

PCE Working Group  
Internet-Draft  
Intended status: Standards Track  
Expires: December 11, 2016

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June 9, 2016

Path Computation Element (PCE) Protocol Extensions for Stateful PCE  
usage for Point-to-Multipoint Traffic Engineering Label Switched Paths  
draft-palle-pce-stateful-pce-p2mp-09

#### Abstract

The Path Computation Element (PCE) has been identified as an appropriate technology for the determination of the paths of point-to-multipoint (P2MP) TE LSPs. This document provides extensions required for Path Computation Element communication Protocol (PCEP) so as to enable the usage of a stateful PCE capability in supporting P2MP TE LSPs.

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## 1. Introduction

As per [RFC4655], the Path Computation Element (PCE) is an entity that is capable of computing a network path or route based on a network graph, and applying computational constraints. A Path Computation Client (PCC) may make requests to a PCE for paths to be computed.

[RFC4857] describes how to set up point-to-multipoint (P2MP) Traffic Engineering Label Switched Paths (TE LSPs) for use in Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) networks. The PCE has been identified as a suitable application for the computation of paths for P2MP TE LSPs ([RFC5671]).

The PCEP is designed as a communication protocol between PCCs and PCEs for point-to-point (P2P) path computations and is defined in [RFC5440]. The extensions of PCEP to request path computation for P2MP TE LSPs are described in [RFC6006].

Stateful PCEs are shown to be helpful in many application scenarios, in both MPLS and GMPLS networks, as illustrated in [I-D.ietf-pce-stateful-pce-app]. These scenarios apply equally to P2P and P2MP TE LSPs. [I-D.ietf-pce-stateful-pce] provides the

fundamental extensions needed for stateful PCE to support general functionality for P2P TE LSP. [I-D.ietf-pce-pce-initiated-lsp] provides the an extensions needed for stateful PCE-initiated P2P TE LSP. Complementarily, this document focuses on the extensions that are necessary in order for the deployment of stateful PCEs to support P2MP TE LSPs. This document describes the setup, maintenance and teardown of PCE-initiated P2MP LSPs under the stateful PCE model.

### 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

Terminology used in this document is same as terminology used in [I-D.ietf-pce-stateful-pce], [I-D.ietf-pce-pce-initiated-lsp], and [RFC6006].

## 3. Supporting P2MP TE LSP for Stateful PCE

### 3.1. Motivation

[I-D.ietf-pce-stateful-pce-app] presents several use cases, demonstrating scenarios that benefit from the deployment of a stateful PCE including optimization, recovery, etc which are equally applicable to P2MP TE LSPs. [I-D.ietf-pce-stateful-pce] defines the extensions to PCEP for P2P TE LSPs. Complementarily, this document focuses on the extensions that are necessary in order for the deployment of stateful PCEs to support P2MP TE LSPs.

In addition to that, the stateful nature of a PCE simplifies the information conveyed in PCEP messages since it is possible to refer to the LSPs via PLSP-ID ([I-D.ietf-pce-stateful-pce]). For P2MP this is an added advantage, where the size of message is much larger. In case of stateless PCE, a modification of P2MP tree requires encoding of all leaves along with the paths in PCReq message, but using a stateful PCE with P2MP capability, the PCEP message can be used to convey only the modifications (the other information can be retrieved from the P2MP LSP identifier in the LSP database (LSPDB)).

In environments where the P2MP TE LSP placement needs to change in response to application demands, it is useful to support dynamic creation and tear down of P2MP TE LSPs. The ability for a PCE to trigger the creation of P2MP TE LSPs on demand can be seamlessly integrated into a controller-based network architecture, where intelligence in the controller can determine when and where to set up

paths. Section 3 of [I-D.ietf-pce-pce-initiated-lsp] further describes the motivation behind the PCE-Initiation capability, which are equally applicable for P2MP TE LSPs.

### 3.2. Objectives

The objectives for the protocol extensions to support P2MP TE LSP for stateful PCE are same as the objectives described in section 3.2 of [I-D.ietf-pce-stateful-pce].

