.g. Real-time-Traffic-Report-Interval, Real-time-Traffic-Report-Threshold) in Section 5.1.2.</td>
</tr>
<tr>
<td></td>
<td>Further extension to</td>
<td>Further extension to report</td>
</tr>
</tbody>
</table>
report the real-time traffic to PCE are also needed (Refer Bandwidth-Usage type in Section 5.2.2).
the real-time traffic to PCE are also needed (Refer Bandwidth-Usage type in Section 5.2.2).

Table 1: Auto-Bandwidth Deployment Models

Additional Auto-Bandwidth deployment considerations are summarized below:

- It is required to identify and inform the PCEP peer, the LSP that are enabled with Auto-Bandwidth feature. Not all LSPs in some deployments would like their bandwidth to be dependent on the real-time traffic but be constant as set by the operator.

- It is also required to identify and inform the PCEP peer the model of operation i.e. if PCC decides the adjusted bandwidth, or PCC reports the real-time traffic instead and the PCE decides the adjusted bandwidth.
  
  Note that PCEP extension for reporting real-time traffic, as specified in this document, is one of the ways for a PCE to learn this information. But at the same time a stateful PCE may choose to learn this information from other means like management, performance tools, which are beyond the scope of this document.

- Further for the LSP with Auto-Bandwidth feature enabled, an operator should be able to specify the adjustment parameters (i.e. configuration knobs) to control this feature (e.g. minimum/maximum bandwidth range) and PCEP peer should be informed.

4. Architectural Overview

4.1. Auto-Bandwidth Overview

Auto-Bandwidth feature allows an LSP to automatically and dynamically adjust its reserved bandwidth over time, i.e. without network operator intervention. The bandwidth adjustment uses the make-before-break signaling method so that there is no interruption to the traffic flow.

The new bandwidth reservation is determined by sampling the actual traffic flowing through the LSP. If the traffic flowing through the LSP is lower than the configured or current bandwidth of the LSP, the
extra bandwidth is being reserved needlessly and being wasted. Conversely, if the actual traffic flowing through the LSP is higher than the configured or current bandwidth of the LSP, it can potentially cause congestion or packet loss in the network. With Auto-Bandwidth feature, the LSP bandwidth can be set to some arbitrary value (including zero) during initial setup time, and it will be periodically adjusted over time based on the actual bandwidth requirement.

Note the following definitions of the Auto-Bandwidth terms:

- **Maximum Average Bandwidth (MaxAvgBw)**: The maximum average bandwidth represents the current traffic demand during a time interval. This is the maximum value of the averaged traffic rate in a given adjustment-interval.

- **Adjusted Bandwidth**: This is the Auto-Bandwidth computed bandwidth that needs to be adjusted for the LSP.

- **Sample-Interval**: The periodic time interval at which the traffic rate is collected as a sample.

- **Bandwidth-Sample (BwSample)**: The bandwidth sample collected at every sample interval to measure the traffic rate.

- **Adjustment-Interval**: The periodic time interval at which the bandwidth adjustment should be made using the MaxAvgBw.

- **Maximum-Bandwidth**: The maximum bandwidth that can be reserved for the LSP.

- **Minimum-Bandwidth**: The minimum bandwidth that can be reserved for the LSP.

- **Adjustment-Threshold**: This value is used to decide when the bandwidth should be adjusted. If the percentage or absolute difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold value, the LSP bandwidth is adjusted to the current bandwidth demand (Adjusted Bandwidth) at the adjustment-interval expiry.

- **Overflow-Threshold**: This value is used to decide when the bandwidth should be adjusted when there is a sudden increase in traffic demand. If the percentage or absolute difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold value, the overflow-condition is set to be met. The LSP bandwidth is adjusted to the current
bandwidth demand bypassing the adjustment-interval if the overflow-condition is met consecutively for the overflow-counts.

Underflow-Threshold: This value is used to decide when the bandwidth should be adjusted when there is a sudden decrease in traffic demand. If the percentage or absolute difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold value, the underflow-condition is set to be met. The LSP bandwidth is adjusted to the current bandwidth demand bypassing the adjustment-interval if the underflow-condition is met consecutively for the underflow-counts.

Report-Interval: This value indicates the periodic interval when the collected real-time traffic bandwidth samples (BwSample) should be reported to the stateful PCE via the PCRpt message.

Report-Threshold: This value is used to decide if the real-time traffic bandwidth samples collected should be reported. Only if the percentage or the absolute difference between at least one of the bandwidth samples collected and the current bandwidth reservation is greater than or equal to the threshold value, the bandwidth samples collected during the Report-Interval are reported otherwise the bandwidth sample(s) are skipped.

Report-Flow-Threshold: This value is used to decide when the real-time traffic bandwidth samples should be reported immediately when there is a sudden change in traffic demand. If the percentage or absolute difference between the current bandwidth sample and the current bandwidth reservation is greater than or equal to the flow threshold value, all the bandwidth samples collected so far are reported to the PCE immediately.

4.2. Theory of Operation

The traffic rate is periodically sampled at each sample-interval (which can be configured by the user and the default value as 5 minutes) by the head-end node of the LSP. The sampled traffic rates are accumulated over the adjustment-interval period (which can be configured by the user and the default value as 24 hours). The PCEP peer which is in-charge of calculating the bandwidth to be adjusted, will adjust the bandwidth of the LSP to the highest sampled traffic rate (MaxAvgBw) amongst the set of bandwidth samples collected over the adjustment-interval.

Note that the highest sampled traffic rate could be higher or lower than the current LSP bandwidth. Only if the difference between the current bandwidth demand (MaxAvgBw) and the current bandwidth reservation is greater than or equal to the Adjustment-Threshold.
(percentage or absolute value), the LSP bandwidth is adjusted to the current bandwidth demand (MaxAvgBw).

In order to avoid frequent re-signaling, an operator may set a longer adjustment-interval value. However, longer adjustment-interval can result in an undesirable effect of masking sudden changes in traffic demands of an LSP. To avoid this, the Auto-Bandwidth feature may pre-maturely expire the adjustment-interval and adjust the LSP bandwidth to accommodate the sudden bursts of increase in traffic demand as an overflow condition or decrease in traffic demand as an underflow condition.

In case of Deployment model 2, the PCC reports the real-time traffic information and the PCE decides the adjusted bandwidth. Multiple bandwidth samples are collected every report-interval, and reported together to the PCE. To avoid reporting minor changes in real-time traffic, report-threshold is used, to suppress the sending of the collected samples during the report-interval. The collected samples are reported if at least one sample crosses the Report-Threshold (percentage or absolute value). In order to accommodate sudden changes in the real-time traffic, report flow threshold is employed by pre-maturely expiry of the report-interval to report the unreported bandwidth samples collected so far.

All thresholds in this document could be represented in both absolute value and percentage, and could be used together.

4.3. Scaling Considerations

There are potential scaling concerns for the model where PCC (ingress LSR) reports real-time traffic information to the stateful PCE for a large number of LSPs. It is recommended to combine multiple bandwidth samples (BwSample) using larger report-interval and report them together to the PCE, thus reducing the number of PCRpt messages. Further Report-Threshold can be use to skip reporting the bandwidth samples for small changes in the bandwidth.

The processing cost of monitoring a large number of LSPs at the PCC and handling bandwidth change requests at PCE should be taken into consideration. Note that, this will be implementation dependent.

5. Extensions to the PCEP

5.1. AUTO-BANDWIDTH-ATTRIBUTE TLV

The AUTO-BANDWIDTH-ATTRIBUTE TLV can be included as an optional TLV in the LSPA object (as described in [RFC5440]). Whenever the LSP with Auto-Bandwidth feature enabled is delegated, AUTO-BANDWIDTH-
ATTRIBUTE TLV is carried in PCRpt message in LSPA object. The TLV provides PCE with the ‘configurable knobs’ of this feature. In case of PCE-Initiated LSP ([I-D.ietf-pce-pce-initiated-lsp]) with Auto-Bandwidth feature enabled, this TLV is included in LSPA object with PCInitiate message.

The format of the AUTO-BANDWIDTH-ATTRIBUTE TLV is shown in the following figure:

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=[TBD]          |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                            sub-TLVs                          |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

AUTO-BANDWIDTH-ATTRIBUTE TLV format

Type: TBD
Length: Variable
Value: This comprises one or more sub-TLVs.

Following sub-TLVs are defined in this document:

<table>
<thead>
<tr>
<th>Type Len Name</th>
<th>Description</th>
<th>Type Len Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 4</td>
<td>Sample-Interval sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 4</td>
<td>Adjustment-Interval sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 4</td>
<td>Adjustment-Threshold sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 4</td>
<td>Adjustment-Threshold-Percentage sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 4</td>
<td>Minimum-Bandwidth sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 4</td>
<td>Maximum-Bandwidth sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 8</td>
<td>Overflow-Threshold sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 4</td>
<td>Overflow-Threshold-Percentage sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 8</td>
<td>Underflow-Threshold sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 4</td>
<td>Underflow-Threshold-Percentage sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 4</td>
<td>Real-time-Traffic-Report-Interval sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 4</td>
<td>Real-time-Traffic-Report-Threshold sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 4</td>
<td>Real-time-Traffic-Report-Threshold-Percentage sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 4</td>
<td>Real-time-Traffic-Report-Flow-Threshold sub-TLV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 4</td>
<td>Real-time-Traffic-Report-Flow-Threshold-Percentage sub-TLV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Future specification can define additional sub-TLVs.
The presence of AUTO-BANDWIDTH-ATTRIBUTE TLV in LSPA object means that the automatic bandwidth adjustment feature is enabled. All sub-TLVs are optional and any unrecognized sub-TLV MUST be silently ignored. If a sub-TLV of same type appears more than once, only the first occurrence is processed and any others MUST be ignored.

If the sub-TLV are not encoded, the defaults based on the local policy are assumed.

The following sub-sections describe the sub-TLVs which are currently defined to be carried within the AUTO-BANDWIDTH-ATTRIBUTE TLV.

5.1.1. Adjustment Parameters

The sub-TLVs in this section are encoded to inform the PCEP peer the various sampling and adjustment parameters, and serves the following purpose -

- For PCE-Initiated LSPs inform the PCC of the various sampling and adjustment parameters.
- For PCC-Initiated LSPs in the Deployment Model 2 (where PCE decides the adjusted bandwidth), inform the PCE of the various sampling and adjustment parameters.

5.1.1.1. Sample-Interval sub-TLV

The Sample-Interval sub-TLV specifies a time interval in seconds at which traffic samples are collected at the PCC.

The Type is 1, Length is 4, and the value comprises of 4-octet time interval, the valid range is from 1 to 604800, in seconds. The default value is 300.

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=1              |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Sample-Interval                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Sample-Interval sub-TLV format
5.1.1.2. Adjustment-Interval sub-TLV

The Adjustment-Interval sub-TLV specifies a time interval in seconds at which bandwidth adjustment should be made.

The Type is 2, Length is 4, and the value comprises of 4-octet time interval, the valid range is from 1 to 604800, in seconds. The default value is 300.

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=2              |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Adjustment-Interval              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Adjustment-Interval sub-TLV format

5.1.1.3. Adjustment Threshold

The sub-TLVs in this section are encoded to inform the PCEP peer the adjustment threshold parameters. An implementation MAY include both sub-TLVs for the absolute value and the percentage, in which case the bandwidth is adjusted when either of the adjustment threshold conditions are met.

5.1.1.3.1. Adjustment-Threshold sub-TLV

The Adjustment-Threshold sub-TLV is used to decide when the LSP bandwidth should be adjusted.

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=3              |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Adjustment Threshold                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Adjustment-Threshold sub-TLV format

The Type is 3, Length is 4, and the value comprises of:

- Adjustment Threshold: The absolute Adjustment-Threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values.
If the difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold value, the LSP bandwidth is adjusted to the current bandwidth demand.

5.1.1.3.2. Adjustment-Threshold-Percentage sub-TLV

The Adjustment-Threshold-Percentage sub-TLV is used to decide when the LSP bandwidth should be adjusted.

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=4              |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Reserved                       |  Percentage |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Adjustment-Threshold-Percentage sub-TLV format

The Type is 4, Length is 4, and the value comprises of:

- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.

- Percentage: The Adjustment-Threshold value, encoded in percentage (an integer from 0 to 100). If the percentage difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold percentage, the LSP bandwidth is adjusted to the current bandwidth demand.

5.1.1.4. Minimum and Maximum Bandwidth

5.1.1.4.1. Minimum-Bandwidth sub-TLV

The Minimum-Bandwidth sub-TLV specify the minimum bandwidth allowed for the LSP, and is expressed in bytes per second. The LSP bandwidth cannot be adjusted below the minimum bandwidth value.

The Type is 5, Length is 4, and the value comprises of 4-octet bandwidth value encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values.
5.1.1.4.2. Maximum-Bandwidth sub-TLV

The Maximum-Bandwidth sub-TLV specify the maximum bandwidth allowed for the LSP, and is expressed in bytes per second. The LSP bandwidth cannot be adjusted above the maximum bandwidth value.

The Type is 6, Length is 4, and the value comprises of 4-octet bandwidth value encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values.

5.1.1.5. Overflow and Underflow Condition

The sub-TLVs in this section are encoded to inform the PCEP peer the overflow and underflow threshold parameters. An implementation MAY include sub-TLVs for the absolute value and the percentage for the threshold, in which case the bandwidth is immediately adjusted when either of the adjustment threshold conditions are met consecutively for the given count.

5.1.1.5.1. Overflow-Threshold sub-TLV

The Overflow-Threshold sub-TLV is used to decide if the bandwidth should be adjusted immediately.
Overflow-Threshold sub-TLV format

The Type is 7, Length is 4, and the value comprises of -

- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.
- Count: The Overflow-Count value, encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the overflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the adjustment-interval.
- Overflow Threshold: The absolute Overflow-Threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values. If the increase of the current MaxAvgBw from the current bandwidth reservation is greater than or equal to the threshold value, the overflow condition is met.

5.1.1.5.2. Overflow-Threshold-Percentage sub-TLV

The Overflow-Threshold-Percentage sub-TLV is used to decide if the bandwidth should be adjusted immediately.

Overflow-Threshold-Percentage sub-TLV format

The Type is 8, Length is 4, and the value comprises of -
o Percentage: The Overflow-Threshold value, encoded in percentage (an integer from 0 to 100). If the percentage increase of the current MaxAvgBw from the current bandwidth reservation is greater than or equal to the threshold percentage, the overflow condition is met.

o Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.

o Count: The Overflow-Count value, encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the overflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the adjustment-interval.

5.1.1.5.3. Underflow-Threshold sub-TLV

The Underflow-Threshold sub-TLV is used to decide if the bandwidth should be adjusted immediately.

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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=9              |           Length=8            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Reserved                     |      Count    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Underflow Threshold                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

Underflow-Threshold sub-TLV format

The Type is 9, Length is 8, and the value comprises of -

o Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.

o Count: The Underflow-Count value, encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the underflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the adjustment-interval.

o Underflow Threshold: The absolute Underflow-Threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values. If the decrease of the current MaxAvgBw from the current bandwidth
reservation is greater than or equal to the threshold value, the underflow condition is met.

5.1.1.5.4. Underflow-Threshold-Percentage sub-TLV

The Underflow-Threshold-Percentage sub-TLV is used to decide if the bandwidth should be adjusted immediately.

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=10             |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Percentage |    Reserved                     |      Count    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Underflow-Threshold-Percentage sub-TLV format

The Type is 10, Length is 4, and the value comprises of -

- Percentage: The Underflow-Threshold value, encoded in percentage (an integer from 0 to 100). If the percentage decrease of the current MaxAvgBw from the current bandwidth reservation is greater than or equal to the threshold percentage, the underflow condition is met.

- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.

- Count: The Underflow-Count value, encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the underflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the adjustment-interval.

5.1.2. Real-time Traffic Reporting

The sub-TLVs in this section are encoded to inform the PCEP peer the various real-time traffic reporting parameters in the Deployment Model 2 (where PCE decides the adjusted bandwidth). In this model, Real-time-Traffic-Report-Interval sub-TLV MUST be included to specify the frequency of reporting.

The report threshold is used to decide if the collected bandwidth samples should be reported or skipped. An implementation MAY include both sub-TLVs for the absolute value and the percentage, in which case the real-time traffic is reported when either of the report threshold conditions are met.
The report flow threshold is used to decide when the collected bandwidth samples should be reported immediately, bypassing the report interval. An implementation MAY include both sub-TLVs for the absolute value and the percentage, in which case the real-time traffic is reported immediately when either of the report flow threshold conditions are met.

5.1.2.1. Real-time-Traffic-Report-Interval sub-TLV

The Real-time-Traffic-Report-Interval sub-TLV specifies a time interval in seconds in which collected bandwidth samples should be reported to PCE.

The Type is 11, Length is 4, and the value comprises of 4-octet time interval, the valid range is from 1 to 604800, in seconds.

```
+----------------+----------------+----------------+----------------+
|     Type=11     |     Length=4    |
+----------------+----------------+
| Real-time-Traffic-Report-Interval |
```

Real-time-Traffic-Report-Interval sub-TLV format

There is no default value. This sub-TLV MUST be included to enable the real-time traffic reporting.

5.1.2.2. Real-time-Traffic-Report-Threshold sub-TLV

The Real-time-Traffic-Report-Threshold sub-TLV is used to decide when the bandwidth samples collected should be reported immediately, bypassing the report-interval.

```
+----------------+----------------+----------------+----------------+
|     Type=12     |     Length=4    |
| Real-time-Traffic-Report Threshold |
```

Real-time-Traffic-Report-Threshold sub-TLV format

The Type is 12, Length is 4, and the value comprises of -
Threshold: The absolute threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values. If the increase or the decrease of at least one of the bandwidth samples (BwSample) collected so far compared to the current bandwidth reservation is greater than or equal to the threshold value, the bandwidth samples collected so far are reported.

5.1.2.3. Real-time-Traffic-Report-Threshold-Percentage sub-TLV

The Real-time-Traffic-Report-Threshold sub-TLV is used to decide when the bandwidth samples collected should be reported immediately, bypassing the report-interval.

Real-time-Traffic-Report-Threshold-Percentage sub-TLV format

0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=13             |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Reserved                       |  Percentage |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

The Type is 13, Length is 4, and the value comprises of:

- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.

- Percentage: The threshold value, encoded in percentage (an integer from 0 to 100). If the percentage increase or the decrease of at least one of the bandwidth sample (BwSample) compared to the current bandwidth reservation is greater than or equal to the threshold percentage, the bandwidth samples collected so far are reported.

5.1.2.4. Real-time-Traffic-Report-Flow-Threshold sub-TLV

The Real-time-Traffic-Report-Flow-Threshold sub-TLV is used to decide when the bandwidth samples collected should be reported immediately, bypassing the report-interval.
The Type is 14, Length is 4, and the value comprises of -

- Threshold: The absolute flow threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values. If the increase or the decrease of the current bandwidth sample (BwSample) compared to the current bandwidth reservation is greater than or equal to the flow threshold value, all the bandwidth samples collected so far are reported immediately, bypassing the report-interval.

5.1.2.5. Real-time-Traffic-Report-Flow-Threshold-Percentage sub-TLV

The Real-time-Traffic-Report-Flow-Threshold sub-TLV is used to decide when the bandwidth samples collected should be reported immediately, bypassing the report-interval.

The Type is 15, Length is 4, and the value comprises of -

- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.

- Percentage: The flow threshold value, encoded in percentage (an integer from 0 to 100). If the percentage increase or the decrease of the current bandwidth sample (BwSample) compared to the current bandwidth reservation is greater than or equal to the threshold percentage, all the bandwidth samples collected so far are reported immediately, bypassing the report-interval.
5.2. BANDWIDTH Object

5.2.1. Auto-Bandwidth Adjusted Bandwidth

As per [RFC5440], the BANDWIDTH object is defined with two Object-Type values as following:

- Requested Bandwidth: BANDWIDTH Object-Type is 1.
- Re-optimization Bandwidth: Bandwidth of an existing TE LSP for which a re-optimization is requested. BANDWIDTH Object-Type is 2.

In the first model, where PCC calculates the adjusted bandwidth, PCC only reports the calculated bandwidth to be adjusted (MaxAvgBw) to the PCE. This is done via the existing ‘Requested Bandwidth with BANDWIDTH Object-Type as 1’.