## 4. Functions to Support P2MP TE LSPs for Stateful PCEs

[I-D.ietf-pce-stateful-pce] specifies new functions to support a stateful PCE. It also specifies that a function can be initiated either from a PCC towards a PCE (C-E) or from a PCE towards a PCC (E-C).

This document extends these functions to support P2MP TE LSPs.

Capability Advertisement (E-C,C-E): both the PCC and the PCE must announce during PCEP session establishment that they support PCEP Stateful PCE extensions for P2MP using mechanisms defined in Section 5.2.

LSP State Synchronization (C-E): after the session between the PCC and a stateful PCE with P2MP capability is initialized, the PCE must learn the state of a PCC's P2MP TE LSPs before it can perform path computations or update LSP attributes in a PCC.

LSP Update Request (E-C): a stateful PCE with P2MP capability requests modification of attributes on a PCC's P2MP TE LSP.

LSP State Report (C-E): a PCC sends an LSP state report to a PCE whenever the state of a P2MP TE LSP changes.

LSP Control Delegation (C-E,E-C): a PCC grants to a PCE the right to update LSP attributes on one or more P2MP TE LSPs; the PCE becomes the authoritative source of the LSP's attributes as long as the delegation is in effect (See Section 5.7 of [I-D.ietf-pce-stateful-pce]); the PCC may withdraw the delegation or the PCE may give up the delegation at any time.

PCE-initiated LSP instantiation (E-C): a PCE sends an LSP Initiate Message to a PCC to instantiate or delete a P2MP TE LSP.

## 5. Architectural Overview of Protocol Extensions

### 5.1. Extension of PCEP Messages

New PCEP messages are defined in [I-D.ietf-pce-stateful-pce] to support stateful PCE for P2P TE LSPs. In this document these messages are extended to support P2MP TE LSPs.

**Path Computation State Report (PCRpt):** Each P2MP TE LSP State Report in a PCRpt message can contain actual P2MP TE LSP path attributes, LSP status, etc. An LSP State Report carried on a PCRpt message is also used in delegation or revocation of control of a P2MP TE LSP to/from a PCE. The extension of PCRpt message is described in Section 6.1.

**Path Computation Update Request (PCUpd):** Each P2MP TE LSP Update Request in a PCUpd message MUST contain all LSP parameters that a PCE wishes to set for a given P2MP TE LSP. An LSP Update Request carried on a PCUpd message is also used to return LSP delegations if at any point PCE no longer desires control of a P2MP TE LSP. The PCUpd message is described in Section 6.2.

A new PCEP message is defined in [I-D.ietf-pce-pce-initiated-lsp] to support stateful PCE instantiation of P2P TE LSPs. In this document this message is extended to support P2MP TE LSPs.

**Path Computation LSP Initiate Message (PCInitiate):** is a PCEP message sent by a PCE to a PCC to trigger P2MP TE LSP instantiation or deletion. The PCInitiate message is described in Section 6.5.

### 5.2. Capability Advertisement

During PCEP Initialization Phase, as per Section 7.1.1 of [I-D.ietf-pce-stateful-pce], PCEP speakers advertises Stateful capability via Stateful PCE Capability TLV in open message. Two new flags are defined for the STATEFUL-PCE-CAPABILITY TLV defined in [I-D.ietf-pce-stateful-pce] and updated in [I-D.ietf-pce-pce-initiated-lsp] and [I-D.ietf-pce-stateful-sync-optimizations].

Three new bits N (P2MP-CAPABILITY), M (P2MP-LSP-UPDATE-CAPABILITY), and P (P2MP-LSP-INSTANTIATION-CAPABILITY) are added in this document:

N (P2MP-CAPABILITY - 1 bit): if set to 1 by a PCC, the N Flag indicates that the PCC is willing to send P2MP LSP State Reports whenever P2MP LSP parameters or operational status changes.; if set to 1 by a PCE, the N Flag indicates that the PCE is interested

in receiving LSP State Reports whenever LSP parameters or operational status changes. The P2MP-CAPABILITY Flag must be advertised by both a PCC and a PCE for PCRpt messages P2MP extension to be allowed on a PCEP session.

M (P2MP-LSP-UPDATE-CAPABILITY - 1 bit): if set to 1 by a PCC, the M Flag indicates that the PCC allows modification of P2MP LSP parameters; if set to 1 by a PCE, the M Flag indicates that the PCE is capable of updating P2MP LSP parameters. The P2MP-LSP-UPDATE-CAPABILITY Flag must be advertised by both a PCC and a PCE for PCUpd messages P2MP extension to be allowed on a PCEP session.

P (P2MP-LSP-INSTITIATION-CAPABILITY - 1 bit): If set to 1 by a PCC, the P Flag indicates that the PCC allows instantiation of an P2MP LSP by a PCE. If set to 1 by a PCE, the P flag indicates that the PCE supports P2MP LSP instantiation. The P2MP-LSP-INSTITIATION-CAPABILITY flag must be set by both PCC and PCE in order to support PCE-initiated P2MP LSP instantiation.

A PCEP speaker should continue to advertise the basic P2MP capability via mechanisms as described in [RFC6006].

### 5.3. IGP Extensions for Stateful PCE P2MP Capabilities Advertisement

When PCCs are LSRs participating in the IGP (OSPF or IS-IS), and PCEs are either LSRs or servers also participating in the IGP, an effective mechanism for PCE discovery within an IGP routing domain consists of utilizing IGP advertisements. Extensions for the advertisement of PCE Discovery Information are defined for OSPF and for IS-IS in [RFC5088] and [RFC5089] respectively.

The PCE-CAP-FLAGS sub-TLV, defined in [RFC5089], is an optional sub-TLV used to advertise PCE capabilities. It MAY be present within the PCED sub-TLV carried by OSPF or IS-IS. [RFC5088] and [RFC5089] provide the description and processing rules for this sub-TLV when carried within OSPF and IS-IS, respectively.

The format of the PCE-CAP-FLAGS sub-TLV is included below for easy reference:

Type: 5

Length: Multiple of 4.

Value: This contains an array of units of 32 bit flags with the most significant bit as 0. Each bit represents one PCE capability.

PCE capability bits are defined in [RFC5088]. This document defines new capability bits for the stateful PCE with P2MP as follows:

Bit	Capability
TBD	Active Stateful PCE with P2MP
TBD	Passive Stateful PCE with P2MP
TBD	PCE-Initiation with P2MP

Note that while active, passive or initiation stateful PCE with P2MP capabilities may be advertised during discovery, PCEP Speakers that wish to use stateful PCEP MUST advertise stateful PCEP capabilities during PCEP session setup, as specified in the current document. A PCC MAY initiate stateful PCEP P2MP capability advertisement at PCEP session setup even if it did not receive any IGP PCE capability advertisements.

#### 5.4. State Synchronization

State Synchronization operations described in Section 5.6 of [I-D.ietf-pce-stateful-pce] are applicable for P2MP TE LSPs as well.

#### 5.5. LSP Delegation

LSP delegation operations described in Section 5.7 of [I-D.ietf-pce-stateful-pce] are applicable for P2MP TE LSPs as well.

#### 5.6. LSP Operations

##### 5.6.1. Passive Stateful PCE

LSP operations for passive stateful PCE described in Section 5.8.1 of [I-D.ietf-pce-stateful-pce] are applicable for P2MP TE LSPs as well.

The Path Computation Request and Response message format for P2MP TE LSPs is described in Section 3.4 and Section 3.5 of [RFC6006] respectively.

The Request and Response message for P2MP TE LSPs are extended to support encoding of LSP object, so that it is possible to refer to a LSP with a unique identifier and simplify the PCEP message exchange. For example, incase of modification of one leaf in a P2MP tree, there should be no need to carry the full P2MP tree in PCReq message.

The extension for the Request and Response message for passive stateful operations on P2MP TE LSPs are described in Section 6.3 and Section 6.4. The extension for the Path Computation LSP State Report (PCRpt) message is described in Section 6.1.



### 5.6.2. Active Stateful PCE

LSP operations for active stateful PCE described in Section 5.8.2 of [I-D.ietf-pce-stateful-pce] are applicable for P2MP TE LSPs as well.