5.2.2. Bandwidth-Usage Report

A new BANDWIDTH object type is defined to report the actual bandwidth usage of a TE LSP.

The Object type is [TBD], the object body has a variable length, multiples of 4 bytes. The payload format is as follows:

```
  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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        BwSample1                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           ...                                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        BwSampleN                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

Bandwidth-Usage format
```

- BwSample: The actual bandwidth usage, (the BwSample collected at the end of each sample-interval) encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second.

The Bandwidth-Usage object can be used in the second deployment model where PCC reports the TE LSP bandwidth usage and the PCE decides the auto-bandwidth adjusted bandwidth.

The Bandwidth-Usage object can also be used for TE LSPs without enabling the auto-bandwidth feature, to learn the actual bandwidth usage.
usage of the LSPs for other applications at the stateful PCE. The
details of which are beyond the scope of this document.

5.3. The PCRpt Message

When LSP is delegated to a PCE for the very first time, BANDWIDTH
object of type 1 is used to specify the requested bandwidth in the
PCRpt message.

When the LSP is enabled with the Auto-Bandwidth feature, and Real-
time-Traffic-Report-Interval sub-TLV is not present (Deployment model
1), PCC SHOULD include the BANDWIDTH object of type 1 to specify the
calculated bandwidth to be adjusted to the PCE in the PCRpt message.

When the LSP is enabled with the Auto-Bandwidth feature, and Real-
time-Traffic-Report-Interval sub-TLV is present (Deployment model 2),
PCC SHOULD include the BANDWIDTH object of type [TBD] to report the
real-time traffic to the PCE in the PCRpt message.

The definition of the PCRpt message (see [I-D.ietf-pce-stateful-pce])
is unchanged by this document.

5.4. The PCInitiate Message

For PCE-initiated LSP [I-D.ietf-pce-pce-initiated-lsp] with Auto-
Bandwidth feature enabled, AUTO-BANDWIDTH-ATTRIBUTE TLV MUST be
included in LSPA object with the PCInitiate message. The rest of the
processing remains unchanged.

6. Security Considerations

This document defines a new BANDWIDTH type and AUTO-BANDWIDTH-
ATTRIBUTE TLV which do not add any new security concerns beyond those
discussed in [RFC5440] and [I-D.ietf-pce-stateful-pce] in itself.

Some deployments may find the reporting of the real-time traffic
information as extra sensitive and thus should employ suitable PCEP
security mechanisms like TCP-AO or [I-D.ietf-pce-pceps].

7. Manageability Considerations

7.1. Control of Function and Policy

The Auto-Bandwidth feature MUST BE controlled per tunnel (at Ingress
(PCC) or PCE), the values for parameters like sample-interval,
adjustment-interval, minimum-bandwidth, maximum-bandwidth,
adjustment-threshold, report-interval, report-threshold SHOULD be
configurable by an operator.
7.2. Information and Data Models

[RFC7420] describes the PCEP MIB, there are no new MIB Objects for this document.

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].

7.5. Requirements On Other Protocols

Mechanisms defined in this document do not imply any new requirements on other protocols.

7.6. Impact On Network Operations

Mechanisms defined in this document do not have any impact on network operations in addition to those already listed in [RFC5440].

8. IANA Considerations

8.1. PCEP TLV Type Indicators

This document defines the following new PCEP TLVs; IANA is requested to make the following allocations from this registry.

http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators

<table>
<thead>
<tr>
<th>Value</th>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>AUTO-BANDWIDTH-ATTRIBUTE</td>
<td>[This I.D.]</td>
</tr>
</tbody>
</table>

8.2. AUTO-BANDWIDTH-ATTRIBUTE Sub-TLV

This document specifies the AUTO-BANDWIDTH-ATTRIBUTE Sub-TLVs. IANA is requested to create an "AUTO-BANDWIDTH-ATTRIBUTE Sub-TLV Types" sub-registry in the "PCEP TLV Type Indicators" for the sub-TLVs carried in the AUTO-BANDWIDTH-ATTRIBUTE TLV. This document defines the following types:
### 8.3. BANDWIDTH Object

This document defines new object type for the BANDWIDTH object; IANA is requested to make the following allocations from this registry.

http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-objects

<table>
<thead>
<tr>
<th>Object-Class Value</th>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>BANDWIDTH</td>
<td>[This I.D.]</td>
</tr>
</tbody>
</table>

Object-Type

TBD: Bandwidth-Usage Report

### 9. Acknowledgments

We would like to thank Venugopal Reddy, Reeja Paul, Sandeep Boina and Avantika for their useful comments and suggestions.

### 10. References

#### 10.1. Normative References


[I-D.ietf-pce-stateful-pce]

[I-D.ietf-pce-pce-initiated-lsp]

[IEEE.754.1985]

10.2. Informative References


[I-D.ietf-pce-stateful-pce-app]

[I-D.ietf-pce-pceps]
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Abstract

The Path Computation Element Communication Protocol (PCEP) provides mechanisms for Path Computation Elements (PCEs) to perform path computations in response to Path Computation Clients (PCCs) requests. The stateful PCE extensions allow stateful control of Multi-Protocol Label Switching (MPLS) Traffic Engineering Label Switched Paths (TE LSPs) via PCEP.

This document describes automatic bandwidth adjustment of such LSPs when employing an Active Stateful PCE. In one of the models described, PCC computes the bandwidth to be adjusted and informs the PCE whereas in the second model, PCC reports the real-time bandwidth usage to a PCE and the PCE computes the adjustment bandwidth.

This document also describes automatic bandwidth adjustment for stateful PCE-initiated LSPs.

Status of This Memo

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

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1. Introduction

[RFC5440] describes the Path Computation Element Protocol (PCEP) as a
communication mechanism between a Path Computation Client (PCC) and a
Path Control Element (PCE), or between PCE and PCE, that enables
computation of Multi-Protocol Label Switching (MPLS) Traffic
Engineering Label Switched Paths (TE LSPs).

[I-D.ietf-pce-stateful-pce] specifies extensions to PCEP to enable
stateful control of MPLS TE LSPs. It describes two mode of
operations - Passive Stateful PCE and Active Stateful PCE. In this
document, the focus is on Active Stateful PCE where LSPs are
configured at the PCC and control over them is delegated to the PCE.
Further [I-D.ietf-pce-pce-initiated-lsp] describes the setup,
maintenance and teardown of PCE-initiated LSPs under the stateful PCE
model.

Over time, based on the varying traffic pattern, an LSP established
with certain bandwidth may require to adjust the bandwidth, reserved
in the network automatically. Ingress Label Switch Router (LSR)
collects the traffic rate at each sample interval to determine the bandwidth demand of the LSP. This bandwidth information is then used to adjust the LSP bandwidth periodically. This feature is commonly referred to as Auto-Bandwidth.

Enabling Auto-Bandwidth feature on an LSP results in the LSP automatically adjusting its bandwidth reservation based on the actual traffic flowing through the LSP. The initial LSP bandwidth can be set to an arbitrary value (including zero), in practice, it can be operator expected value based on design and planning. Once the LSP is set-up, the LSP monitors the traffic flow and adjusts its bandwidth every adjustment-interval period. The bandwidth adjustment uses the make-before-break signaling method so that there is no interruption to the traffic flow. The Auto-Bandwidth is described in detail in Section 4.1. [I-D.ietf-pce-stateful-pce-app] describes the use-case for Auto-Bandwidth adjustment for passive and active stateful PCE.

In this document, following deployment models are considered for employing Auto-Bandwidth feature with active stateful PCE.

- Deployment model 1: PCC to decide adjusted bandwidth:
  * In this model, the PCC (head-end of the LSP) monitors and calculates the new adjusted bandwidth. The PCC reports the calculated bandwidth to be adjusted to the PCE.
  * This approach would be similar to passive stateful PCE model, while the passive stateful PCE uses path request/reply mechanism, the active stateful PCE uses report/update mechanism to adjust the LSP bandwidth.
  * For PCE-initiated LSP, the PCC is requested during the LSP initiation to monitor and calculate the new adjusted bandwidth.

- Deployment model 2: PCE to decide adjusted bandwidth:
  * In this model, the PCE calculates the new adjusted bandwidth for the LSP.
  * Active stateful PCE can use information such as historical trending data, application-specific information about expected demands and central policy information along with real-time bandwidth usage to make smarter bandwidth adjustment to the delegated LSPs. Since the LSP has delegated control to the PCE, it is inherently suited that it should be the stateful PCE that decides the bandwidth adjustments.
* For PCE-initiated LSP, the PCC is requested during initiation, to monitor and report the real-time bandwidth usage.

* This model does not exclude use of any other mechanism employed by stateful PCE to learn real-time bandwidth usage information. But at the same time, using the same protocol (PCEP in this case) for updating and reporting the adjustment parameters as well as to learn real-time bandwidth usage is operationally beneficial.

This document defines extensions needed to support Auto-Bandwidth feature on the LSPs in a active stateful PCE model using PCEP.

2. Conventions Used in This Document

2.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2.2. Terminology

The following terminology is used in this document.

Active Stateful PCE: PCE that uses tunnel state information learned from PCCs to optimize path computations. Additionally, it actively updates tunnel parameters in those PCCs that delegated control over their tunnels to the PCE.

Delegation: An operation to grant a PCE temporary rights to modify a subset of tunnel parameters on one or more PCC’s tunnels. Tunnels are delegated from a PCC to a PCE.

PCC: Path Computation Client. Any client application requesting a path computation to be performed by a Path Computation Element.

PCE: Path Computation Element. An entity (component, application, or network node) that is capable of computing a network path or route based on a network graph and applying computational constraints.

TE LSP: Traffic Engineering Label Switched Path.

Note the Auto-Bandwidth feature specific terms defined in Section 4.1.
3. Requirements for PCEP Extensions

As discussed in Section 1, there are two deployment models considered in this document for automatic bandwidth adjustments in case of active stateful PCE. In the model 1, where PCC decides the adjusted bandwidth, PCC reports the new adjusted bandwidth and an active stateful PCE updates the bandwidth of a delegated LSP via existing mechanisms defined in [I-D.ietf-pce-stateful-pce]. PCEP extensions required for both models are summarized in the following table.

<table>
<thead>
<tr>
<th>Model 1: PCC decides adjusted BW</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC Initiated</td>
<td>PCE Initiated</td>
</tr>
<tr>
<td>PCC monitors the traffic and reports the calculated bandwidth to be adjusted to the PCE.</td>
<td>At the time of initiation, PCE request PCC to monitor the traffic and report the calculated bandwidth to be adjusted to the PCE.</td>
</tr>
<tr>
<td>No new extensions are needed.</td>
<td>Extension is needed for PCE to pass on the adjustment parameters at the time of Initiation.</td>
</tr>
<tr>
<td>Optionally AUTO-BANDWIDTH-ATTRIBUTE TLV can be used to identify the LSP with Auto-Bandwidth Feature enabled.</td>
<td>Refer the AUTO-BANDWIDTH-ATTRIBUTE TLV (and sub-TLVs e.g. Adjustment-Interval, Minimum-Bandwidth) in Section 5.1.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 2: PCC reports bandwidth-usage, PCE decides adjusted BW</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC Initiated</td>
<td>PCE Initiated</td>
</tr>
<tr>
<td>PCC monitors bandwidth usage and reports the real-time bandwidth usage to the PCE. It is PCE that decides the calculated bandwidth to be adjusted and updates the LSP accordingly.</td>
<td>At the time of initiation, PCE request PCC to monitor the traffic and reports the real-time bandwidth usage to the PCE. It is PCE that decides the calculated bandwidth to be adjusted and updates the LSP accordingly.</td>
</tr>
</tbody>
</table>
Further extension to report the bandwidth-usage to PCE are also needed (Refer Bandwidth-Usage type in Section 5.3.2).

Further Auto-Bandwidth deployment considerations are summarized below:

- It is required to identify and inform the PCEP peer, the LSP that are enabled with Auto-Bandwidth feature. Not all LSPs in some deployments would like their bandwidth to be dependent on the real-time bandwidth usage but be constant as set by the operator.

- It is also required to identify and inform the PCEP peer the model of operation i.e. if PCC decides the adjusted bandwidth, or PCC reports the real-time bandwidth usage instead and the PCE decides the adjusted bandwidth.

  * Note that PCEP extension for reporting real-time bandwidth usage, as specified in this document, is one of the ways for a PCE to learn this information. But at the same time a stateful PCE may choose to learn this information from other means like management, performance tools, which are beyond the scope of this document.

- Further for the LSP with Auto-Bandwidth feature enabled, an operator should be able to specify the adjustment parameters (i.e.
configuration knobs) to control this feature (e.g. minimum/maximum bandwidth range) and PCEP peer should be informed.

4. Architectural Overview

4.1. Auto-Bandwidth Overview

Auto-Bandwidth feature allows an LSP to automatically and dynamically adjust its reserved bandwidth over time, i.e. without network operator intervention. The bandwidth adjustment uses the make-before-break signaling method so that there is no interruption to the traffic flow.

The new bandwidth reservation is determined by sampling the actual traffic flowing through the LSP. If the traffic flowing through the LSP is lower than the configured or current bandwidth of the LSP, the extra bandwidth is being reserved needlessly and being wasted. Conversely, if the actual traffic flowing through the LSP is higher than the configured or current bandwidth of the LSP, it can potentially cause congestion or packet loss in the network. With Auto-Bandwidth feature, the LSP bandwidth can be set to some arbitrary value (including zero) during initial setup time, and it will be periodically adjusted over time based on the actual bandwidth requirement.

Note the following definitions of the Auto-Bandwidth terms:

Maximum Average Bandwidth (MaxAvgBw): The maximum average bandwidth represents the current traffic bandwidth demand during a time interval. This is the maximum value of the averaged traffic bandwidth rate in a given adjustment-interval.

Adjusted Bandwidth: This is the Auto-Bandwidth computed bandwidth that needs to be adjusted for the LSP.

Sample-Interval: The periodic time interval at which the traffic rate is collected as a sample.

Bandwidth-Sample (BwSample): The bandwidth sample collected at every sample interval to measure the traffic rate.

Adjustment-Interval: The periodic time interval at which the bandwidth adjustment should be made using the MaxAvgBw.

Maximum-Bandwidth: The maximum bandwidth that can be reserved for the LSP.
Minimum-Bandwidth: The minimum bandwidth that can be reserved for the LSP.

Adjustment-Threshold: This value is used to decide when the bandwidth should be adjusted. If the percentage or absolute difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold value, the LSP bandwidth is adjusted to the current bandwidth demand (Adjusted Bandwidth) at the adjustment-interval expiry.

Overflow-Count: This value is used to decide when the bandwidth should be adjusted when there is a sudden increase in traffic demand. This value indicates how many times consecutively, the percentage or absolute difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the Overflow-Threshold value.

Overflow-Threshold: This value is used to decide when the bandwidth should be adjusted when there is a sudden increase in traffic demand. If the percentage or absolute difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold value, the overflow-condition is set to be met. The LSP bandwidth is adjusted to the current bandwidth demand bypassing the adjustment-interval if the overflow-condition is met consecutively for the Overflow-Count.

Underflow-Count: This value is used to decide when the bandwidth should be adjusted when there is a sudden decrease in traffic demand. This value indicates how many times consecutively, the percentage or absolute difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the Underflow-Threshold value.

Underflow-Threshold: This value is used to decide when the bandwidth should be adjusted when there is a sudden decrease in traffic demand. If the percentage or absolute difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold value, the underflow-condition is set to be met. The LSP bandwidth is adjusted to the current bandwidth demand bypassing the adjustment-interval if the underflow-condition is met consecutively for the Underflow-Count.

Report-Interval: This value indicates the periodic interval when the collected real-time bandwidth-usage samples (BwSample) should be reported to the stateful PCE via the PCRpt message.

Report-Threshold: This value is used to decide if the real-time bandwidth-usage samples collected should be reported. Only if the
percentage or the absolute difference between at least one of the bandwidth samples collected and the current bandwidth reservation is greater than or equal to the threshold value, the bandwidth samples collected during the Report-Interval are reported otherwise the bandwidth sample(s) are skipped.

Report-Flow-Threshold: This value is used to decide when the real-time traffic bandwidth samples should be reported immediately when there is a sudden change in traffic demand. If the percentage or absolute difference between the current bandwidth sample and the current bandwidth reservation is greater than or equal to the flow-threshold value, all the bandwidth samples collected so far are reported to the PCE immediately.

4.2. Theory of Operation

The traffic rate is periodically sampled at each sample-interval (which can be configured by the user and the default value as 5 minutes) by the head-end node of the LSP. The sampled traffic rates are accumulated over the adjustment-interval period (which can be configured by the user and the default value as 24 hours). The PCEP peer which is in-charge of calculating the bandwidth to be adjusted, will adjust the bandwidth of the LSP to the highest sampled traffic rate (MaxAvgBw) amongst the set of bandwidth samples collected over the adjustment-interval.

Note that the highest sampled traffic rate could be higher or lower than the current LSP bandwidth. Only if the difference between the current bandwidth demand (MaxAvgBw) and the current bandwidth reservation is greater than or equal to the Adjustment-Threshold (percentage or absolute value), the LSP bandwidth is adjusted to the current bandwidth demand (MaxAvgBw). Some LSPs are less eventful while other LSPs may encounter a lot of changes in the traffic pattern. PCE sets the intervals for reporting and adjustment based on the traffic pattern of the LSP.

In order to avoid frequent re-signaling, an operator may set a longer adjustment-interval value. However, longer adjustment-interval can result in an undesirable effect of masking sudden changes in traffic demands of an LSP. To avoid this, the Auto-Bandwidth feature may pre-maturely expire the adjustment-interval and adjust the LSP bandwidth to accommodate the sudden bursts of increase in traffic demand as an overflow condition or decrease in traffic demand as an underflow condition.

In case of Deployment model 2, the PCC reports the real-time bandwidth-usage information and the PCE decides the adjusted bandwidth. Multiple bandwidth samples are collected every report-
interval, and reported together to the PCE. To avoid reporting minor changes in real-time bandwidth usage, report-threshold is used, to suppress the sending of the collected samples during the report-interval. The collected samples are reported if at least one sample crosses the Report-Threshold (percentage or absolute value). In order to accommodate sudden changes in the bandwidth usage, report-flow-threshold is employed by pre-maturely expiry of the report-interval to report the unreported bandwidth samples collected so far.

All thresholds in this document could be represented in both absolute value and percentage, and could be used together.

4.3. Scaling Considerations

There are potential scaling concerns for the model where PCC (ingress LSR) reports real-time bandwidth-usage information to the stateful PCE for a large number of LSPs. It is recommended to combine multiple bandwidth samples (BwSamples) using larger report-interval and report them together to the PCE, thus reducing the number of PCRpt messages. Further Report-Threshold can be used to skip reporting the bandwidth samples for small changes in the bandwidth.

The processing cost of monitoring a large number of LSPs at the PCC and handling bandwidth change requests at PCE should be taken into consideration. Note that, this will be implementation dependent.

5. Extensions to the PCEP

5.1. AUTO-BANDWIDTH-ATTRIBUTE TLV

The AUTO-BANDWIDTH-ATTRIBUTE TLV can be included as an optional TLV in the LSPA Object (as described in [RFC5440]). Whenever the LSP with Auto-Bandwidth feature enabled is delegated, AUTO-BANDWIDTH-ATTRIBUTE TLV is carried in PCRpt message in LSPA Object. The TLV provides PCE with the ‘configurable knobs’ of this feature. In case of PCE-Initiated LSP ([I-D.ietf-pce-pce-initiated-lsp]) with Auto-Bandwidth feature enabled, this TLV is included in LSPA Object with PCInitiate message.

The format of the AUTO-BANDWIDTH-ATTRIBUTE TLV is shown in the following figure:

```
+---------------+---------------+---------------+---------------+
|                |                |                |                |
|                |                |                |                |
|     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     |
+---------------+---------------+---------------+---------------+
|              |              |              |              |
|    +----------+----------+----------+----------+    |
|        Type=[TBD1]     |        Length     |
|    +----------+----------+----------+----------+    |
```
AUTO-BANDWIDTH-ATTRIBUTE TLV format

Type: TBD1
Length: Variable
Value: This comprises one or more sub-TLVs.