The extension for the Path Computation LSP Update (PCUpd) message for active stateful operations on P2MP TE LSPs are described in Section 6.2.

### 5.6.3. PCE-Initiated LSP

As per section 5.1 of [I-D.ietf-pce-pce-initiated-lsp], the PCE sends a Path Computation LSP Initiate Request (PCInitiate) message to the PCC to suggest instantiation or deletion of a P2P TE LSP. This document extends the PCInitiate message to support P2MP TE LSP (see details in Section 6.5).

P2MP TE LSP suggested instantiation and deletion operations are same as P2P LSP as described in section 5.3 and 5.4 of [I-D.ietf-pce-pce-initiated-lsp].

#### 5.6.3.1. P2MP TE LSP Instantiation

The Instantiation operation of P2MP TE LSP is same as defined in section 5.3 of [I-D.ietf-pce-pce-initiated-lsp] including handling of PLSP-ID, SYMBOLIC-PATH-NAME TLV etc. Rules of processing and error codes remains unchanged. The N bit MUST be set in LSP object in PCInitiate message by PCE to specify the instantiation is for P2MP TE LSP.

Though N bit is set in the LSP object, P2MP-LSP-IDENTIFIER TLV MUST NOT be included in the LSP object in PCInitiate message as it SHOULD be generated by PCC and carried in PCRpt message.

#### 5.6.3.2. P2MP TE LSP Deletion

The deletion operation of P2MP TE LSP is same as defined in section 5.4 of [I-D.ietf-pce-pce-initiated-lsp] by sending an LSP Initiate Message with an LSP object carrying the PLSP-ID of the LSP to be removed and an SRP object with the R flag set (LSP-REMOVE as per section 5.2 of [I-D.ietf-pce-pce-initiated-lsp]). Rules of processing and error codes remains unchanged.

#### 5.6.3.3. Adding and Pruning Leaves for the P2MP TE LSP

Adding of new leaves and Pruning of old Leaves for the PCE initiated P2MP TE LSP MUST be carried in PCUpd message and SHOULD refer Section 6.2 for P2MP TE LSP extensions. As defined in [RFC6006],

leaf type = 1 for adding of new leaves, leaf type = 2 for pruning of old leaves of P2MP END-POINTS Object are used in PCUpd message.

PCC MAY use the Incremental State Update mechanisms as described in [RFC4875] to signal adding and pruning of leaves.

#### 5.6.3.4. P2MP TE LSP Delegation and Cleanup

P2MP TE LSP delegation and cleanup operations are same as defined in section 6 of [I-D.ietf-pce-pce-initiated-lsp]. Rules of processing and error codes remains unchanged.

### 6. PCEP Message Extensions

#### 6.1. The PCRpt Message

As per Section 6.1 of [I-D.ietf-pce-stateful-pce], PCRpt message is used to report the current state of a P2P TE LSP. This document extends the PCRpt message in reporting the status of P2MP TE LSP.

The format of PCRpt message is as follows:

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

Where:

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

```

<state-report> ::= [<SRP>]
                  <LSP>
                  <end-point-path-pair-list>
                  <attribute-list>

```

Where:

```
<end-point-path-pair-list> ::=
    [ <END-POINTS> ]
    [ <S2LS> ]
    <intended_path>
    [ <actual_path> ]
    [ <end-point-path-pair-list> ]
```

$$\langle \text{intended\_path} \rangle ::= (\langle \text{ERO} \rangle | \langle \text{SERO} \rangle) \\ [\langle \text{intended\_path} \rangle]$$
$$\langle \text{actual\_path} \rangle ::= (\langle \text{RRO} \rangle | \langle \text{SRRO} \rangle) \\ [\langle \text{actual\_path} \rangle]$$

`<attribute-list>` is defined in [RFC5440] and extended by PCEP extensions.

The P2MP END-POINTS object defined in [RFC6006] is mandatory for specifying address of P2MP leaves grouped based on leaf types.

- o New leaves to add (leaf type = 1)
- o Old leaves to remove (leaf type = 2)
- o Old leaves whose path can be modified/reoptimized (leaf type = 3)
- o Old leaves whose path must be left unchanged (leaf type = 4)

When reporting the status of a P2MP TE LSP, the destinations are grouped in END-POINTS object based on the operational status (O field in S2LS object) and leaf type (in END-POINTS). This way the leaves that share the same operational status are grouped together. For reporting the status of delegated P2MP TE LSP, leaf-type = 3, where as for non-delegated P2MP TE LSP, leaf-type = 4 is used.

For delegated P2MP TE LSP configuration changes are reported via PCRpt message. For example, adding of new leaves END-POINTS (leaf-type = 1) is used where as removing of old leaves (leaf-type = 2) is used.

Note that we preserve compatibility with the [I-D.ietf-pce-stateful-pce] definition of <state-report>. At least one instance of <END-POINTS> MUST be present in this message for P2MP LSP.

During state synchronization, the PCRpt message must report the status of the full P2MP TE LSP.

The S2LS object MUST be carried in PCRpt message along with END-POINTS object when N bit is set in LSP object for P2MP TE LSP. If the S2LS object is missing, the receiving PCE MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=TBD (S2LS object missing). If the END-POINTS object is missing, the receiving PCE MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=3 (END-POINTS object missing) (defined in [RFC5440]).

## 6.2. The PCUpd Message

As per Section 6.2 of [I-D.ietf-pce-stateful-pce], PCUpd message is used to update P2P TE LSP attributes. This document extends the PCUpd message in updating the attributes of P2MP TE LSP.

The format of a PCUpd message is as follows:

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

Where:

```
<update-request-list> ::= <update-request>
                        [<update-request-list>]
```

```
<update-request> ::= <SRP>
                        <LSP>
                        <end-point-path-pair-list>
```

<attribute-list>

Where:

```
<end-point-path-pair-list> ::=
                        [<END-POINTS>]
                        <path>
                        [<end-point-path-pair-list>]
```

```
<path> ::= (<ERO>|<SERO>)
            [<path>]
```

<attribute-list> is defined in [RFC5440] and extended by PCEP extensions.

Note that we preserve compatibility with the [I-D.ietf-pce-stateful-pce] definition of <update-request>.

The PCC MAY use the make-before-break or sub-group-based procedures described in [RFC4875] based on a local policy decision.

The END-POINTS object MUST be carried in PCUpd message when N bit is set in LSP object for P2MP TE LSP. If the END-POINTS object is missing, the receiving PCC MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=3 (END-POINTS object missing) (defined in [RFC5440]).

### 6.3. The PCReq Message

As per Section 3.4 of [RFC6006], PCReq message is used for a P2MP path computation request. This document extends the PCReq message such that a PCC MAY include the LSP object in the PCReq message if the stateful PCE P2MP capability has been negotiated on a PCEP session between the PCC and a PCE.

The format of PCReq message is as follows:

```

<PCReq Message> ::= <Common Header>
                    <request>

```

where:

```

<request> ::= <RP>
              <end-point-rro-pair-list>
              [<LSP>]
              [<OF>]
              [<LSPA>]
              [<BANDWIDTH>]
              [<metric-list>]
              [<IRO>]
              [<LOAD-BALANCING>]

```

where:

```

<end-point-rro-pair-list> ::= <END-POINTS> [<RRO-List>] [<BANDWIDTH>]
                               [<end-point-rro-pair-list>]

```

```

<RRO-List> ::= (<RRO> | <SRRO>) [<BANDWIDTH>] [<RRO-List>]

```

```

<metric-list> ::= <METRIC> [<metric-list>]

```

#### 6.4. The PCRep Message

As per Section 3.5 of [RFC6006], PCRep message is used for a P2MP path computation reply. This document extends the PCRep message such that a PCE MAY include the LSP object in the PCRep message if the stateful PCE P2MP capability has been negotiated on a PCEP session between the PCC and a PCE.