Following sub-TLVs are defined in this document:

<table>
<thead>
<tr>
<th>Type</th>
<th>Len</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>Sample-Interval sub-TLV</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Adjustment-Interval sub-TLV</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>Adjustment-Threshold sub-TLV</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Adjustment-Threshold-Percentage sub-TLV</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>Minimum-Bandwidth sub-TLV</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>Maximum-Bandwidth sub-TLV</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>Overflow-Threshold sub-TLV</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>Overflow-Threshold-Percentage sub-TLV</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>Underflow-Threshold sub-TLV</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>Underflow-Threshold-Percentage sub-TLV</td>
</tr>
</tbody>
</table>

Future specification can define additional sub-TLVs.

The presence of AUTO-BANDWIDTH-ATTRIBUTE TLV in LSPA Object means that the automatic bandwidth adjustment feature is enabled. All sub-TLVs are optional and any unrecognized sub-TLV MUST be silently ignored. If a sub-TLV of same type appears more than once, only the first occurrence is processed and all others MUST be ignored.

The AUTO-BANDWIDTH-ATTRIBUTE TLV can also be carried in PCUpd message in LSPA Object in order to make updates to auto-bandwidth attributes such as Adjustment-Interval.

If sub-TLVs are not present, the default values based on the local policy are assumed.

The sub-TLVs are encoded to inform the PCEP peer the various sampling and adjustment parameters, and serves the following purpose -

- For PCE-Initiated LSPs, inform the PCC of the various sampling and adjustment parameters.
For PCC-Initiated LSPs in the Deployment Model 2 (where PCE decides the adjusted bandwidth), inform the PCE of the various sampling and adjustment parameters.

The following sub-sections describe the sub-TLVs which are currently defined to be carried within the AUTO-BANDWIDTH-ATTRIBUTE TLV.

5.1.1. Sample-Interval sub-TLV

The Sample-Interval sub-TLV specifies a time interval in seconds at which traffic samples are collected at the PCC.

The Type is 1, Length is 4, and the value comprises of 4-octet time interval, the valid range is from 1 to 604800, in seconds. The default value is 300 seconds.

```
          0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
        |           Type=1              |           Length=4            |
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
        |                      Sample-Interval                          |
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Sample-Interval sub-TLV format

5.1.2. Adjustment-Interval sub-TLV

The Adjustment-Interval sub-TLV specifies a time interval in seconds at which bandwidth adjustment should be made.

The Type is 2, Length is 4, and the value comprises of 4-octet time interval, the valid range is from 1 to 604800, in seconds. The default value is 300 seconds.

```
          0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
        |           Type=2              |           Length=4            |
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
        |                     Adjustment-Interval                       |
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Adjustment-Interval sub-TLV format

5.1.3. Adjustment Threshold

The sub-TLVs in this section are encoded to inform the PCEP peer the
adjustment threshold parameters. An implementation MAY include both sub-TLVs for the absolute value and the percentage, in which case the bandwidth is adjusted when either of the adjustment threshold conditions are met.

5.1.3.1. Adjustment-Threshold sub-TLV

The Adjustment-Threshold sub-TLV is used to decide when the LSP bandwidth should be adjusted.

![Type=3, Length=4, Adjustment Threshold]


do Adjustment Threshold: The absolute Adjustment-Threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values.

If the difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold value, the LSP bandwidth is adjusted to the current bandwidth demand.

5.1.3.2. Adjustment-Threshold-Percentage sub-TLV

The Adjustment-Threshold-Percentage sub-TLV is used to decide when the LSP bandwidth should be adjusted.

![Type=4, Length=4, Reserved, Percentage]


do Adjustment Threshold: The absolute Adjustment-Threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values.

If the difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold value, the LSP bandwidth is adjusted to the current bandwidth demand.
o Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.

o Percentage: The Adjustment-Threshold value, encoded in percentage (an integer from 0 to 100). If the percentage difference between the current MaxAvgBw and the current bandwidth reservation is greater than or equal to the threshold percentage, the LSP bandwidth is adjusted to the current bandwidth demand.

5.1.4. Minimum and Maximum Bandwidth Values

5.1.4.1. Minimum-Bandwidth sub-TLV

The Minimum-Bandwidth sub-TLV specify the minimum bandwidth allowed for the LSP, and is expressed in bytes per second. The LSP bandwidth cannot be adjusted below the minimum bandwidth value.

The Type is 5, Length is 4, and the value comprises of 4-octet bandwidth value encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values.

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=5              |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Minimum-Bandwidth                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Minimum-Bandwidth sub-TLV format

5.1.4.2. Maximum-Bandwidth sub-TLV

The Maximum-Bandwidth sub-TLV specify the maximum bandwidth allowed for the LSP, and is expressed in bytes per second. The LSP bandwidth cannot be adjusted above the maximum bandwidth value.

The Type is 6, Length is 4, and the value comprises of 4-octet bandwidth value encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values.

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=6              |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Minimum-Bandwidth sub-TLV format

5.1.5. Overflow and Underflow Condition

The sub-TLVs in this section are encoded to inform the PCEP peer the overflow and underflow threshold parameters. An implementation MAY include sub-TLVs for the absolute value and the percentage for the threshold, in which case the bandwidth is immediately adjusted when either of the adjustment threshold conditions are met consecutively for the given count.

5.1.5.1. Overflow-Threshold sub-TLV

The Overflow-Threshold sub-TLV is used to decide if the bandwidth should be adjusted immediately.

<table>
<thead>
<tr>
<th>Type</th>
<th>Length</th>
<th>Reserved</th>
<th>Count</th>
<th>Overflow Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>8</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overflow-Threshold sub-TLV format

The Type is 7, Length is 4, and the value comprises of:

- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.

- Count: The Overflow-Count value, encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the overflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the adjustment-interval.

- Overflow Threshold: The absolute Overflow-Threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values. If the increase of the current MaxAvgBw from the current bandwidth reservation is greater than or equal to the threshold value, the
overflow condition is met.

5.1.5.2. Overflow-Threshold-Percentage sub-TLV

The Overflow-Threshold-Percentage sub-TLV is used to decide if the bandwidth should be adjusted immediately.

```
+----------------+----------------+
|           Type=8|           Length=4|
| Percentage | Reserved             |
| Count       |                     |
```

Overflow-Threshold-Percentage sub-TLV format

The Type is 8, Length is 4, and the value comprises of -

- Percentage: The Overflow-Threshold value, encoded in percentage (an integer from 0 to 100). If the percentage increase of the current MaxAvgBw from the current bandwidth reservation is greater than or equal to the threshold percentage, the overflow condition is met.
- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.
- Count: The Overflow-Count value, encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the overflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the adjustment-interval.

5.1.5.3. Underflow-Threshold sub-TLV

The Underflow-Threshold sub-TLV is used to decide if the bandwidth should be adjusted immediately.

```
+----------------+----------------+
|           Type=9|           Length=8|
| Reserved | Count             |
| Underflow Threshold |         |
```

Underflow-Threshold sub-TLV format

The Type is 9, Length is 8, and the value comprises of -

- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.
- Count: The Underflow-Count value, encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the underflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the adjustment-interval.
- Underflow Threshold: The absolute Underflow-Threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values. If the decrease of the current MaxAvgBw from the current bandwidth reservation is greater than or equal to the threshold value, the underflow condition is met.

5.1.5.4. Underflow-Threshold-Percentage sub-TLV

The Underflow-Threshold-Percentage sub-TLV is used to decide if the bandwidth should be adjusted immediately.

Underflow-Threshold-Percentage sub-TLV format

The Type is 10, Length is 4, and the value comprises of -

- Percentage: The Underflow-Threshold value, encoded in percentage (an integer from 0 to 100). If the percentage decrease of the current MaxAvgBw from the current bandwidth reservation is greater than or equal to the threshold percentage, the underflow condition is met.
- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.
5.2. BANDWIDTH-USAGE-ATTRIBUTE TLV

The BANDWIDTH-USAGE-ATTRIBUTE TLV can be included as an optional TLV in the LSPA Object (as described in [RFC5440]). Whenever the LSP Bandwidth Usage needs to be reported to the PCE, the BANDWIDTH-USAGE-ATTRIBUTE TLV is carried in PCRpt message in LSPA Object. The TLV provides PCE with the ‘configurable knobs’ of this feature. In case of PCE-Initiated LSP ([I-D.ietf-pce-pce-initiated-lsp]), this TLV is included in the LSPA Object with PCInitiate message.

The format of the BANDWIDTH-USAGE-ATTRIBUTE TLV is shown in the following figure:

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=[TBD2]         |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                            sub-TLVs                          //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

**BANDWIDTH-USAGE-ATTRIBUTE TLV format**

- **Type**: TBD2
- **Length**: Variable
- **Value**: This comprises one or more sub-TLVs.

Following sub-TLVs are defined in this document:

<table>
<thead>
<tr>
<th>Type</th>
<th>Len</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>Bandwidth-Usage-Report-Interval sub-TLV</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Bandwidth-Usage-Report-Threshold sub-TLV</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>Bandwidth-Usage-Report-Threshold-Percentage sub-TLV</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Bandwidth-Usage-Report-Flow-Threshold sub-TLV</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>Bandwidth-Usage-Report-Flow-Threshold-Percentage sub-TLV</td>
</tr>
</tbody>
</table>

Future specification can define additional sub-TLVs.
The presence of BANDWIDTH-USAGE-ATTRIBUTE TLV in LSPA Object means that the bandwidth usage reporting to PCE is enabled. All sub-TLVs are optional and any unrecognized sub-TLV MUST be silently ignored. If a sub-TLV of same type appears more than once, only the first occurrence is processed and all others MUST be ignored.

The BANDWIDTH-USAGE-ATTRIBUTE TLV can also be carried in PCUpd message in LSPA Object in order to make updates to the attributes such as Bandwidth-Usage-Report-Interval.

If sub-TLVs are not present, the default values based on the local policy are assumed.

The following sub-sections describe the sub-TLVs which are currently defined to be carried within the BANDWIDTH-USAGE-ATTRIBUTE TLV.

5.2.1. Bandwidth-Usage-Report-Interval sub-TLV

The Bandwidth-Usage-Report-Interval sub-TLV specifies a time interval in seconds in which collected bandwidth samples should be reported to PCE.

The Type is 1, Length is 4, and the value comprises of 4-octet time interval, the valid range is from 1 to 604800, in seconds. Default value is 3600 seconds.

```
<table>
<thead>
<tr>
<th>Type=1</th>
<th>Length=4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth-Usage-Report-Interval</td>
<td></td>
</tr>
</tbody>
</table>
```

5.2.2. Bandwidth-Usage-Report-Threshold sub-TLV

The Bandwidth-Usage-Report-Threshold sub-TLV is used to decide when the bandwidth samples collected so far should be reported immediately, bypassing the report-interval.

```
<table>
<thead>
<tr>
<th>Type=2</th>
<th>Length=4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth-Usage-Report-Interval</td>
<td></td>
</tr>
</tbody>
</table>
```
Bandwidth-Usage-Report Threshold sub-TLV format

The Type is 2, Length is 4, and the value comprises of -

- Threshold: The absolute threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values. If the increase or the decrease of at least one of the bandwidth samples (BwSamples) collected so far compared to the current bandwidth reservation is greater than or equal to the threshold value, the bandwidth samples collected so far are reported.

5.2.3. Bandwidth-Usage-Report-Threshold-Percentage sub-TLV

The Bandwidth-Usage-Report-Threshold-Percentage sub-TLV is used to decide when the bandwidth samples collected so far should be reported immediately, bypassing the report-interval.

Bandwidth-Usage-Report-Threshold-Percentage sub-TLV format

The Type is 3, Length is 4, and the value comprises of -

- Reserved: SHOULD be set to zero on transmission and MUST be ignored on receipt.

- Percentage: The threshold value, encoded in percentage (an integer from 0 to 100). If the percentage increase or the decrease of at least one of the bandwidth sample (BwSample) compared to the current bandwidth reservation is greater than or equal to the threshold percentage, the bandwidth samples collected so far are reported.

5.2.4. Bandwidth-Usage-Report-Flow-Threshold sub-TLV

The Bandwidth-Usage-Report-Flow-Threshold sub-TLV is used to decide when the bandwidth samples collected should be reported immediately,
bypassing the report-interval.

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=4              |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Bandwidth-Usage-Report-Flow Threshold               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

**Bandwidth-Usage-Report-Flow-Threshold sub-TLV format**

The Type is 4, Length is 4, and the value comprises of -

- **Threshold**: The absolute flow threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section 3.1.2 of [RFC3471] for a table of commonly used values. If the increase or the decrease of the current bandwidth sample (BwSample) compared to the current bandwidth reservation is greater than or equal to the flow threshold value, all the bandwidth samples collected so far are reported immediately, bypassing the report-interval.

5.2.5. Bandwidth-Usage-Report-Flow-Threshold-Percent sub-TLV

The Bandwidth-Usage-Report-Flow-Threshold-Percent sub-TLV is used to decide when the bandwidth samples collected should be reported immediately, bypassing the report-interval.

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=5              |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Reserved                       |  Percentage |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

**Bandwidth-Usage-Report-Flow-Threshold-Percentage sub-TLV format**

The Type is 5, Length is 4, and the value comprises of -

- **Reserved**: SHOULD be set to zero on transmission and MUST be ignored on receipt.

- **Percentage**: The flow threshold value, encoded in percentage (an integer from 0 to 100). If the percentage increase or the decrease of the current bandwidth sample (BwSample) compared to the current bandwidth reservation is greater than or equal to the
threshold percentage, all the bandwidth samples collected so far are reported immediately, bypassing the report-interval.

5.3. BANDWIDTH Object

5.3.1. Auto-Bandwidth Adjusted Bandwidth

As per [RFC5440], the BANDWIDTH object is defined with two Object-Type values as following:

- Requested Bandwidth: BANDWIDTH Object-Type value is 1.
- Re-optimization Bandwidth: Bandwidth of an existing TE LSP for which a re-optimization is requested. BANDWIDTH Object-Type value is 2.

In the first model, where PCC calculates the adjusted bandwidth, PCC only reports the calculated bandwidth to be adjusted (MaxAvgBw) to the PCE. This is done via the existing ‘Requested Bandwidth with BANDWIDTH Object-Type as 1.

5.3.2. Bandwidth-Usage Report

A new BANDWIDTH object-type is defined to report the real-time bandwidth usage of a TE LSP.

The Object-type is [TBD3], the object length is variable with multiples of 4 bytes. The payload format is as follows:

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        BwSample1                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           ...                                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        BwSampleN                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Bandwidth-Usage format

- BwSample: The actual bandwidth usage, (the BwSample collected at the end of each sample-interval) encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second.

The Bandwidth-Usage object-type is used in the second deployment model where PCC reports the TE LSP bandwidth usage and the PCE decides the Auto-Bandwidth adjusted bandwidth.
5.4. The PCRpt Message

When LSP is delegated to a PCE for the very first time, BANDWIDTH object of type 1 is used to specify the requested bandwidth in the PCRpt message.

When the LSP is enabled with the Auto-Bandwidth feature, and BANDWIDTH-USAGE-ATTRIBUTE TLV is not present (Deployment model 1), PCC SHOULD include the BANDWIDTH object of type 1 to specify the calculated bandwidth to be adjusted to the PCE in the PCRpt message.

When the LSP is enabled with the Auto-Bandwidth feature, and BANDWIDTH-USAGE-ATTRIBUTE TLV is present (Deployment model 2), PCC SHOULD include the BANDWIDTH object of type [TBD] to report the real-time bandwidth-usage to the PCE in the PCRpt message.

The definition of the PCRpt message (see [I-D.ietf-pce-stateful-pce]) is unchanged by this document.

5.5. The PCInitiate Message

For PCE-initiated LSP [I-D.ietf-pce-pce-initiated-lsp] with Auto-Bandwidth feature enabled, AUTO-BANDWIDTH-ATTRIBUTE TLV MUST be included in LSPA object with the PCInitiate message. The rest of the processing remains unchanged.

6. Security Considerations

This document defines a new BANDWIDTH type, AUTO-BANDWIDTH-ATTRIBUTE TLV and BANDWIDTH-USAGE-ATTRIBUTE TLV which do not add any new security concerns beyond those discussed in [RFC5440] and [I-D.ietf-pce-stateful-pce].

Some deployments may find the reporting of the real-time bandwidth-usage information as extra sensitive and thus should employ suitable PCEP security mechanisms like TCP-AO or [I-D.ietf-pce-pceps].

7. Manageability Considerations

7.1. Control of Function and Policy

The Auto-Bandwidth feature MUST BE controlled per tunnel (at ingress
(PCC) or PCE), the values for parameters like sample-interval, adjustment-interval, minimum-bandwidth, maximum-bandwidth, adjustment-threshold, report-interval, report-threshold SHOULD be configurable by an operator.

7.2. Information and Data Models

[RFC7420] describes the PCEP MIB, there are no new MIB Objects defined in this document.

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].

7.5. Requirements On Other Protocols

Mechanisms defined in this document do not add any new requirements on other protocols.

7.6. Impact On Network Operations

Mechanisms defined in this document do not have any impact on network operations in addition to those already listed in [RFC5440].
8. IANA Considerations

8.1. PCEP TLV Type Indicators

This document defines the following new PCEP TLVs; IANA is requested to make the following allocations from this registry.

http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators

<table>
<thead>
<tr>
<th>Value</th>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
</table>
| TBD1  | AUTO-BANDWIDTH-ATTRIBUTE                | [This I.D.]
| TBD2  | BANDWIDTH-USAGE-ATTRIBUTE               | [This I.D.]

8.2. AUTO-BANDWIDTH-ATTRIBUTE Sub-TLV

This document specifies the AUTO-BANDWIDTH-ATTRIBUTE Sub-TLVs. IANA is requested to create an "AUTO-BANDWIDTH-ATTRIBUTE Sub-TLV Types" sub-registry in the "PCEP TLV Type Indicators" for the sub-TLVs carried in the AUTO-BANDWIDTH-ATTRIBUTE TLV. This document defines the following types:

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
</table>
| 0     | Reserved                        | [This I.D.]
| 1     | Sample-Interval sub-TLV         | [This I.D.]
| 2     | Adjustment-Interval sub-TLV     | [This I.D.]
| 3     | Adjustment-Threshold sub-TLV    | [This I.D.]
| 4     | Adjustment-Threshold-Percentage sub-TLV | [This I.D.]
| 5     | Minimum-Bandwidth sub-TLV       | [This I.D.]
| 6     | Maximum-Bandwidth sub-TLV       | [This I.D.]
| 7     | Overflow-Threshold sub-TLV      | [This I.D.]
| 8     | Overflow-Threshold-Percentage sub-TLV | [This I.D.]
| 9     | Underflow-Threshold sub-TLV     | [This I.D.]
| 10    | Underflow-Threshold-Percentage sub-TLV | [This I.D.]
| 11-   | Unassigned                      | [This I.D.]
| 65535 |                                  |            |

8.3. BANDWIDTH-USAGE-ATTRIBUTE Sub-TLV

This document specifies the BANDWIDTH-USAGE-ATTRIBUTE Sub-TLVs. IANA is requested to create an "BANDWIDTH-USAGE-ATTRIBUTE Sub-TLV Types" sub-registry in the "PCEP TLV Type Indicators" for the sub-TLVs carried in the BANDWIDTH-USAGE-ATTRIBUTE TLV. This document defines the following types:

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
</table>
| 0     | Reserved                        | [This I.D.]

8.4. BANDWIDTH Object

This document defines new object type for the BANDWIDTH object; IANA is requested to make the following allocations from this registry.  
http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-objects

<table>
<thead>
<tr>
<th>Object-Class Value</th>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>BANDWIDTH</td>
<td>[This I.D.]</td>
</tr>
<tr>
<td></td>
<td>Object-Type</td>
<td>TBD3: Bandwidth-Usage Report</td>
</tr>
</tbody>
</table>

9. References

9.1. Normative References


[IEEE.754.1985]

9.2. Informative References


Acknowledgments

Authors would like to thank Venugopal Reddy, Reeja Paul, Sandeep Boina and Avantika for their useful comments and suggestions.

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Abstract

In order to compute and provide optimal paths, Path Computation Elements (PCEs) require an accurate and timely Traffic Engineering Database (TED). Traditionally this TED has been obtained from a link state (LS) routing protocol supporting traffic engineering extensions.

This document extends the Path Computation Element Communication Protocol (PCEP) with Link-State and TE Information.

Status of This Memo

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

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1. Introduction

In Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS), a Traffic Engineering Database (TED) is used in computing paths for connection oriented packet services and for circuits. The TED contains all relevant information that a Path Computation Element (PCE) needs to perform its computations. It is important that the TED be complete and accurate each time the PCE performs a path computation.

In MPLS and GMPLS, interior gateway routing protocols (IGPs) have been used to create and maintain a copy of the TED at each node running the IGP. One of the benefits of the PCE architecture [RFC4655] is the use of computationally more sophisticated path computation algorithms and the realization that these may need enhanced processing power not necessarily available at each node participating in an IGP.

Section 4.3 of [RFC4655] describes the potential load of the TED on a network node and proposes an architecture where the TED is maintained by the PCE rather than the network nodes. However, it does not describe how a PCE would obtain the information needed to populate its TED. PCE may construct its TED by participating in the IGP ([RFC3630] and [RFC5305] for MPLS-TE; [RFC4203] and [RFC5307] for GMPLS). An alternative is offered by BGP-LS [I-D.ietf-idr-ls-distribution].

[I-D.leedhody-teas-pcep-ls] proposes some other approaches for learning and maintaining the Link-State and TE information directly on a PCE as an alternative to IGPs and BGP flooding and investigate the impact from the PCE, routing protocol, and node perspectives.

[RFC5440] describes the specifications for the Path Computation Element Communication Protocol (PCEP). PCEP specifies the communication between a Path Computation Client (PCC) and a Path Computation Element (PCE), or between two PCEs based on the PCE architecture [RFC4655].
This document describes a mechanism by which Link State and TE information can be collected from networks and shared with PCE using the PCEP itself. This is achieved using a new PCEP message format. The mechanism is applicable to physical and virtual links as well as further subjected to various policies.

A network node maintains one or more databases for storing link-state and TE information about nodes and links in any given area. Link attributes stored in these databases include: local/remote IP addresses, local/remote interface identifiers, link metric and TE metric, link bandwidth, reservable bandwidth, per CoS class reservation state, preemption and Shared Risk Link Groups (SRLG). The node’s PCEP process can retrieve topology from these databases and distribute it to a PCE, either directly or via another PCEP Speaker, using the encoding specified in this document.

Further [RFC6805] describes Hierarchical-PCE architecture, where a parent PCE maintains a domain topology map. The child PCE MAY transport (abstract) Link-State and TE information from child PCE to a Parent PCE using the mechanism described in this document.

[I-D.ietf-pce-stateful-pce] describe LSP state synchronization between PCCs and PCEs in case of stateful PCE. This document does not make any change to the LSP state synchronization process. The mechanism described in this document are on top of the existing LSP state synchronization.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2. Terminology

The terminology is as per [RFC4655] and [RFC5440].

3. Applicability

As per [I-D.leedhody-teas-pcep-ls], the mechanism specified in this draft is applicable to:

- Where there is no IGP or BGP-LS running in the network.
- Where there is no IGP or BGP-LS running at the PCE to learn link-state and TE information.
Where there is IGP or BGP-LS running but with a need for a faster TE and link-state population and convergence at the PCE.

* A PCE may receive partial information (say basic TE, link-state) from IGP and other information (optical and impairment) from PCEP.

* A PCE may receive an incremental update (as opposed to the entire information of the node/link).

* A PCE may receive full information from both existing mechanism (IGP or BGP) and PCEP.

Where there is a need for transporting (abstract) Link-State and TE information from child PCE to a Parent PCE in H-PCE [RFC6805]; as well as for Physical Network Controller (PNC) to Multi-Domain Service Coordinator (MDSC) in Abstraction and Control of TE Networks (ACTN) [I-D.ceccarelli-teas-actn-framework].

A PCC may further choose to send only local information or both local and remote learned information.

How a PCE manages the link-state (and TE) information is implementation specific and thus out of scope of this document.

4. Requirements for PCEP extension

Following key requirements associated with link-state (and TE) distribution are identified for PCEP:

1. The PCEP speaker supporting this draft MUST be a mechanism to advertise the Link-State (and TE) distribution capability.

2. PCC supporting this draft MUST have the capability to report the link-state (and TE) information to the PCE. This includes self originated information and remote information learned via routing protocols. PCC MUST be capable to do the initial bulk sync at the time of session initialization as well as changes after.

3. A PCE MAY learn link-state (and TE) from PCEP as well as from existing mechanism like IGP/BGP-LS. PCEP extension MUST have a mechanism to link the information learned via other means. There MUST NOT be any changes to the existing link-state (and TE) population mechanism via IGP/BGP-LS. PCEP extension SHOULD keep the properties in a protocol (IGP or BGP-LS) neutral way, such that an implementation may not need to know about any OSPF or IS-IS or BGP protocol specifics.
4. It SHOULD be possible to encode only the changes in link-state (and TE) properties (after the initial sync) in PCEP messages.

5. The same mechanism should be used for both MPLS TE as well as GMPLS, optical and impairment aware properties.

6. The same mechanism should be used for PCE to PCE Link-state (and TE) synchronization.

7. The extension in this draft SHOULD be extensible to support various architecture options listed in [I-D.leedhody-teas-pcep-ls].

5. New Functions to distribute link-state (and TE) via PCEP

Several new functions are required in PCEP to support distribution of link-state (and TE) information. A function can be initiated either from a PCC towards a PCE (C-E) or from a PCE towards a PCC (E-C). The new functions are:

- Capability advertisement (E-C,C-E): both the PCC and the PCE must announce during PCEP session establishment that they support PCEP extensions for distribution of link-state (and TE) information defined in this document.

- Link-State (and TE) synchronization (C-E): after the session between the PCC and a PCE is initialized, the PCE must learn Link-State (and TE) information before it can perform path computations. In case of stateful PCE it is RECOMMENDED that this operation be done before LSP state synchronization.

- Link-State (and TE) Report (C-E): a PCC sends a LS (and TE) report to a PCE whenever the Link-State and TE information changes.

6. Overview of Extension to PCEP

6.1. New Messages

In this document, we define a new PCEP messages called LS Report (LSRpt), a PCEP message sent by a PCC to a PCE to report link-state (and TE) information. Each LS Report in a LSRpt message can contain the node or link properties. An unique PCEP specific LS identifier (LS-ID) is also carried in the message to identify a node or link and that remains constant for the lifetime of a PCEP session. This identifier on its own is sufficient when no IGP or BGP-LS running in the network for PCE to learn link-state (and TE) information. In case PCE learns some information from PCEP and some from the existing mechanism, the PCC SHOULD include the mapping of IGP or BGP-LS.
6.2. Capability Advertisement

During PCEP Initialization Phase, PCEP Speakers (PCE or PCC) advertise their support of LS (and TE) distribution via PCEP extensions. A PCEP Speaker includes the "LS Capability" TLV, described in Section 9.1.1, in the OPEN Object to advertise its support for PCEP-LS extensions. The presence of the LS Capability TLV in PCC’s OPEN Object indicates that the PCC is willing to send LS Reports whenever local link-state (and TE) information changes. The presence of the LS Capability TLV in PCE’s OPEN message indicates that the PCE is interested in receiving LS Reports whenever local link-state (and TE) information changes.

The PCEP protocol extensions for LS (and TE) distribution MUST NOT be used if one or both PCEP Speakers have not included the LS Capability TLV in their respective OPEN message. If the PCE that supports the extensions of this draft but did not advertise this capability, then upon receipt of a LSRpt message from the PCC, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD1 (Attempted LS Report if LS capability was not advertised) and it will terminate the PCEP session.

The LS reports sent by PCC MAY carry the remote link-state (and TE) information learned via existing means like IGP and BGP-LS only if both PCEP Speakers set the R (remote) Flag in the "LS Capability" TLV to ‘Remote Allowed (R Flag = 1)’. If this is not the case and LS reports carry remote link-state (and TE) information, then a PCErr with error-type 19 (Invalid Operation) and error-value TBD1 (Attempted LS Report if LS remote capability was not advertised) and it will terminate the PCEP session.

6.3. Initial Link-State (and TE) Synchronization

The purpose of LS Synchronization is to provide a checkpoint-in-time state replica of a PCC’s link-state (and TE) data base in a PCE. State Synchronization is performed immediately after the Initialization phase (see [RFC5440]). In case of stateful PCE ([I-D.ietf-pce-stateful-pce]) it is RECOMMENDED that the LS synchronization should be done before LSP state synchronization.

During LS Synchronization, a PCC first takes a snapshot of the state of its database, then sends the snapshot to a PCE in a sequence of LS Reports. Each LS Report sent during LS Synchronization has the SYNC Flag in the LS Object set to 1. The end of synchronization marker is a LSRpt message with the SYNC Flag set to 0 for an LS Object with LS-
ID equal to the reserved value 0. If the PCC has no link-state to synchronize, it will only send the end of synchronization marker.

Either the PCE or the PCC MAY terminate the session using the PCEP session termination procedures during the synchronization phase. If the session is terminated, the PCE MUST clean up state it received from this PCC. The session re-establishment MUST be re-attempted per the procedures defined in [RFC5440], including use of a back-off timer.

If the PCC encounters a problem which prevents it from completing the LS synchronization, it MUST send a PCErr message with error-type TBD2 (LS Synchronization Error) and error-value 5 (indicating an internal PCC error) to the PCE and terminate the session.

The PCE does not send positive acknowledgements for properly received LS synchronization messages. It MUST respond with a PCErr message with error-type TBD2 (LS Synchronization Error) and error-value 1 (indicating an error in processing the LSRpt) if it encounters a problem with the LS Report it received from the PCC and it MUST terminate the session.

The LS reports can carry local as well as remote link-state (and TE) information depending on the R flag in LS capability TLV.

The successful LS Synchronization sequences is shown in Figure 1.
Figure 1: Successful LS synchronization

The sequence where the PCE fails during the LS Synchronization phase is shown in Figure 2.

Figure 2: Failed LS synchronization (PCE failure)
The sequence where the PCC fails during the LS Synchronization phase is shown in Figure 3.

```
+---+   +---+
|PCC|   |PCE|
+---+   +---+

-----LSRpt, SYNC=1------>
-----LSRpt, SYNC=1------>
            .
            .
------- PCErr--------->
```

Figure 3: Failed LS synchronization (PCC failure)

6.3.1. Optimizations for LS Synchronization

These optimizations are described in [I-D.kondreddy-pce-pcep-ls-sync-optimizations].

6.4. LS Report

The PCC MUST report any changes in the link-state (and TE) information to the PCE by sending a LS Report carried on a LSRpt message to the PCE. Each node and Link would be uniquely identified by a PCEP LS identifier (LS-ID). The LS reports may carry local as well as remote link-state (and TE) information depending on the R flag in LS capability TLV. In case R flag is set, It MAY also include the mapping of IGP or BGP-LS identifier to map the information populated via PCEP with IGP/BGP-LS.

More details about LSRpt message are in Section 8.1.

7. Transport

A permanent PCEP session MUST be established between a PCE and PCC supporting link-state (and TE) distribution via PCEP. In the case of session failure, session re-establishment MUST be re-attempted per the procedures defined in [RFC5440].
8. 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.

8.1. LS Report Message

A PCEP LS Report message (also referred to as LSRpt message) is a PCEP message sent by a PCC to a PCE to report the link-state (and TE) information. A LSRpt message can carry more than one LS Reports. The Message-Type field of the PCEP common header for the LSRpt message is set to [TBD3].

The format of the LSRpt message is as follows:

<LSRpt Message> ::= <Common Header> <ls-report-list>

Where:

<ls-report-list> ::= <LS>[<ls-report-list>]

The LS object is a mandatory object which carries LS information of a node or a link. Each LS object has an unique LS-ID as described in Section 9.2. If the LS object is missing, the receiving PCE MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=[TBD4] (LS object missing).

A PCE may choose to implement a limit on the LS information a single PCC can populate. If a LSRpt is received that causes the PCE to exceed this limit, it MUST send a PCErr message with error-type 19 (invalid operation) and error-value 4 (indicating resource limit exceeded) in response to the LSRpt message triggering this condition and SHOULD terminate the session.

8.2. The PCErr Message

If a PCEP speaker has advertised the LS capability on the PCEP session, the PCErr message MAY include the LS object. If the error reported is the result of an LS report, then the LS-ID number MUST be the one from the LSRpt that triggered the error.
The format of a PCErr message from [RFC5440] is extended as follows:

The format of the PCErr message is as follows:

<PCErr Message> ::= <Common Header>
                  ( <error-obj-list> [Open] ) | <error>
                  [<error-list>]

<error-obj-list>::=<PCEP-ERROR>[<error-obj-list>]

<error>::=[<request-id-list> | <ls-id-list>]
            <error-obj-list>

<request-id-list>::=<RP>[<request-id-list>]

<ls-id-list>::=<LS>[<ls-id-list>]

<error-list>::=<error>[<error-list>]

9. Objects and TLV

The PCEP objects defined in this document are compliant with the PCEP object format defined in [RFC5440]. The P flag and the I flag of the PCEP objects defined in this document MUST always be set to 0 on transmission and MUST be ignored on receipt since these flags are exclusively related to path computation requests.

9.1. Open Object

This document defines a new optional TLV for use in the OPEN Object.

9.1.1. LS Capability TLV

The LS-CAPABILITY TLV is an optional TLV for use in the OPEN Object for link-state (and TE) distribution via PCEP capability advertisement. Its format is shown in the following figure:

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Type=[TBD5]     |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             Flags                           |R|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The type of the TLV is [TBD5] and it has a fixed length of 4 octets.

The value comprises a single field – Flags (32 bits):
o R (remote - 1 bit): if set to 1 by a PCC, the R Flag indicates that the PCC allows reporting of remote LS information learned via other means like IGP and BGP-LS; if set to 1 by a PCE, the R Flag indicates that the PCE is capable of receiving remote LS information (from the PCC point of view). The R Flag must be advertised by both a PCC and a PCE for LSRpt messages to report remote as well as local LS information on a PCEP session. The TLVs related to IGP/BGP-LS identifier MUST be encoded when both PCEP speakers have the R Flag set.

Unassigned bits are considered reserved. They MUST be set to 0 on transmission and MUST be ignored on receipt.

Advertisement of the LS capability implies support of local link-state (and TE) distribution, as well as the objects, TLVs and procedures defined in this document.

9.2. LS Object

The LS (link-state) object MUST be carried within LSRpt messages and MAY be carried within PCEErr messages. The LS object contains a set of fields used to specify the target node or link. It also contains a flag indicating to a PCE that the LS synchronization is in progress. The TLVs used with the LS object correlate with the IGP/BGP-LS encodings.

LS Object-Class is [TBD6].

Four Object-Type values are defined for the LS object so far:

- LS Node: LS Object-Type is 1.
- LS Link: LS Object-Type is 2.
- LS IPv4 Topology Prefix: LS Object-Type is 3.
- LS IPv6 Topology Prefix: LS Object-Type is 4.

The format of all types of LS object is as follows:
Protocol-ID (8-bit): The field provides the source information. In case PCC only provides local information (R flag is not set), it MUST use Protocol-ID as Direct. The following values are defined (same as [I-D.ietf-idr-ls-distribution]):

<table>
<thead>
<tr>
<th>Protocol-ID</th>
<th>Source protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IS-IS Level 1</td>
</tr>
<tr>
<td>2</td>
<td>IS-IS Level 2</td>
</tr>
<tr>
<td>3</td>
<td>OSPFv2</td>
</tr>
<tr>
<td>4</td>
<td>Direct</td>
</tr>
<tr>
<td>5</td>
<td>Static configuration</td>
</tr>
<tr>
<td>6</td>
<td>OSPFv3</td>
</tr>
</tbody>
</table>

Flags (32-bit):

- S (SYNC - 1 bit): the S Flag MUST be set to 1 on each LSRpt sent from a PCC during LS Synchronization. The S Flag MUST be set to 0 in other LSRpt messages sent from the PCC.

- R (Remove - 1 bit): On LSRpt messages the R Flag indicates that the node/link/prefix has been removed from the PCC and the PCE SHOULD remove from its database. Upon receiving an LS Report with the R Flag set to 1, the PCE SHOULD remove all state for the node/link/prefix identified by the LS Identifiers from its database.

LS-ID (64-bit): A PCEP-specific identifier for the node or link or prefix information. A PCC creates an unique LS-ID for each node/link/prefix that is constant for the lifetime of a PCEP session. The PCC will advertise the same LS-ID on all PCEP sessions it maintains at a given times. All subsequent PCEP messages then address the node/link/prefix by the LS-ID. The values of 0 and 0xFFFFFFFFFFFFFFFF are reserved.
Unassigned bits are considered reserved. They MUST be set to 0 on transmission and MUST be ignored on receipt.

TLVs that may be included in the LS Object are described in the following sections.

9.2.1. Routing Universe TLV

In case of remote link-state (and TE) population when existing IGP/BGP-LS are also used, OSPF and IS-IS may run multiple routing protocol instances over the same link as described in [I-D.ietf-idr-ls-distribution]. See [RFC6822] and [RFC6549] for more information. These instances define independent "routing universes". The 64-Bit 'Identifier' field is used to identify the "routing universe" where the LS object belongs. The LS objects representing IGP objects (nodes or links or prefix) from the same routing universe MUST have the same 'Identifier' value; LS objects with different 'Identifier' values MUST be considered to be from different routing universes.

The format of the ROUTING-UNIVERSE TLV is shown in the following figure:

```
+--------+--------+--------+--------+
| 0 1 2 3| 4 5 6 7| 8 9 0 1| 2 3 4 5|
+--------+--------+--------+--------+
| Type=[TBD7] | Length=8 |
+--------+--------+--------+--------+
| Identifier |
+--------+--------+--------+--------+
```

Below table lists the 'Identifier' values that are defined as well-known in this draft (same as [I-D.ietf-idr-ls-distribution]).

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Routing Universe</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Default Layer 3 Routing topology</td>
</tr>
<tr>
<td>1-31</td>
<td>Reserved</td>
</tr>
</tbody>
</table>

If this TLV is not present the default value 0 is assumed.
9.2.2. Local Node Descriptors TLV

As described in [I-D.ietf-idr-ls-distribution], each link is anchored by a pair of Router-IDs that are used by the underlying IGP, namely, 48 Bit ISO System-ID for IS-IS and 32 bit Router-ID for OSPFv2 and OSPFv3. In case of additional auxiliary Router-IDs used for TE, these MUST also be included in the link attribute TLV (see Section 9.2.8.2).

It is desirable that the Router-ID assignments inside the Node Descriptor are globally unique. Some considerations for globally unique Node/Link/Prefix identifiers are described in [I-D.ietf-idr-ls-distribution].

The Local Node Descriptors TLV contains Node Descriptors for the node anchoring the local end of the link. This TLV MUST be included in the LS Report when during a given PCEP session a node/link/prefix is first reported to a PCE. A PCC sends to a PCE the first LS Report either during State Synchronization, or when a new node/link/prefix is learned at the PCC. The value contains one or more Node Descriptor Sub-TLVs, which allows specification of a flexible key for any given node/link/prefix information such that global uniqueness of the node/link/prefix is ensured.

```
+---------------+---------------+---------------+---------------+
|               |               |               |               |
|     Type=[TBD8]     |        Length        |
+---------------+---------------+---------------+---------------+
|               |               |               |               |
//              Node Descriptor Sub-TLVs (variable) //
|               |               |               |               |
+---------------+---------------+---------------+---------------+
```

The value contains one or more Node Descriptor Sub-TLVs defined in Section 9.2.4.

9.2.3. Remote Node Descriptors TLV

The Remote Node Descriptors contains Node Descriptors for the node anchoring the remote end of the link. This TLV MUST be included in the LS Report when during a given PCEP session a link is first reported to a PCE. A PCC sends to a PCE the first LS Report either during State Synchronization, or when a new link is learned at the PCC. The length of this TLV is variable. The value contains one or more Node Descriptor Sub-TLVs defined in Section 9.2.4.
9.2.4. Node Descriptors Sub-TLVs

The Node Descriptor Sub-TLV type Type and lengths are listed in the following table:

<table>
<thead>
<tr>
<th>Sub-TLV</th>
<th>Description</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD10</td>
<td>Autonomous System</td>
<td>4</td>
</tr>
<tr>
<td>TBD11</td>
<td>BGP-LS Identifier</td>
<td>4</td>
</tr>
<tr>
<td>TBD12</td>
<td>OSPF Area-ID</td>
<td>4</td>
</tr>
<tr>
<td>TBD13</td>
<td>IGP Router-ID</td>
<td>Variable</td>
</tr>
<tr>
<td>TBD44</td>
<td>Multi-Topology-ID</td>
<td>Variable</td>
</tr>
</tbody>
</table>

The sub-TLV values in Node Descriptor TLVs are defined as follows (similar to [I-D.ietf-idr-ls-distribution]):

- **Autonomous System**: opaque value (32 Bit AS Number)
- **BGP-LS Identifier**: opaque value (32 Bit ID). In conjunction with ASN, uniquely identifies the BGP-LS domain as described in [I-D.ietf-idr-ls-distribution]. This sub-TLV is present only if the node implements BGP-LS and the ID is set by the operator.
- **OSPF Area ID**: It is used to identify the 32 Bit area to which the LS object belongs. Area Identifier allows the different LS objects of the same node to be discriminated.
- **IGP Router ID**: opaque value. Usage is described in [I-D.ietf-idr-ls-distribution] for IGP Router ID. In case only local information is transported and PCE learns link-state (and TE) information only from PCEP, it contain the unique local TE IPv4 or IPv6 router ID.
- **Multi-Topology-ID**: Usage is described in [I-D.ietf-idr-ls-distribution] for MT-ID.
9.2.5. Multi-Topology ID TLV

The Multi-Topology ID (MT-ID) TLV carries one or more IS-IS or OSPF Multi-Topology IDs for a link, node or prefix. The semantics of the IS-IS MT-ID are defined in Section 7.2 of [RFC5120]. The MT-ID TLV MAY be present in a Link Descriptor, a Prefix Descriptor, or in the attribute of a node (Node Attributes TLV) in LS object.

The format and handling of the MT-ID TLV is as defined in [I-D.ietf-idr-ls-distribution].

In a Link or Prefix Descriptor, only a single MT-ID TLV containing the MT-ID of the topology where the link or the prefix is reachable is allowed. In case one wants to advertise multiple topologies for a given Link Descriptor or Prefix Descriptor, multiple reports need to be generated where each LS object contains an unique MT-ID. In the attribute of a node (Node Attributes TLV) in LS object, one MT-ID TLV containing the array of MT-IDs of all topologies where the node is reachable is allowed.

9.2.6. Link Descriptors TLV

The Link Descriptors TLV contains Link Descriptors for each link. This TLV MUST be included in the LS Report when during a given PCEP session a link is first reported to a PCE. A PCC sends to a PCE the first LS Report either during State Synchronization, or when a new link is learned at the PCC. The length of this TLV is variable. The value contains one or more Link Descriptor Sub-TLVs.

The ‘Link descriptor’ TLVs uniquely identify a link among multiple parallel links between a pair of anchor routers similar to [I-D.ietf-idr-ls-distribution].

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=[TBD14]        |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//              Link Descriptor Sub-TLVs (variable)            //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The Link Descriptor Sub-TLV type and lengths are listed in the following table:
<table>
<thead>
<tr>
<th>Sub-TLV</th>
<th>Description</th>
<th>IS-IS TLV</th>
<th>Value defined in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD15</td>
<td>Link Local/Remote Identifiers</td>
<td>22/4</td>
<td>[RFC5307]/1.1</td>
</tr>
<tr>
<td>TBD16</td>
<td>IPv4 interface address</td>
<td>22/6</td>
<td>[RFC5305]/3.2</td>
</tr>
<tr>
<td>TBD17</td>
<td>IPv4 neighbor address</td>
<td>22/8</td>
<td>[RFC5305]/3.3</td>
</tr>
<tr>
<td>TBD18</td>
<td>IPv6 interface address</td>
<td>22/12</td>
<td>[RFC6119]/4.2</td>
</tr>
<tr>
<td>TBD19</td>
<td>IPv6 neighbor address</td>
<td>22/13</td>
<td>[RFC6119]/4.3</td>
</tr>
<tr>
<td>TBD44</td>
<td>Multi-Topology identifier</td>
<td>-</td>
<td>[I-D.ietf-idr-ls-distribution]/3.2.1.5</td>
</tr>
</tbody>
</table>

The format and semantics of the ‘value’ fields in most ‘Link Descriptor’ sub-TLVs correspond to the format and semantics of value fields in IS-IS Extended IS Reachability sub-TLVs, defined in [RFC5305], [RFC5307] and [RFC6119]. Although the encodings for ‘Link Descriptor’ TLVs were originally defined for IS-IS, the TLVs can carry data sourced either by IS-IS or OSPF or direct.

The information about a link present in the LSA/LSP originated by the local node of the link determines the set of sub-TLVs in the Link Descriptor of the link as described in [I-D.ietf-idr-ls-distribution].

9.2.7. Prefix Descriptors

The ‘Prefix Descriptor’ field is a set of Type/Length/Value (TLV) triplets. ‘Prefix Descriptor’ TLVs uniquely identify an IPv4 or IPv6 Prefix originated by a Node. The following TLVs are valid as Prefix Descriptors in the IPv4/IPv6 Prefix-
### 9.2.8. PCEP-LS Attributes TLV

#### 9.2.8.1. Node Attributes TLV

This is an optional attribute that is used to carry node attributes. The node attribute TLV may be encoded in the LS node Object.

```plaintext
+-----------------+-----------------+-----------------+-----------------+
| 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=[TBD20] | Length |
|+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+|
| // Node Attributes Sub-TLVs (variable) // |
|+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+|
```

The Node Attributes Sub-TLV type and lengths are listed in the following table:

<table>
<thead>
<tr>
<th>TLV Code Point</th>
<th>Description</th>
<th>Length</th>
<th>Value defined in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD44</td>
<td>Multi-Topology Identifier</td>
<td>variable</td>
<td>[I-D.ietf-idr-ls-distribution]</td>
</tr>
<tr>
<td>TBD45</td>
<td>OSPF Route Type</td>
<td>1</td>
<td>[I-D.ietf-idr-ls-distribution]</td>
</tr>
<tr>
<td>TBD46</td>
<td>IP Reachability Information</td>
<td>variable</td>
<td>[I-D.ietf-idr-ls-distribution]</td>
</tr>
</tbody>
</table>
9.2.8.2.  Link Attributes TLV

Link attribute TLV may be encoded in the LS Link Object.  The format and semantics of the 'value' fields in some 'Link Attribute' sub-TLVs correspond to the format and semantics of value fields in IS-IS Extended IS Reachability sub-TLVs, defined in [RFC5305], [RFC5307] and [I-D.ietf-idr-ls-distribution].  Although the encodings for 'Link Attribute' TLVs were originally defined for IS-IS, the TLVs can carry data sourced either by IS-IS or OSPF or direct.

<table>
<thead>
<tr>
<th>Sub TLV</th>
<th>Description</th>
<th>Length</th>
<th>Value defined in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD44</td>
<td>Multi-Topology Identifier</td>
<td>variable</td>
<td>[I-D.ietf-idr-ls-distribution]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>/3.2.1.5</td>
</tr>
<tr>
<td>TBD21</td>
<td>Node Flag Bits</td>
<td>1</td>
<td>[I-D.ietf-idr-ls-distribution]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>/3.3.1.1</td>
</tr>
<tr>
<td>TBD22</td>
<td>Opaque Node Properties</td>
<td>variable</td>
<td>[I-D.ietf-idr-ls-distribution]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>/3.3.1.5</td>
</tr>
<tr>
<td>TBD23</td>
<td>Node Name</td>
<td>variable</td>
<td>[I-D.ietf-idr-ls-distribution]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>/3.3.1.3</td>
</tr>
<tr>
<td>TBD24</td>
<td>IS-IS Area Identifier</td>
<td>variable</td>
<td>[I-D.ietf-idr-ls-distribution]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>/3.3.1.2</td>
</tr>
<tr>
<td>TBD25</td>
<td>IPv4 Router-ID of Local Node</td>
<td>4</td>
<td>[RFC5305]/4.3</td>
</tr>
<tr>
<td></td>
<td>IPv6 Router-ID of Local Node</td>
<td>16</td>
<td>[RFC6119]/4.1</td>
</tr>
</tbody>
</table>

The following 'Link Attribute' sub-TLVs are valid:

\[\text{Link attribute TLV may be encoded in the LS Link Object. The format and semantics of the 'value' fields in some 'Link Attribute' sub-TLVs correspond to the format and semantics of value fields in IS-IS Extended IS Reachability sub-TLVs, defined in [RFC5305], [RFC5307] and [I-D.ietf-idr-ls-distribution]. Although the encodings for 'Link Attribute' TLVs were originally defined for IS-IS, the TLVs can carry data sourced either by IS-IS or OSPF or direct.}\]
<table>
<thead>
<tr>
<th>Sub-TLV</th>
<th>Description</th>
<th>IS-IS TLV</th>
<th>Defined in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD25</td>
<td>IPv4 Router-ID of Local Node</td>
<td>134/----</td>
<td>[RFC5305]/4.3</td>
</tr>
<tr>
<td>TBD26</td>
<td>IPv6 Router-ID of Local Node</td>
<td>140/----</td>
<td>[RFC6119]/4.1</td>
</tr>
<tr>
<td>TBD30</td>
<td>IPv4 Router-ID of Remote Node</td>
<td>134/----</td>
<td>[RFC5305]/4.3</td>
</tr>
<tr>
<td>TBD31</td>
<td>IPv6 Router-ID of Remote Node</td>
<td>140/----</td>
<td>[RFC6119]/4.1</td>
</tr>
<tr>
<td>TBD32</td>
<td>Link Local/Remote Identifiers</td>
<td>22/4</td>
<td>[RFC5307]/1.1</td>
</tr>
<tr>
<td>TBD33</td>
<td>Administrative group (color)</td>
<td>22/3</td>
<td>[RFC5305]/3.1</td>
</tr>
<tr>
<td>TBD34</td>
<td>Maximum link bandwidth</td>
<td>22/9</td>
<td>[RFC5305]/3.3</td>
</tr>
<tr>
<td>TBD35</td>
<td>Max. reservable link bandwidth</td>
<td>22/10</td>
<td>[RFC5305]/3.5</td>
</tr>
<tr>
<td>TBD36</td>
<td>Unreserved link bandwidth</td>
<td>22/11</td>
<td>[RFC5305]/3.6</td>
</tr>
<tr>
<td>TBD37</td>
<td>TE Default Metric</td>
<td>22/18</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.2.3</td>
</tr>
<tr>
<td>TBD38</td>
<td>Link Protection Type</td>
<td>22/20</td>
<td>[RFC5307]/1.2</td>
</tr>
<tr>
<td>TBD39</td>
<td>MPLS Protocol Mask</td>
<td>1094</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.2.2</td>
</tr>
<tr>
<td>TBD40</td>
<td>IGP Metric</td>
<td>1095</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.2.4</td>
</tr>
<tr>
<td>TBD41</td>
<td>Shared Risk Link Group</td>
<td>1096</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.2.5</td>
</tr>
<tr>
<td>TBD42</td>
<td>Opaque link attributes</td>
<td>1097</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.2.6</td>
</tr>
<tr>
<td>TBD43</td>
<td>Link Name attribute</td>
<td>1098</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.2.7</td>
</tr>
</tbody>
</table>
9.2.8.3. Prefix Attributes TLV

Prefix attribute TLV may be encoded in the LS Prefix Object. Prefixes are learned from the IGP (IS-IS or OSPF) or BGP topology with a set of IGP attributes (such as metric, route tags, etc.). This section describes the different attributes related to the IPv4/IPv6 prefixes. Prefix Attributes TLVs SHOULD be encoded in the LS Prefix Object.

```
+--------+--------+--------+--------+
| 0 1 2 3| 4 5 6 7| 8 9 0 1| 2 3 4 5|
+--------+--------+--------+--------+
|     Type=[TBD53]     |   Length   |
+---------------------+-------------+
| Prefix Attributes Sub-TLVs (variable) |
+--------------------------------------+
```

The following 'Link Attribute' sub-TLVs are are valid:

<table>
<thead>
<tr>
<th>Sub-TLV</th>
<th>Description</th>
<th>BGP-LS TLV</th>
<th>Defined in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD47</td>
<td>IGP Flags</td>
<td>1152</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.3.1</td>
</tr>
<tr>
<td>TBD48</td>
<td>Route Tag</td>
<td>1153</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.3.2</td>
</tr>
<tr>
<td>TBD49</td>
<td>Extended Tag</td>
<td>1154</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.3.3</td>
</tr>
<tr>
<td>TBD50</td>
<td>Prefix Metric</td>
<td>1155</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.3.4</td>
</tr>
<tr>
<td>TBD51</td>
<td>OSPF Forwarding Address</td>
<td>1156</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.3.5</td>
</tr>
<tr>
<td>TBD52</td>
<td>Opaque Prefix Attribute</td>
<td>1157</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.3.6</td>
</tr>
</tbody>
</table>
10. Other Considerations

10.1. Inter-AS Links

The main source of LS (and TE) information is the IGP, which is not active on inter-AS links. In some cases, the IGP may have information of inter-AS links ([RFC5392], [RFC5316]). In other cases, an implementation SHOULD provide a means to inject inter-AS links into PCEP. The exact mechanism used to provision the inter-AS links is outside the scope of this document.

11. Security Considerations

This document extends PCEP for LS (and TE) distribution including a new LSRpt message with new object and TLVs. Procedures and protocol extensions defined in this document do not effect the overall PCEP security model. See [RFC5440], [I-D.ietf-pce-pceps]. Tampering with the LSRpt message may have an effect on path computations at PCE. It also provides adversaries an opportunity to eavesdrop and learn sensitive information and plan sophisticated attacks on the network infrastructure. The PCE implementation SHOULD provide mechanisms to prevent strains created by network flaps and amount of LS (and TE) information. Thus it is suggested that any mechanism used for securing the transmission of other PCEP message be applied here as well. As a general precaution, it is RECOMMENDED that these PCEP extensions only be activated on authenticated and encrypted sessions belonging to the same administrative authority.

12. Manageability Considerations

12.1. Control of Function and Policy

TBD.

12.2. Information and Data Models

TBD.

12.3. Liveness Detection and Monitoring

TBD.

12.4. Verify Correct Operations

TBD.
12.5. Requirements On Other Protocols

TBD.

12.6. Impact On Network Operations

TBD.

13. IANA Considerations

14. TLV/Sub-TLV Code Points Summary

This section contains the global table of all TLVs/Sub-TLVs in LS object defined in this document.

<table>
<thead>
<tr>
<th>Sub-TLV</th>
<th>Description</th>
<th>Ref TLV/Sub-TLV</th>
<th>Value defined in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD7</td>
<td>Routing Universe</td>
<td>--</td>
<td>Sec 9.2.1 [I-D.ietf-idr-ls-distribution]</td>
</tr>
<tr>
<td>TBD8</td>
<td>Local Node Descriptors</td>
<td>256</td>
<td>[I-D.ietf-idr-ls-distribution] 3.2.1.2</td>
</tr>
<tr>
<td>TBD9</td>
<td>Remote Node Descriptors</td>
<td>257</td>
<td>[I-D.ietf-idr-ls-distribution] 3.2.1.3</td>
</tr>
<tr>
<td>TBD10</td>
<td>Autonomous System</td>
<td>512</td>
<td>[I-D.ietf-idr-ls-distribution] 3.2.1.4</td>
</tr>
<tr>
<td>TBD11</td>
<td>BGP-LS Identifier</td>
<td>513</td>
<td>[I-D.ietf-idr-ls-distribution] 3.2.1.4</td>
</tr>
<tr>
<td>TBD12</td>
<td>OSPF Area-ID</td>
<td>514</td>
<td>[I-D.ietf-idr-ls-distribution] 3.2.1.4</td>
</tr>
<tr>
<td>TBD13</td>
<td>IGP Router-ID</td>
<td>515</td>
<td>[I-D.ietf-idr-ls-distribution] 3.2.1.4</td>
</tr>
<tr>
<td>TBD44</td>
<td>Multi-Topology-ID</td>
<td>263</td>
<td>[I-D.ietf-idr-ls-distribution] 3.2.1.5</td>
</tr>
<tr>
<td>TBD14</td>
<td>Link Descriptors</td>
<td>--</td>
<td>Sec 9.2.6</td>
</tr>
<tr>
<td>TBD15</td>
<td>Link Local/Remote Identifiers</td>
<td>22/4</td>
<td>[RFC5307]/1.1</td>
</tr>
<tr>
<td>TBD16</td>
<td>IPv4 interface address</td>
<td>22/6</td>
<td>[RFC5305]/3.2</td>
</tr>
<tr>
<td>TBD17</td>
<td>IPv4 neighbor address</td>
<td>22/8</td>
<td>[RFC5305]/3.3</td>
</tr>
<tr>
<td>------</td>
<td>----------------------</td>
<td>------</td>
<td>---------------</td>
</tr>
<tr>
<td>TBD18</td>
<td>IPv6 interface address</td>
<td>22/12</td>
<td>[RFC6119]/4.2</td>
</tr>
<tr>
<td>TBD19</td>
<td>IPv6 neighbor address</td>
<td>22/13</td>
<td>[RFC6119]/4.3</td>
</tr>
<tr>
<td>TBD45</td>
<td>OSPF Route Type</td>
<td>264</td>
<td>[I-D.ietf-idr-ls-distribution]/3.2.3.1</td>
</tr>
<tr>
<td>TBD46</td>
<td>IP Reachability Information</td>
<td>265</td>
<td>[I-D.ietf-idr-ls-distribution]/3.2.3.2</td>
</tr>
<tr>
<td>TBD20</td>
<td>Node Attributes</td>
<td>--</td>
<td>Sec 9.2.8.1</td>
</tr>
<tr>
<td>TBD21</td>
<td>Node Flag Bits</td>
<td>1024</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.1.1</td>
</tr>
<tr>
<td>TBD22</td>
<td>Opaque Node Properties</td>
<td>1025</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.1.5</td>
</tr>
<tr>
<td>TBD23</td>
<td>Node Name</td>
<td>1026</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.1.3</td>
</tr>
<tr>
<td>TBD24</td>
<td>IS-IS Area Identifier</td>
<td>1027</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.1.2</td>
</tr>
<tr>
<td>TBD25</td>
<td>IPv4 Router-ID of Local Node</td>
<td>134/--</td>
<td>[RFC5305]/4.3</td>
</tr>
<tr>
<td>TBD26</td>
<td>IPv6 Router-ID of Local Node</td>
<td>140/--</td>
<td>[RFC6119]/4.1</td>
</tr>
<tr>
<td>TBD27</td>
<td>Link Attributes</td>
<td>--</td>
<td>Sec 9.2.8.2</td>
</tr>
<tr>
<td>TBD30</td>
<td>IPv4 Router-ID of Remote Node</td>
<td>134/--</td>
<td>[RFC5305]/4.3</td>
</tr>
<tr>
<td>TBD31</td>
<td>IPv6 Router-ID of Remote Node</td>
<td>140/--</td>
<td>[RFC6119]/4.1</td>
</tr>
<tr>
<td>TBD32</td>
<td>Link Local/Remote Identifiers</td>
<td>22/4</td>
<td>[RFC5307]/1.1</td>
</tr>
<tr>
<td>TBD33</td>
<td>Administrative group (color)</td>
<td>22/3</td>
<td>[RFC5305]/3.1</td>
</tr>
<tr>
<td>TBD34</td>
<td>Maximum link bandwidth</td>
<td>22/9</td>
<td>[RFC5305]/3.3</td>
</tr>
<tr>
<td>TBD35</td>
<td>Max. reservable link bandwidth</td>
<td>22/10</td>
<td>[RFC5305]/3.5</td>
</tr>
<tr>
<td>TBD36</td>
<td>Unreserved bandwidth</td>
<td>22/11</td>
<td>[RFC5305]/3.6</td>
</tr>
<tr>
<td>TBD37</td>
<td>TE Default Metric</td>
<td>22/18</td>
<td>[I-D.ietf-idr-ls-distribution]/3.3.2.3</td>
</tr>
<tr>
<td>TBD38</td>
<td>Link Protection</td>
<td>22/20</td>
<td>[RFC5307]/1.2</td>
</tr>
<tr>
<td>Type</td>
<td>1094</td>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------</td>
<td>--------------------------------</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.2.2</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.2.4</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.2.5</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.2.6</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.2.7</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.2.8.3</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.3.1</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.3.2</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.3.3</td>
<td></td>
</tr>
<tr>
<td>[I-D.ietf-idr-ls-distribution]</td>
<td></td>
<td>3.3.3.4</td>
<td></td>
</tr>
<tr>
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<td></td>
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<td></td>
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<tr>
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<td></td>
<td>3.3.3.6</td>
<td></td>
</tr>
</tbody>
</table>

15. Acknowledgments

This document borrows some of the structure and text from the [I-D.ietf-idr-ls-distribution].

Thanks to Eric Wu, Venugopal Kondreddy, Mahendra Singh Negi, and Zhengbin Li for the reviews.
16. References

16.1. Normative References


16.2. Informative References


[I-D.kondreddy-pce-pcep-ls-sync-optimizations]

[I-D.leedhody-teas-pcep-ls]

[I-D.ceccarelli-teas-actn-framework]
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BGP Extensions for Path Computation Element (PCE) Discovery
draft-dong-pce-discovery-proto-bgp-03

Abstract

In networks where Path Computation Element (PCE) is used for centralized path computation, it is desirable for Path Computation Clients (PCCs) to automatically discover a set of PCEs and select the suitable ones to establish the PCEP session. RFC 5088 and RFC 5089 define the PCE discovery mechanisms based on Interior Gateway Protocols (IGP). This document describes several scenarios in which the IGP based PCE discovery mechanisms cannot be used directly. This document specifies the BGP extensions for PCE discovery in these scenarios. The BGP based PCE discovery mechanism is complementary to the existing IGP based mechanisms.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

Status of This Memo

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This Internet-Draft will expire on March 4, 2016.
1. Introduction

In network scenarios where Path Computation Element (PCE) is used for centralized path computation, it is desirable for Path Computation Clients (PCCs) to automatically discover a set of PCEs and select the suitable ones to establish the PCEP session. [RFC5088] and [RFC5089] define the PCE discovery mechanisms based on Interior Gateway Protocols (IGP). Those IGP based mechanisms may not work in several scenarios where the PCEs do not participate in the IGP, and it is difficult for PCEs to participate in multiple IGP domains where PCE discovery is needed.

In some scenarios, Backward Recursive Path Computation (BRPC) [RFC5441] can be used by cooperating PCEs to compute inter-domain path, in which case these cooperating PCEs should be known to each other in advance. In case of inter-AS networks where the PCEs do not participate in a common IGP, the existing IGP discovery mechanism cannot be used to discover the PCEs in other domains.
In the Hierarchical PCE scenario [RFC6805], the child PCEs need to know the address of the parent PCEs. This cannot be achieved through IGP based discovery, as normally the child PCEs and the parent PCE are under different administration and reside in different domains.

Besides, as BGP could be used for north-bound distribution of routing and Label Switched Path (LSP) information to PCE as described in [I-D.ietf-idr-ls-distribution] [I-D.ietf-idr-te-lsp-distribution] and [I-D.ietf-idr-te-pm-bgp], PCEs can obtain the routing information without participating in IGP. In this scenario, some other PCE discovery mechanism is needed.

A detailed set of requirements for a PCE discovery mechanism are provided in [RFC4674].

This document proposes to extend BGP for PCE discovery in the above scenarios. In networks where BGP-LS is used for the north-bound routing information distribution to PCE, the BGP based PCE discovery can reuse the existing BGP sessions and mechanisms to achieve PCE discovery. It should be noted that in each IGP domain, the IGP based PCE discovery mechanism may be used in conjunction with the BGP based PCE discovery. Thus the BGP based PCE discovery is complementary to the existing IGP based mechanisms.
As shown in the network architecture in Figure 1, BGP is used for both routing information distribution and PCE information discovery. The routing information is collected from the network elements and distributed to PCE, while the PCE discovery information is advertised from PCE to PCCs, or between different PCEs. The PCCs may be co-located with the BGP speakers as shown in Figure 1. The IGP based PCE discovery mechanism may be used for the distribution of PCE discovery information in IGP domain.

2. Carrying PCE Discovery Information in BGP

2.1. PCE Address Information

The PCE discovery information is advertised in BGP UPDATE messages using the MP_REACH_NLRI and MP_UNREACH_NLRI attributes [RFC4760]. The AFI and SAFI defined in [I-D.ietf-idr-ls-distribution] are reused, and a new NLRI Type is defined for PCE discovery information as below:
Type = TBD: PCE Discovery NLRI

The format of PCE Discovery NLRI is shown in the following figure:

```
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 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Protocol-ID  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Identifier                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            (64 bits)                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
| PCE-Address (4 or 16 octets)                                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
Figure 2. PCE Discovery NLRI
```

The ‘Protocol-ID’ field SHOULD be set to a new value which indicates the information source protocol is PCE.

```
+-------------+----------------------------------+
| Protocol-ID | NLRI information source protocol |
+-------------+----------------------------------+
|    TBD      |       PCE                        |
+-------------+----------------------------------+
```

As defined in [I-D.ietf-idr-ls-distribution], the 64-Bit ‘Identifier’ field is used to identify the "routing universe" where the PCE belongs.

2.2. PCE Discovery TLVs

The detailed PCE discovery information is carried in the BGP-LS attribute [I-D.ietf-idr-ls-distribution] with a new "PCE Discovery TLV", which contains a set of sub-TLVs for specific PCE discovery information. The PCE Discovery TLV and sub-TLVs SHOULD only be used with the PCE Discovery NLRI.

The format of the PCE Discovery TLV is shown as below:
The PCE Discovery sub-TLVs are listed as below. The format of the PCE Discovery sub-TLVs are consistent with the IGP PCED sub-TLVs as defined in [RFC5088] and [RFC5089]. The PATH-SCOPE sub-TLV MUST always be carried in the PCE Discovery TLV. Other PCE Discovery sub-TLVs are optional and may facilitate the PCE selection process on the PCCs.

<table>
<thead>
<tr>
<th>Type</th>
<th>Length</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>3</td>
<td>PATH-SCOPE sub-TLV</td>
</tr>
<tr>
<td>TBD</td>
<td>variable</td>
<td>PCE-CAP-FLAGS sub-TLV</td>
</tr>
<tr>
<td>TBD</td>
<td>variable</td>
<td>OSPF-PCE-DOMAIN sub-TLV</td>
</tr>
<tr>
<td>TBD</td>
<td>variable</td>
<td>IS-IS-PCE-DOMAIN sub-TLV</td>
</tr>
<tr>
<td>TBD</td>
<td>variable</td>
<td>OSPF-NEIG-PCE-DOMAIN sub-TLV</td>
</tr>
<tr>
<td>TBD</td>
<td>variable</td>
<td>IS-IS-NEIG-PCE-DOMAIN sub-TLV</td>
</tr>
</tbody>
</table>

More PCE Discovery sub-TLVs may be defined in future and the format SHOULD be in line with the new sub-TLVs defined for IGP based PCE discovery.

3. Operational Considerations

Existing BGP operational procedures apply to the advertisement of PCE discovery information. This information is treated as pure application level data which has no immediate impact on forwarding states. Normal BGP path selection can be applied to PCE Discovery NLRI only for the information propagation in the network, while the PCE selection on the PCCs would be based on the information carried in the PCE Discovery TLV.

The PCE discovery information is considered relatively stable and does not change frequently, thus this information will not bring significant impact on the amount of BGP updates in the network.
4. IANA Considerations

IANA needs to assign a new NLRI Type for ‘PCE Discovery NLRI’ from the "BGP-LS NLRI-Types" registry.

IANA needs to assign a new Protocol-ID for "PCE" from the "BGP-LS Protocol-IDs" registry.

IANA needs to assign a new TLV code point for ‘PCE Discovery TLV’ from the "node anchor, link descriptor and link attribute TLVs" registry.

IANA needs to create a new registry for "PCE Discovery Sub-TLVs". The registry will be initialized as shown in section 2.2 of this document.

5. Security Considerations

Procedures and protocol extensions defined in this document do not affect the BGP security model. See the ‘Security Considerations’ section of [RFC4271] for a discussion of BGP security. Also refer to [RFC4272] and [RFC6952] for analysis of security issues for BGP.

6. Acknowledgements

The authors would like to thank Zhenbin Li and Hannes Gredler for their discussion and comments.

7. References

7.1. Normative References

[I-D.ietf-idr-ls-distribution]  


7.2. Informative References

[I-D.ietf-idr-te-lsp-distribution]

[I-D.ietf-idr-te-pm-bgp]


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Abstract

For a Path Computation Element (PCE) to perform its computations, it is important that Link-State (and TE) information be complete and accurate each time. This requires a reliable Link-State Synchronization mechanism between the PCE and path computation clients (PCCs), and between cooperating PCEs. The basic mechanism for Link-State Synchronization is part of the PCEP Link-State (and TE) draft. This draft presents motivations for optimizations to the base PCEP Link-State (and TE) procedure and specifies the required Path Computation Element Communication Protocol (PCEP) extensions.

Status of This Memo

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This Internet-Draft will expire on April 11, 2016.

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1. Introduction

The Path Computation Element Communication Protocol (PCEP) provides mechanisms for Path Computation Elements (PCEs) to perform path computations in response to Path Computation Clients (PCCs) requests. [I-D.dhodylee-pce-pcep-ls] describes a set of extensions to PCEP to provide Link-State (and TE) distribution. This draft presents motivations for optimizations to the base PCEP Link-State transport procedure and specifies the required Path Computation Element Communication Protocol (PCEF) extensions. This draft specifies following optimizations for Link-State Synchronization and the corresponding PCEP procedures and extensions:

- Link-State Synchronization Avoidance: To skip Link-State (and TE) synchronization if the state has survived and not changed during session restart. (See Section 3)
- Incremental Link-State Synchronization: To do incremental (delta) Link-State (and TE) Synchronization when possible. (See Section 4)
- PCE-triggered Initial Synchronization: To let PCE control the timing of the initial Link-State (and TE) Synchronization. (See Section 5)
- PCE-triggered Re-synchronization: To let PCE re-synchronize the Link-State (and TE) information for sanity check. (See Section 6)

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2. Terminology

This document uses the following terms defined in [RFC5440]: PCC, PCE, PCEP Peer.

This document uses the following terms defined in [I-D.dhodylee-pce-pcep-ls]: LSRpt, Link-State (and TE), LS Link-State (and TE): "LS" is interchangeably used for the keyword "Link-State (and TE)".

Within this document, when describing PCE-PCE communications, the requesting PCE fills the role of a PCC. This provides a saving in documentation without loss of function.
The following terms are defined in this document:

**LS-DB**: Link-State (and TE) Database.

**LS Sync**: LS Synchronization, an operation to send LS information synchronization request to PCC by LSRpt message with LS-ID 0.

**LS-Info**: One LS information (i.e. LS Node/Link/Prefix defined in I-D.dhodylee-pce-pcep-ls).

3. **LS Synchronization Avoidance**

3.1. **Motivation**

The purpose of LS Synchronization is to provide a checkpoint-in-time state replica of a PCC’s Link-State (and TE) information in a PCE. LS Synchronization is performed immediately after the initialization phase ([RFC5440]). [I-D.dhodylee-pce-pcep-ls] describes the basic mechanism for LS synchronization.

LS Synchronization is not always necessary following a PCEP session restart. If the Link-State (and TE) information of both PCEP peers did not change, the synchronization phase may be skipped. This can result in significant savings in both control-plane data exchanges and the time it takes for the PCE to become fully operational.

3.2. **LS Synchronization Avoidance Procedure**

LS Synchronization MAY be skipped following a PCEP session restart if the Link-State (and TE) information of both PCEP peers did not change during the period prior to session re-initialization. To be able to make this determination, LS-DB must be exchanged and maintained by both PCE and PCC during normal operation. This is accomplished by keeping track of the changes to the Link-State (and TE) Database (LS-DB), using a version tracking field called the LS-DB Version Number.

The LS-DB Version Number, carried in LS-DB-VERSION TLV (see Section 7.2), is owned by a PCC and it MUST be incremented by 1 for each successive change in the PCC’s LS-DB. The LS-DB Version Number MUST start at 1 and may wrap around. Values 0 and 0xFFFFFFFFFFFFFFFF are reserved. If either of the two values are used during LS re-synchronization, the PCE speaker receiving this node should send back a PCErr with Error-type TBD1 Error-value 1 'Received an invalid LS-DB Version Number’, and close the PCEP session. Operations that trigger a change to the local LS-DB include but not limited to:

- a change in the link status or attributes(i.e. bandwidth, metric etc), addition or deletion of link.
- a change in the node attributes, addition or deletion of node.
- a change in the prefix attributes, addition or deletion of prefix.

LS Synchronization avoidance is advertised on a PCEP session during session startup using the LS-INCLUDE-DB-VERSION (S) bit in the LS-CAPABILITY TLV (see Section 7.3). The peer may move in the network, either physically or logically, which may cause its connectivity details and transport-level identity (such as IP address) to change. To ensure that a PCEP peer can recognize a previously connected peer even in case of such mobility, each PCEP peer includes the SPEAKER-ENTITY-ID TLV in the OPEN message. SPEAKER-ENTITY-ID TLV is described in [I-D.ietf-pce-stateful-sync-optimizations]

If both PCEP speakers set the S flag in the OPEN object’s LS-CAPABILITY TLV to 1, the PCC MUST include the LS-DB-VERSION TLV in each LS object of the LSRpt message. If the LS-DB-VERSION TLV is missing in a LSRpt message, the PCE will generate an error with Error-Type 6 (mandatory object missing) and Error-Value TBD2 ‘LS-DB-VERSION TLV missing’ and close the session. If LS Synchronization avoidance has not been enabled on a PCEP session, the PCC SHOULD NOT include the LS-DB-VERSION TLV in the LS object and the PCE SHOULD ignore it, if it were to receive one.

If a PCE’s LS-DB survived the restart of a PCEP session, the PCE will include the LS-DB-VERSION TLV in its OPEN object, and the TLV will contain the last LS-DB Version Number received on an LS Report from the PCC in the previous PCEP session. If a PCC’s LS-DB survived the restart of a PCEP session, the PCC will include the LS-DB-VERSION TLV in its OPEN object and the TLV will contain the latest LS-DB Version Number. If a PCEP speaker’s LS-DB did not survive the restart of a PCEP session, the PCEP speaker MUST NOT include the LS-DB-VERSION TLV in the OPEN object.

If both PCEP speakers include the LS-DB-VERSION TLV in the OPEN Object and the TLV values match, the PCC MAY skip LS Synchronization. Otherwise, the PCC MUST perform complete LS Synchronization. If the PCC attempts to skip LS Synchronization (i.e., the SYNC Flag = 0 on the first LS Report from the PCC, the PCE MUST send back a PCErr with Error-Type TBD1 Error-Value 2 ‘LS-DB version mismatch’, and close the PCEP session.

If LS Synchronization is required, then prior to completing the initialization phase, the PCE MUST mark any LS-Infos in the LS-DB that were previously reported by the PCC as stale. When the PCC reports a LS-Info during LS Synchronization, if the LS-Info already exists in the LS-DB, the PCE MUST update the LS-DB and clear the stale marker from the LS-Info. When it has finished LS
Synchronization, the PCC MUST immediately send an end of LS Synchronization marker. The end of synchronization marker is a LS Report (LSRpt) message with an LS object containing a LS-ID of 0 and with the SYNC flag set to 0. The LS-DB-VERSION TLV MUST be included in this LSRpt message. On receiving this LS Report, the PCE MUST purge any LS-Infos from the LS-DB that are still marked as stale. It should be noted that PCE may receive the same Link-state and TE information from multiple PCCs and the purging should take that into account.

Note that a PCE/PCC MAY force LS Synchronization by not including the LS-DB-VERSION TLV in its OPEN object.

Since a PCE does not make changes to the LS-DB Version Number, a PCC should never encounter this TLV in a message from the PCE (other than the OPEN message). A PCC SHOULD ignore the LS-DB-VERSION TLV, were it to receive one from a PCE.

Figure 1 shows an example sequence where the LS synchronization is skipped.

```
+-----+                        +-----+
| PCC |                        | PCE |
+-----+                        +-----+
      +-----+                        +-----+
      |     |                        |      |
      +-----+                        +-----+
      | ---Open--,                  |
      | LS-DBv=82 \ ,---Open------|
      | S=1 \ /LS-DBv=82           |
      |   \  \ S=1                |
      |    \                     |
      |     \ '--------------->
      |      (OK to skip          |
      |      LS sync)            |
      |                           |
      | <--------------            |
      | (Skip LS sync)           |
      |                           |
      | ---LSRpt,LS-DBv=83,SYNC=0---> (Regular LS Report)
      | ---LSRpt,LS-DBv=84,SYNC=0---> (Regular LS Report)
      | ---LSRpt,LS-DBv=85,SYNC=0--->
```

Figure 1: LS Synchronization Skipped
Figure 2 shows an example sequence where the LS Synchronization is performed due to LS-DB Version mismatch during the PCEP session setup. Note that the same LS Synchronization sequence would happen if either the PCC or the PCE would not include the LS-DB-VERSION TLV in their respective Open messages.

```
++-+-+                      +-+-+
|PCC|                        |PCE|
++-+-+                      +-+-+

---Open--, LS-DBv=86        ---Open-----
   
   S=1 \ /LS-DBv=82
   \ / S=1
   / '-----------> (Expect sync)

(Do sync) <---------'                

---LSRpt,LS-DBv=86,SYNC=1--> (Sync start)
   .
   .

---LSRpt,LS-DBv=86,SYNC=0--> (Sync done)
   . (Purge LS-Info
   .   if applicable)

---LSRpt,LS-DBv=87,SYNC=0--> (Regular
   .   LS Report)
---LSRpt,LS-DBv=88,SYNC=0--> (Regular
   .   LS Report)
---LSRpt,LS-DBv=89,SYNC=0-->

Figure 2: LS Synchronization Performed

Figure 3 shows an example sequence where the LS Synchronization is skipped, but because one or both PCEP speakers set the S Flag to 0, the PCC does not send LS-DB-VERSION TLVs in subsequent LSRpt messages to the PCE. If the current PCEP session restarts, the PCEP speakers will have to perform LS Synchronization, since the PCE does not know the PCC’s latest LS-DB Version Number information.
4. Incremental LS Synchronization

[I-D.dhodylee-pce-pcep-ls] describes the LS synchronization mechanism during session initialization between PCCs and PCEs. During the LS synchronization, a PCC sends the information of its LS-DB to the PCE based on the local policy. In order to reduce the LS Synchronization overhead when there is a small number of LS-DB change in the network between PCEP session restart, this section defines a mechanism for incremental (Delta) LS synchronization.

4.1. Motivation

According to [I-D.dhodylee-pce-pcep-ls], if a PCEP session restarts, PCCs send snapshot of LS-DB information to the PCE, though LS-DB did not change. And as per Section 3 (LS Synchronization Avoidance Procedure), if there is a change in a small number of LS-Infos. PCC yet sends complete snapshot of LS-DB information to the PCE, which takes a long time and consume large communication channel bandwidth.
4.2. Incremental Synchronization Procedure

Section 3 describes LS Synchronization avoidance by using LS-DB-VERSION TLV in its OPEN object. This section extends this idea to only synchronize the delta (changes) in case of version mismatch.

If both PCEP speakers include the LS-DB-VERSION TLV in the OPEN object and the LS-DB-VERSION TLV values match, the PCC MAY skip LS Synchronization. Otherwise, the PCC MUST perform LS Synchronization. Incremental LS Synchronization capability is advertised on a PCEP session during session startup using the LS-DELTA-SYNC-CAPABILITY (D) bit in the capabilities TLV (see Section 7.3). Instead of dumping full LS-DB to the PCE again, PCC synchronizes the delta (changes) as described in Figure 4 when D flag and S flag is set to 1 by both PCC and PCE. Other combinations of D and S flags setting by PCC and PCE result in complete LS Synchronization procedure as described in [I-D.dhodylee-pce-pcep-ls]. If a PCC has to force complete LS Synchronization due to reasons including but not limited: (1) local policy configured at the PCC; (2) no sufficient LS-DB caches for incremental update, the PCC can set the D flag to 0. Note a PCC may have to bring down the current session and force a complete LS Synchronization with D flag set to 0 in the subsequent open message.
Figure 4: Incremental Synchronization Procedure

As per Section 3, the LS-DB Version Number is incremented each time a change is made to the PCC’s local LS-DB. Each LS-Info is associated with the DB version at the time of change. This is needed to determine which LS-Info needs to be synchronized in incremental LS Synchronization.

PCC MAY store a then history of LS-DB change that happened between the PCEP session(s) restart in order to carry out incremental LS Synchronization. After the synchronization procedure finishes, the PCC can dump this history information. In the example shown in Figure 4, the PCC needs to store the LS-DB changes that happened between DB Version 83 to 86 and synchronizes these changes only when performing incremental LS-DB update. So a PCC needs to remember the LS-DB changes that happened when an existing PCEP session to a PCE goes down in the hope of doing incremental synchronization when the session is re-established.
If a PCC finds out it does not have sufficient information to complete incremental synchronization after advertising incremental LS Synchronization capability, it MUST send a PCErr with Error-Type TBD1 and Error-Value 3 ‘A PCC indicates to a PCE that it can not complete the LS synchronization’ and terminate the session.

5. PCE-triggered Initial Synchronization

5.1. Motivation

In networks such as optical transport networks, the control channel between network nodes can be realized through in-band overhead thus has limited bandwidth. With a PCE connected to the network via one network node, it is desirable to control the timing of PCC LS Synchronization so as not to overload the low communication channel available in the network during the initial synchronization (be it incremental or full) when the session restarts, when there is comparatively large amount of control information needing to be synchronized between the PCE and the network. The method proposed, i.e., allowing PCE to trigger the LS synchronization, is similar to the function proposed in Section 6 but is used in different scenarios and for different purposes.

5.2. PCE-triggered Initial LS Synchronization Procedure

Support of PCE-triggered LS Synchronization is advertised during session startup using the LS-TRIGGERED-INITIAL-SYNC (F) bit in the LS-CAPABILITY TLV (see Section 7.3).

As per [I-D.dhodylee-pce-pcep-ls], LSRpt is sent from PCC to PCE, this document extends the usage of LSRpt to trigger synchronization. Where a PCC can send a LSRpt (for LS Sync) with an LS object containing a LS-ID of 0 and with the SYNC flag set to 1. This LSRpt message is the trigger for the PCC to enter the synchronization phase and start sending LSRpt messages.

If the LS-TRIGGERED-INITIAL-SYNC capability is not advertised and the PCC receives a LSRpt with the SYNC flag set to 1, it MUST send a PCErr for LSRpt (LS Sync from PCE) with Error-Type TBD1 and Error-Value 4 ‘Attempt to trigger synchronization when the PCE triggered synchronization capability has not been advertised’.

A PCE MAY choose to control the LS Synchronization process. To allow PCE to do so, PCEP speakers MUST set T bit to 1 to indicate this (as described in Section 7.3). If the LS-DB version is mis-matched, it can send a LSRpt message with LS-ID = 0 and SYNC = 1 in order to trigger the LS Synchronization process. In this way, the PCE can control the sequence of LS Synchronization among all the PCCs that

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are re-establishing PCEP sessions with it. When the capability of PCE control is enabled, only after a PCC receives this message, it will start sending information to the PCE. The PCC SHOULD NOT send LSRpt messages to the PCE before it triggers the LS Synchronization. This PCE-triggering capability can be applied to both full and incremental LS Synchronization. If applied to the later, the PCCs only send information that PCE does not possess, which is inferred from the LS-DB version information exchanged in the OPEN message (see Section 3.2) for detailed procedure).

6. PCE-triggered Re-synchronization

6.1. Motivation

The accuracy of the computations performed by the PCE is tied to the accuracy of the view the PCE has on the LS-DB. Therefore, it can be beneficial to be able to re-synchronize LS-DB even after the session has been established. The PCE may use this approach to continuously sanity check its LS-DB against the network, or to recover from error conditions without having to tear down sessions.

6.2. PCE-triggered LS Re-synchronization Procedure

Support of PCE-triggered LS Synchronization is advertised during session startup using the LS-TRIGGERED-RESYNC (T) bit in the LS-CAPABILITY TLV (see Section 7.3).

The PCE triggers re-synchronization of the entire LS-DB. The PCE MUST first mark all LS-Infos in the LS-DB that were previously reported by the PCC as stale and then send a LSRpt (for LS Sync) with an LS object containing a LS-ID of 0 and with the SYNC flag set to 1. This LSRpt message is the trigger for the PCC to enter the synchronization phase and start sending LSRpt messages. After the receipt of the end-of-synchronization marker, the PCE will purge LS-Infos which were not refreshed.

If the LS-TRIGGERED-RESYNC capability is not advertised and the PCC receives a LSRpt with the SYNC flag set to 1, it MUST send a PCErr with Error-Type TBD1 and Error-Value 4 'Attempt to trigger synchronization when the TRIGGERED-SYNC capability has not been advertised'.

Once the state re-synchronization is triggered by the PCE, the procedures and error checks remain unchanged from the full state synchronization ([I-D.dhodylee-pce-pcep-ls]). This would also include PCE triggering multiple state re-synchronization requests while synchronization is in progress.
Figure 5: PCE Triggered Complete LS re-synchronization

7. PCEP Extensions

7.1. Link-State (LS) Report Message

A PCEP LS Report message (also referred to as LSRpt message) is a PCEP message sent by a PCC to a PCE to report the LS information. The definition of the LSRpt message from [I-D.dhodylee-pce-pcep-ls] is extended to use LSRpt message with LS-ID = 0 to request LS Synchronization from PCE to PCC.

If a PCC that does not support extention defined in this document receives a LSRpt message, it will act according to existing behavior of receiving invalid message. If a PCC supports the extention, but did not set the flag T or F, and receives the LSRpt message, it sends PCErr message as described earlier in section [x] and [y]. If a PCC supports the extention and set the flag T or F, and receives the LSRpt message without LS-ID as 0 and SYNC flag set, PCC will send an error message with Error-Type TBD1 Error-Value 6 ‘Invalid LSRpt message’.
7.2. Capability Advertisement

The LS-DB Version Number is an carried in optional LS-DB-VERSION TLV that MAY be included in the OPEN object and the LS object. This TLV MUST NOT be included if LS-INCLUDE-DB-VERSION bit in LS-CAPABILITY TLV is not set.

The format of the LS-DB-VERSION TLV is shown in the following figure:

```
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=8           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 LS-DB Version Number                          |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6: LS-DB-VERSION TLV format

The type of the TLV is [TBD] and it has a fixed length of 8 octets. The value contains a 64-bit unsigned integer, representing the LS-DB Version Number.

7.3. Advertising Support of Synchronization Optimizations

Support for each of the optimizations described in this document requires advertising the corresponding capabilities during session establishment.

New flags are defined for the LS-CAPABILITY TLV defined in [I-D.dhodylee-pce-pcep-ls].

```
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            |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             Flags                   |F|D|T|S|R|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 7: LS-CAPABILITY TLV Format
The value comprises a single field - Flags (32 bits):

R (LS-REMOTE-BIT - 1 bit): Defined in [I-D.dhodylee-pce-pcep-1s]

S (LS-INCLUDE-DB-VERSION - 1 bit): If set to 1 by both PCEP speakers, the PCC will include the LS-DB-VERSION TLV in each LS object. See Section 3 for details.

T (LS-TRIGGERED-RESYNC - 1 bit): If set to 1 by both PCEP speakers, the PCE can trigger re-synchronization of LS-Infos at any point in the life of the session. See Section 6 for details.

D (LS-DELTA-SYNC-CAPABILITY - 1 bit): If set to 1 by a PCEP speaker, it indicates that the PCEP speaker allows incremental (delta) state synchronization. See Section 4 for details.

F (LS-TRIGGERED-INITIAL-SYNC - 1 bit): If set to 1 by both PCEP speakers, the PCE SHOULD trigger initial (first) LS synchronization. See Section 5 for details.

8. IANA Considerations

This document requests IANA actions to allocate code points for the protocol elements defined in this document.

8.1. PCEP-Error Object

IANA is requested to make the following allocation in the "PCEP-ERROR Object Error Types and Values" registry.
Error-Type Meaning Reference
6 Mandatory Object missing [RFC5440]
   Error-Value= TBD2 This document
   LS-DB-VERSION TLV missing
TBD1 LS synchronization error
   Error-Value= TBD(suggested value 1):Received an invalid LSDB Version Number
   Error-Value= TBD(suggested value 2): LS-DB version mismatch.
   Error-Value= TBD(suggested value 3): PCC indicates to a PCE that it cannot complete the LS Synchronization Error-Value= TBD(suggested value 4): Attempt to trigger a synchronization when the PCE triggered synchronization capability has not been advertised.
   Error-Value= TBD(suggested value 5): LS-DB-VERSION TLV Missing when LS synchronization avoidance is enabled.
   Error-Value= TBD(suggested value 6): Invalid LSRpt message.

8.2. PCEP TLV Type Indicators

This document defines the following new PCEP TLVs:

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>LS-DB-VERSION</td>
<td>This document</td>
</tr>
</tbody>
</table>

8.3. LS-CAPABILITY Flags

The following values are defined in this document for the Flags field in the LS-CAPABILITY TLV in the OPEN object:
9. Manageability Considerations

All manageability requirements and considerations listed in [RFC5440] and [I-D.dhodylee-pce-pcep-is] apply to PCEP protocol extensions defined in this document. In addition, requirements and considerations listed in this section apply.

9.1. Control of Function and Policy

A PCE or PCC implementation MUST allow configuring the state synchronization optimization capabilities as described in this document.

9.2. Information and Data Models

PCEP session configuration and information in the PCEP MIB module SHOULD be extended to include advertised LS Capabilities, LS-DB Version Number and LS synchronization status, Message statistics.

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 section 8.4 of [RFC5440] also apply to PCEP protocol extensions defined in this document. In addition to monitoring parameters defined in [RFC5440], a PCEP implementation with LS-DB SHOULD provide the following parameters:

- Total number of LSRpt(Synchronization request) requests
- LS-DB Version Number and synchronization status

9.5. Requirements On Other Protocols

Mechanisms defined in this document do not imply any new requirements on other protocols.

Mechanisms defined in section 8.6 of [RFC5440] also apply to PCEP protocol extensions defined in this document.

Additionally, a PCEP implementation SHOULD allow a limit to be placed on the amount and rate of LSRpt messages sent by a PCEP speaker and processed by the peer. It SHOULD also allow sending a notification when a rate threshold is reached.

10. Security Considerations

The security considerations listed in [I-D.dhodylee-pce-pcep-ls] apply to this document as well. However, because the protocol modifications outlined in this document allow the PCE to control LS Re-synchronization timing and sequence, it also introduces a new attack vector: an attacker may flood the PCC with triggered re-synchronization request at a rate which exceeds the PCC’s ability to process them, either by spoofing messages or by compromising the PCE itself. The PCC is free to drop any trigger re-synchronization request without additional processing.

11. Acknowledgement

The document borrows some of the text and structure from [I-D.ietf-pce-stateful-sync-optimizations].

12. References

12.1. Normative References


12.2. Informative References

[I-D.ietf-pce-stateful-sync-optimizations]
Crabbe, E., Minei, I., Medved, J., Varga, R., Zhang, X.,
and D. Dhody, "Optimizations of Label Switched Path State
Synchronization Procedures for a Stateful PCE", draft-
ietf-pce-stateful-sync-optimizations-03 (work in
progress), October 2015.
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PCEP Extensions for Establishing Relationships Between Sets of LSPs

draft-minei-pce-association-group-02

Abstract

This document introduces a generic mechanism to create a grouping of LSPs in the context of a PCE. This grouping can then be used to define associations between sets of LSPs or between a set of LSPs and a set of attributes (such as configuration parameters or behaviors), and is equally applicable to the active and passive modes of a stateful PCE as well as a stateless PCE.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

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1. Introduction

[RFC5440] describes the Path Computation Element Protocol PCEP. PCEP enables the communication between a Path Computation Client (PCC) and a Path Control Element (PCE), or between PCE and PCE, for the purpose of computation of Multiprotocol Label Switching (MPLS) as well as Generalized MPLS (GMPLS) for Traffic Engineering Label Switched Path (TE LSP) characteristics.

Stateful pce [I-D.ietf-pce-stateful-pce] specifies a set of extensions to PCEP to enable stateful control of TE LSPs between and
across PCEP sessions in compliance with [RFC4657] and focuses on a
model where LSPs are configured on the PCC and control over them is
delegated to the PCE. The model of operation where LSPs are
initiated from the PCE is described in
[I-D.ietf-pce-pce-initiated-lsp].

This document introduces a generic mechanism to create a grouping of
LSPs. This grouping can then be used to define associations between
sets of LSPs or between a set of LSPs and a set of attributes (such
as configuration parameters or behaviors), and is equally applicable
to the active and passive modes of a stateful PCE and a stateless
PCE.

2. Terminology

This document uses the following terms defined in [RFC5440]: PCC,
PCE, PCEP Peer.

3. Architectural Overview

3.1. Motivation

Stateful PCE provides the ability to update existing LSPs and to
instantiate new ones. To enable support for PCE-controlled make-
before-break and for protection, there is a need to define
associations between LSPs. For example, the association between the
original and the re-optimized path in the make-before-break scenario,
or between the working and protection path in end-to-end protection.
Another use for LSP grouping is for applying a common set of
configuration parameters or behaviors to a set of LSPs.

For a stateless PCE, it might be useful to associate a path
computation request to an association group, thus enabling it to
associate a common set of configuration parameters or behaviors with
the request.

Rather than creating separate mechanisms for each use case, this
draft defines a generic mechanism that can be reused as needed.

3.2. Operation Overview

LSPs are associated with other LSPs with which they interact by
adding them to a common association group. Association groups as
defined in this document can be applied to LSPs originating at the
same head end or different head ends. For LSPs originating at the
same head end, the association can be initiated by either the PCC
(head end) or by a PCE. Only a stateful PCE can initiate an
association for LSPs originating at different head ends. For both
cases, the association is uniquely identified by the combination of
an association identifier and the address of the PCE peer that
created the association.

Multiple types of groups can exist, each with their own identifiers
space. The definition of the different association types and their
behaviors is outside the scope of this document. The establishment
and removal of the association relationship can be done on a per LSP
basis. An LSP may join multiple association groups, of different or
of the same type.

In the case of a stateless PCE, associations are created out of band,
and PCEP peers should be aware of the association and its
significance outside of the protocol.

4. ASSOCIATION Object

4.1. Object Definition

Creation of an association group and modifications to its membership
can be initiated by either the PCE or the PCC. Association groups
and their memberships are defined using the ASSOCIATION object for
stateful PCE.

ASSOCIATION Object-Class is to be assigned by IANA (TBD).

ASSOCIATION Object-Type is 1 for IPv4 and its format is shown in
Figure 1:

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type |            Flags    |R|          Reserved             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Association ID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              IPv4 Association Source                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                   Optional TLVs                             //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1: The IPv4 ASSOCIATION Object format

ASSOCIATION Object-Type is 2 for IPv6 and its format is shown in
Figure 2:
Figure 2: The IPv6 ASSOCIATION Object format

Type: 4 bits - the association type (for example protection). The association type will be defined in separate documents.

Flags: 12 bits - The following flags are currently defined:

R (Removal - 1 bit): when set, the requesting PCE peer requires the removal of an LSP from the association group.

Reserved: MUST be set to 0 and ignored upon receipt.

Association ID: 32 bits - the identifier of the association group. When combined with Type and Association Source, this value uniquely identifies an association group. The value 0xffffffff and 0x0 are reserved. The value 0xffffffff is used to indicate all association groups.

Association Source: 4 or 16 bytes - An IPv4 or IPv6 address, which is associated to the PCE peer that originated the association.

Optional TLVs: Variable - no TLVs are defined in this document.

4.2. Object Encoding in PCEP messages

The ASSOCIATION Object is OPTIONAL and MAY be carried in the Path Computation Update (PCUpd), Path Computation Report (PCRpt) and Path Computation Initiate (PCinit) messages.

When carried in PCRpt message, it is used to report the association group membership information pertaining to a LSP to a stateful PCE. It can also be used to remove an LSP from one or more association groups.
groups by setting the R flag to 1. Unless, a PCE wants to delete an association from an LSP, it does not need to carry the ASSOCIATION object while updating other LSP attributes using the PCUpd message.

The PCRpt message is defined in [I-D.ietf-pce-stateful-pce] and updated as below:

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

<state-report-list> ::= <state-report>[<state-report-list>]
<state-report> ::= [<SRP>]<LSP>[<association-list>]<path>

Where:

<association-list> ::= <ASSOCIATION> [association-list]

When an LSP is delegated to a stateful PCE, the stateful PCE can initiate a new association group for this LSP, or associate it with one or more existing association groups. This is done by including the ASSOCIATION Object in a PCUpd message or in a PCInit message. A stateful PCE can also remove a delegated LSP from one or more association groups by setting the R flag to 1.

The PCUpd message is defined in [I-D.ietf-pce-stateful-pce] and updated as below:

<PCUpd Message> ::= <Common Header> <update-request-list>
Where:

$update-request-list> ::= <update-request>[update-request-list]
$update-request> ::= <SRP><LSP>[<association-list>]<path>

Where: <association-list> ::= <ASSOCIATION> [association-list]

The PCInitiate message is defined in [I-D.ietf-pce-pce-initiated-lsp] and updated as below:
<PCInitiate Message> ::= <Common Header>
    <PCE-initiated-lsp-list>

Where:

<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-instantiation> ::= <SRP>
    <LSP>
    <END-POINTS>
    <ERO>
    [<association-list>]
    [<attribute-list>]

Where:

<association-list> ::=<ASSOCIATION> [<association-list>]

In case of passive stateful or stateless PCE, the ASSOCIATION Object is OPTIONAL and MAY be carried in the Path Computation Request (PCReq) message.

When carried in a PCReq message, the ASSOCIATION Object is used to associate the path computation request to an association group, the association might be further informed via PCRpt message in case of passive stateful PCE later or it might be created out of band in case of stateless PCE.

The PCReq message is defined in [RFC5440] and updated in [I-D.ietf-pce-stateful-pce], it is further updated below for association:
<PCReq Message>::= <Common Header>
                   [<svec-list>]
                   <request-list>

Where:
     <svec-list>::= <SVEC>[<svec-list>]
     <request-list>::= <request>[<request-list>]

     <request>::= <RP>
                   <END-POINTS>
                   [<LSP>]
                   [<LSPA>]
                   [<BANDWIDTH>]
                   [<metric-list>]
                   [<association-list>]
                   [<RRO][<BANDWIDTH>]]
                   [<IRO>]
                   [<LOAD-BALANCING>]

Where:
     <association-list> ::= <ASSOCIATION> [<association-list>]

Note that LSP object MAY be present for the passive stateful PCE.

4.3.  Processing Rules

Both a PCC and a PCE can create one or more association groups for an LSP. But a PCE peer cannot add new members for association group created by another peer. If a PCC receives a PCUpd or a PCInitiate message including an ASSOCIATION Object but the sender address does not match the association source, a PCErr message MUST be sent with Error-Type = TBD2 (Association Error) and Error-value= 1 (association source and sender source mismatch in PCUpd). Error handling for situations such as PCE failures after association groups are created and other scenarios will be included in future versions of this draft.

If a PCE peer does not recognize the ASSOCIATION object, it MUST return a PCErr message with Error-Type "Unknown Object" as described in [RFC5440]. If a PCE peer is unwilling or unable to process the ASSOCIATION object, it MUST return a PCErr message with the Error-Type "Not supported object" and follow the relevant procedures described in [RFC5440].
5. IANA Considerations

The "PCEP Parameters" registry contains a subregistry "PCEP Objects". This document requests IANA to allocate the values from this registry.

<table>
<thead>
<tr>
<th>Object-Class</th>
<th>Value</th>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td></td>
<td>Association</td>
<td>This document</td>
</tr>
</tbody>
</table>

Object-Type

1: IPv4
2: IPv6

This document requests IANA to create a subregistry of the "PCEP Parameters" for the bits carried in the Flags field of the ASSOCIATION object. The subregistry is called "ASSOCIATION Flags Field".

The field contains 12 bits numbered from bit 0 as the most significant bit.

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name: Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>R: Removal</td>
<td>This document</td>
</tr>
</tbody>
</table>

This document defines new Error Type and Error-Value for the following new error conditions:

<table>
<thead>
<tr>
<th>Error-Type</th>
<th>Meaning</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>Error-Value=1: association source and sender source does not match</td>
<td>This document</td>
</tr>
</tbody>
</table>

6. Security Considerations

The security considerations described in [I-D.ietf-pce-stateful-pce] apply to the extensions described in this document. Additional considerations related to a malicious PCE are introduced, as the PCE may now create additional state on the PCC through the creation of association groups.

7. Acknowledgements

We would like to thank Yuji Kamite and Joshua George for their contributions to this document. Also, Thank Venugopal Reddy and Cyril Margaria for their useful comments.
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9. References

9.1. Normative References

[I-D.ietf-pce-pce-initiated-lsp]

[I-D.ietf-pce-stateful-pce]


9.2. Informative References


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Abstract

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[RFC5440] describes the Path Computation Element Protocol PCEP. PCEP enables the communication between a Path Computation Client (PCC) and a Path Control Element (PCE), or between PCE and PCE, for the purpose of computation of Multiprotocol Label Switching (MPLS) as well as Generalized MPLS (GMPLS) for Traffic Engineering Label Switched Path (TE LSP) characteristics.
Stateful pce [I-D.ietf-pce-stateful-pce] specifies a set of extensions to PCEP to enable stateful control of TE LSPs between and across PCEP sessions in compliance with [RFC4657] and focuses on a model where LSPs are configured on the PCC and control over them is delegated to the PCE. The model of operation where LSPs are initiated from the PCE is described in [I-D.ietf-pce-pce-initiated-lsp].

This document introduces a generic mechanism to create a grouping of LSPs. This grouping can then be used to define associations between sets of LSPs or between a set of LSPs and a set of attributes (such as configuration parameters or behaviors), and is equally applicable to the active and passive modes of a stateful PCE and a stateless PCE.

2. Terminology

This document uses the following terms defined in [RFC5440]: PCC, PCE, PCEP Peer.

The following term is defined in this document:

Association Timeout Interval: when a PCEP session is terminated, a PCC waits for this time period before deleting associations created by the PCEP peer.

3. Architectural Overview

3.1. Motivation

Stateful PCE provides the ability to update existing LSPs and to instantiate new ones. To enable support for PCE-controlled make-before-break and for protection, there is a need to define associations between LSPs. For example, the association between the original and the re-optimized path in the make-before break scenario, or between the working and protection path in end-to-end protection. Another use for LSP grouping is for applying a common set of configuration parameters or behaviors to a set of LSPs.

For a stateless PCE, it might be useful to associate a path computation request to an association group, thus enabling it to associate a common set of configuration parameters or behaviors with the request.

Rather than creating separate mechanisms for each use case, this draft defines a generic mechanism that can be reused as needed.
3.2. Operation Overview

LSPs are associated with other LSPs with which they interact by adding them to a common association group. Association groups as defined in this document can be applied to LSPs originating at the same head end or different head ends. For LSPs originating at the same head end, the association can be initiated by either the PCC (head end) or by a PCE. Only a stateful PCE can initiate an association for LSPs originating at different head ends. For both cases, the association is uniquely identified by the combination of an association identifier and the address of the node that created the association.

Multiple types of groups can exist, each with their own identifiers space. The definition of the different association types and their behaviors is outside the scope of this document. The establishment and removal of the association relationship can be done on a per LSP basis. An LSP may join multiple association groups, of different or of the same type.

In the case of a stateless PCE, associations are created out of band, and PCEP peers should be aware of the association and its significance outside of the protocol.

Association groups can be created by both PCC and PCE. When a PCC’s PCEP session with a PCE terminates unexpectedly, the PCC cleans up associations (as per the processing rules in this document).

4. ASSOCIATION Object

4.1. Object Definition

Creation of an association group and modifications to its membership can be initiated by either the PCE or the PCC. Association groups and their memberships are defined using the ASSOCIATION object for stateful PCE.

ASSOCIATION Object-Class is to be assigned by IANA (TBD).

ASSOCIATION Object-Type is 1 for IPv4 and its format is shown in Figure 1:
<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Reserved</td>
<td>Flags</td>
<td>R</td>
<td></td>
</tr>
</tbody>
</table>
| +-----------------------------------------------+
| +-----------------------------------------------+
| | Association type | Association ID |
| +-----------------------------------------------+
| +-----------------------------------------------+
| | IPv4 Association Source | |
| +-----------------------------------------------+
| +-----------------------------------------------+
| | // Optional TLVs | // |

Figure 1: The IPv4 ASSOCIATION Object format

ASSOCIATION Object-Type is 2 for IPv6 and its format is shown in Figure 2:

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Reserved</td>
<td>Flags</td>
<td>R</td>
<td></td>
</tr>
</tbody>
</table>
| +-----------------------------------------------+
| +-----------------------------------------------+
| | Association type | Association ID |
| +-----------------------------------------------+
| +-----------------------------------------------+
| | IPv6 Association Source | |
| +-----------------------------------------------+
| +-----------------------------------------------+
| | // Optional TLVs | // |

Figure 2: The IPv6 ASSOCIATION Object format

Reserved: 16 bits - MUST be set to 0 and ignored upon receipt.

Flags: 16 bits - The following flags are currently defined:

R (Removal - 1 bit): when set, the requesting PCE peer requires the removal of an LSP from the association group.

Association type: 16 bits - the association type (for example protection). The association type will be defined in separate documents.
Association ID: 16 bits - the identifier of the association group. When combined with Type and Association Source, this value uniquely identifies an association group. The value 0xffff and 0x0 are reserved. The value 0xffffffff is used to indicate all association groups.

Association Source: 4 or 16 bytes - An IPv4 or IPv6 address, which is associated to the node that originated the association.

Optional TLVs: The optional TLVs follow the PCEP TLV format of [RFC5440]. This document defines two optional TLVs.

4.1.1. Global Association Source TLV

The Global Association Source TLV is an optional TLV for use in the Association Object.

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Type                  |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Global Association Source                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

Figure 3: The Global Association Source TLV format
```

Type: To be allocated by IANA

Length: Fixed value of 4 bytes

Global Association Source: as defined in [RFC6780]

4.1.2. Extended Association ID TLV

The Extended Association ID TLV is an optional TLV for use in the Association Object.
Figure 4: The Extended Association ID TLV format

Type: To be allocated by IANA

Length: variable

Extended Association ID: as defined in [RFC6780]

4.2. Object Encoding in PCEP messages

The ASSOCIATION Object is OPTIONAL and MAY be carried in the Path Computation Update (PCUpd), Path Computation Report (PCRpt) and Path Computation Initiate (PCinit) messages.

When carried in PCRpt message, it is used to report the association group membership information pertaining to a LSP to a stateful PCE. It can also be used to remove an LSP from one or more association groups by setting the R flag to 1. Unless, a PCE wants to delete an association from an LSP, it does not need to carry the ASSOCIATION object while updating other LSP attributes using the PCUpd message.

The PCRpt message is defined in [I-D.ietf-pce-stateful-pce] and updated as below:

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

   <state-report-list> ::= <state-report>[<state-report-list>]
   
   <state-report> ::= [<SRP>]
      <LSP>
      [<association-list>]
      <path>
   
Where:

   <association-list> ::= <ASSOCIATION> [<association-list>]
When an LSP is delegated to a stateful PCE, the stateful PCE can initiate a new association group for this LSP, or associate it with one or more existing association groups. This is done by including the ASSOCIATION Object in a PCUpd message or in a PCInit message. A stateful PCE can also remove a delegated LSP from one or more association groups by setting the R flag to 1.

The PCUpd message is defined in [I-D.ietf-pce-stateful-pce] and updated as below:

<PCUpd Message> ::= <Common Header> 
<update-request-list>
Where:
<update-request-list> ::= <update-request>[<update-request-list>]
<update-request> ::= <SRP>
<LSP>
[<association-list>]
<path>
Where: <association-list> ::= <ASSOCIATION> [<association-list>]

The PCInitiate message is defined in [I-D.ietf-pce-pce-initiated-lsp] and updated as below:

<PCE-initiate Message> ::= <Common Header>
<PCE-initiated-lsp-list>
Where:
<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-instantiation> ::= <SRP>
<LSP>
<END-POINTS>
<ERO>
[<association-list>]
[<attribute-list>]
Where:
<association-list> ::= <ASSOCIATION> [<association-list>]

In case of passive stateful or stateless PCE, the ASSOCIATION Object is OPTIONAL and MAY be carried in the Path Computation Request (PCReq) message.
When carried in a PCReq message, the ASSOCIATION Object is used to associate the path computation request to an association group, the association might be further informed via PCRpt message in case of passive stateful PCE later or it might be created out of band in case of stateless PCE.

The PCReq message is defined in [RFC5440] and updated in [I-D.ietf-pce-stateful-pce], it is further updated below for association:

\[
\text{<PCReq Message>::= <Common Header>}
\quad \text{[<svec-list>]}
\quad \text{<request-list>}
\]

Where:
\[
\text{<svec-list>::= <SVEC>[<svec-list>]}
\quad \text{<request-list>::= <request>[<request-list>]}
\]

\[
\text{<request>::= <RP>}
\quad \text{<END-POINTS>}
\quad \text{[<LSP>]}
\quad \text{[<LSPA>]}
\quad \text{[<BANDWIDTH>]
\quad \text{[<metric-list>]
\quad \text{[<association-list>]}
\quad \text{[<RRO>[<BANDWIDTH>]]}
\quad \text{[<IRO>]
\quad \text{[<LOAD-BALANCING>]

Where:
\[
\text{<association-list> ::= <ASSOCIATION> [<association-list>]}
\]

Note that LSP object MAY be present for the passive stateful PCE.

4.3. Processing Rules

Both a PCC and a PCE can create one or more association groups for an LSP. But a PCE peer cannot add new members for association group created by another peer. If a PCE peer does not recognize the ASSOCIATION object, it MUST return a PCErr message with Error-Type "Unknown Object" as described in [RFC5440]. If a PCE peer is unwilling or unable to process the ASSOCIATION object, it MUST return a PCErr message with the Error-Type "Not supported object" and follow the relevant procedures described in [RFC5440].

The association timeout interval is as a PCC-local value that can be operator-configured or computed by the PCC based on local policy and is used in the context of cleaning up associations on session failure. The association timeout must be set to a value no larger
than the state timeout interval (defined in [I-D.ietf-pce-stateful-pce]) and larger than the delegation timeout interval (defined in [I-D.ietf-pce-stateful-pce]).

When a PCC’s PCEP session with the PCE terminates unexpectedly, the PCC MUST wait for the association timeout interval before cleaning up the association. If this PCEP session can be re-established before the association timeout interval time expires, no action is taken to clean the association created by this PCE. During the time window of the redelegation timeout interval and the association timeout interval, the PCE, after re-establishing the session, can also ask for redelegation following the procedure defined in [I-D.ietf-pce-stateful-pce] and [I-D.ietf-pce-pce-initiated-lsp]. When the association timeout interval timers expires, the PCC clears all the associations which are not delegated to any PCEs.

Upon LSP delegation revocation, the PCC MAY clear the association created by the related PCE, but in order to avoid traffic loss, it can perform this in a make-before-break fashion, which is the same as what is defined in Stateful pce [I-D.ietf-pce-stateful-pce] for handling LSP state cleanup.

Error handling for situations for multiple PCE scenarios will be included in future versions of this draft.

5. IANA Considerations

The "PCEP Parameters" registry contains a subregistry "PCEP Objects". This document requests IANA to allocate the values from this registry.

<table>
<thead>
<tr>
<th>Object-Class Value</th>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>Association</td>
<td>This document</td>
</tr>
<tr>
<td></td>
<td>Object-Type</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1: IPv4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2: IPv6</td>
<td></td>
</tr>
</tbody>
</table>

This document defines the following new PCEP TLVs:

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>Global Association Source</td>
<td>This document</td>
</tr>
<tr>
<td>TBD</td>
<td>Extended Association Id</td>
<td>This document</td>
</tr>
</tbody>
</table>

This document requests IANA to create a subregistry of the "PCEP Parameters" for the bits carried in the Flags field of the ASSOCIATION object. The subregistry is called "ASSOCIATION Flags Field".
The field contains 12 bits numbered from bit 0 as the most significant bit.

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>R</td>
<td>Removal</td>
<td>This document</td>
</tr>
</tbody>
</table>

6. Security Considerations

The security considerations described in [I-D.ietf-pce-stateful-pce] apply to the extensions described in this document. Additional considerations related to a malicious PCE are introduced, as the PCE may now create additional state on the PCC through the creation of association groups.

7. Acknowledgements

We would like to thank Yuji Kamite and Joshua George for their contributions to this document. Also Thank Venugopal Reddy and Cyril Margaria for their useful comments.

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9. References

9.1. Normative References

[I-D.ietf-pce-pce-initiated-lsp]

[I-D.ietf-pce-stateful-pce]
9.2. Informative References


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Conveying policies associated with traffic engineering paths over PCEP session

draft-sivabalan-pce-policy-identifier-00.txt

Abstract

This document describes a simple extension to the Path Computation Element (PCE) Communication Protocol (PCEP) using which a PCEP speaker can enforce one or more policies on the other PCEP speaker. A policy is represented by a numeric value which can be interpreted only by the receiving PCEP speaker. Using the proposed extension, a path computation client (PCC) can signal one or more policies that must be taken into consideration by a PCE during path computation. Similarly, when initiating or updating a path, a stateful PCE can signal one or more policies (e.g., traffic steering rules) that a PCC is expected to apply to the path.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

Status of This Memo

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

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Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."
1. Introduction

[RFC5440] describes the Path Computation Element Protocol (PCEP) for communication between a Path Computation Client (PCC) and a PCE or between a pair of PCEs. [I-D.ietf-pce-stateful-pce] specifies extension to PCEP that allows a PCC to delegate its LSPs to a PCE. The PCE can then update the state of LSPs delegated to it. [I-D.ietf-pce-pce-initiated-lsp] specifies a mechanism allowing a PCE to dynamically instantiate, maintain, and tear down Label Switched Paths (LSPs) without the need for configuring those LSPs on the PCC. Currently, the LSPs can either be signaled via RSVP-TE or can be segment routed as specified in [I-D.ietf-pce-segment-routing].

As described in the next section, a PCEP speaker may want to influence its PCEP counterpart with respect to path selection and other policies. This document describes a PCEP extension to signal policy identifier represented by numeric value using OPTIONAL PCEP
The specification is applicable to both stateful and stateless PCEP sessions.

2. Motivation

Paths computed using PCEP are subject to various policies on both PCE as well as PCC. For example, in a centralized traffic engineering scenario, network operators may instantiate LSPs and specifies policies for traffic steering, path monitoring, etc., for those LSPs via stateful PCE. Similarly, a PCC can request a path that is diverse from any other path originating from other PCC(s) from a stateful PCE. With a current state of PCEP, introducing such policy requires new PCEP extension. A generic mechanism that allows a PCEP speaker to specify the path policies without the need to know the details of such policies simplifies network operations, avoids frequent software upgrades, as well provides an ability to introduce new policy faster.

Case 1: Policy initiated by PCE and enforced by PCC

Case 2: Policy initiated by PCC and enforced by PCE

Figure 1: Sample use-cases for carrying policies over PCEP session
3. Terminology

The following terminologies are used in this document:

LSP: Label Switched Path.
PCC: Path Computation Client.
PCE: Path Computation Element

PCEP: Path Computation Element Protocol.

TLV: Type, Length, and Value.

4. Policy Identifier TLV

The new optional TLV is called "POLICY-ID-TLV" whose format is shown in the diagram below is defined to indicate the policies applied to a path. This TLV is associated with the RP or SRP objects specified in [RFC5440] and [I-D.ietf-pce-stateful-pce] respectively. The type of this TLV is to be allocated by IANA.

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Type (TBD)           |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Flags    |M|             Policy ID                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
- VENDOR-INFORMATION-TLV (optional) -
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: Format of POLICY-ID-TLV

The TLV is formatted according to the rules specified in [RFC5440]. The body of the POLICY-ID-TLV contains one 1-Octet flags and 3-Octet policy identifier. By default, a policy is OPTIONAL. If the M-flag is set, the policy is considered MANDATORY. This TLV can optionally carry vendor-specific information via VENDOR-INFORMATION-TLV whose format and processing rules are specified in [RFC7470]. The presence of VENDOR-INFORMATION-TLV is detected based on the TLV length, and the content and processing rule of vendor-specific information is outside the scope of this specification.
5. Operation

A single message MAY contain more than one POLICY-ID-TLVs. In case, a speaker receives a message containing multiple POLICY-ID-TLVs with the same policy ID, it MUST ignore all except for the first one it encounters in the message. If a PCEP speaker does not recognize the TLV, it MUST ignore the TLV in accordance with ([RFC5440]). If a PCEP speaker recognizes the TLV but does not support a mandatory policy included in the message, it MUST ignore the whole message and send PCErr with Error-Type = 2 (Capability not supported) as well include the POLICY-ID-TLV corresponding to the unsupported policies.

When requesting a path from a PCE using a PCReq message ([RFC5440]), a PCC MAY include the POLICY-ID-TLV in the RP object. The PCE MUST take into account all the policies included in the PCReq otherwise it MUST ignore the whole message and send PCErr message as mentioned above.

In the case of stateful PCE, POLICY-ID-TLV MAY be included in PCReq, PCRpt, PCUpd, and PCInitiate messages as well. When including POLICY-ID-TLV in PCRpt message, the SRP object MUST be present even in cases when the SRP-ID-number is the reserved value of 0x00000000.

6. Security Considerations

No additional security measure is required.

7. IANA Considerations

IANA is requested to allocate a new code point in the PCEP TLV Type Indicators registry, as follows:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>POLICY-ID-TLV</td>
<td>This document</td>
</tr>
</tbody>
</table>

8. Acknowledgements

9. Normative References

[I-D.ietf-pce-pce-initiated-lsp]


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Abstract

This document introduces extensions of PCEP Link-State to export path segment information to a PCE.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

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1. Introduction

PCE-LS [I-D.dhodylee-pce-pcep-te-data-extn] is designed to collect
topology information and TED across IGP domains. In order to better
support SR-TE, this document introduces extensions of PCEP-LS to
export path segment information.

2. PCEP Extensions for Segment Routing

PCEP-LS [I-D.dhodylee-pce-pcep-te-data-extn] introduces new message
type and new object to accommodate link-state information in PCEP.
This document defines new additional TLVs to accommodate segment
routing information. The value portion of these new TLVs can reuse
the structure defined in [I-D.ietf-isis-segment-routing-extensions]
and [I-D.ietf-idr-bgpls-segment-routing-epe].

2.1. Node Attribute TLVs

New

optional, non-transitive node attribute TLVs are defined for carrying
segment routing information and are listed as below:
Table 1: Node Attribute TLVs

2.2. Link Attribute TLVs

New optional, non-transitive link attribute TLVs are defined for carrying segment routing information and are listed below:

Table 2: Link Attribute TLVs

2.3. Prefix Attribute TLVs

A new optional, non-transitive link attribute TLV is defined for carrying segment routing information and are listed below:

Table 3: Prefix Attribute TLVs
3. Operational Considerations

The procedure for segment routing information reporting from PCC to PCE will follow those defined in [I-D.dhodylee-pce-pcep-te-data-extn].

4. IANA Considerations

TBD.

5. Security Considerations

This document does not introduce new security threat.

6. References

6.1. Normative References

[I-D.dhodylee-pce-pcep-te-data-extn]

[I-D.ietf-idr-bgpls-segment-routing-epe]

[I-D.ietf-isis-segment-routing-extensions]

[I-D.ietf-spring-segment-routing]

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