The format of PCRep message is as follows:

```
<PCRep Message> ::= <Common Header>
                     <response>
```

```
<response> ::= <RP>
               [<end-point-path-pair-list>]
               [<NO-PATH>]
               [<attribute-list>]
```

where:

```
<end-point-path-pair-list> ::=
    [<END-POINTS>]<path>[<end-point-path-pair-list>]
```

```
<path> ::= (<ERO>|<SERO>) [<path>]
```

```
<attribute-list> ::= [<LSP>]
                     [<OF>]
                     [<LSPA>]
                     [<BANDWIDTH>]
                     [<metric-list>]
                     [<IRO>]
```

#### 6.5. The PCInitiate message

As defined in section 5.1 of [I-D.ietf-pce-pce-initiated-lsp], PCE sends a PCInitiate message to a PCC to recommend instantiation of a P2P TE LSP, this document extends the format of PCInitiate message for the creation of P2MP TE LSPs but the creation and deletion operations of P2MP TE LSP are same to the P2P TE LSP.

The format of PCInitiate message is as follows:

```
<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-point-path-pair-list>
                                       [<attribute-list>]
```

```
<PCE-initiated-lsp-deletion> ::= <SRP>
                                   <LSP>
```

Where:

```
<end-point-path-pair-list> ::=
    [<END-POINTS>]
    <path>
    [<end-point-path-pair-list>]
```

```
<path> ::= (<ERO> | <SERO>)
            [<path>]
```

<attribute-list> is defined in [RFC5440] and extended by PCEP extensions.

The PCInitiate message with an LSP object with N bit (P2MP) set is used to convey operation on a P2MP TE LSP. The SRP object is used to correlate between initiation requests sent by the PCE and the error reports and state reports sent by the PCC as described in [I-D.ietf-pce-stateful-pce].

The END-POINTS object MUST be carried in PCInitiate message when N bit is set in LSP object for P2MP TE LSP. If the END-POINTS object is missing, the receiving PCC MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=3 (END-POINTS object missing) (defined in [RFC5440]).



## 6.6. Example

### 6.6.1. P2MP TE LSP Update Request

LSP Update Request message is sent by an active stateful PCE to update the P2MP TE LSP parameters or attributes. An example of a PCUpd message for P2MP TE LSP is described below:

```
Common Header
SRP
LSP with P2MP flag set
END-POINTS for leaf type 3
ERO list
```

In this example, a stateful PCE request updation of path taken by some of the leaves in a P2MP tree. The update request uses the END-POINT type 3 (modified/reoptimized). The ERO list represents the S2LS path after modification. The update message does not need to encode the full P2MP tree in this case.

### 6.6.2. P2MP TE LSP Report

LSP State Report message is sent by a PCC to report or delegate the P2MP TE LSP. An example of a PCRpt message for a delegated P2MP TE LSP is described below to add new leaves to an existing P2MP TE LSP:

```
Common Header
LSP with P2MP flag set
END-POINTS for leaf type 1
S2LS (O=DOWN)
ERO list (empty)
```

An example of a PCRpt message for P2MP TE LSP is described below to prune leaves from an existing P2MP TE LSP:

```
Common Header
LSP with P2MP flag set
END-POINTS for leaf type 2
S2LS (O=UP)
ERO list
```

An example of a PCRpt message for a delegated P2MP TE LSP is described below to report status of leaves in an existing P2MP TE LSP:

```
Common Header
LSP with P2MP flag set
END-POINTS for leaf type 3
  S2LS (O=UP)
  ERO list
END-POINTS for leaf type 3
  S2LS (O=DOWN)
  ERO list
```

An example of a PCRpt message for a non-delegated P2MP TE LSP is described below to report status of leaves:

```
Common Header
LSP with P2MP flag set
END-POINTS for leaf type 4
  S2LS (O=ACTIVE)
  ERO list
END-POINTS for leaf type 4
  S2LS (O=DOWN)
  ERO list
```

## 7. PCEP Object Extensions

The PCEP TLV defined in this document is compliant with the PCEP TLV format defined in [RFC5440].

### 7.1. Extension of LSP Object

LSP Object is defined in Section 7.3 of [I-D.ietf-pce-stateful-pce]. It specifies PLSP-ID to uniquely identify an LSP that is constant for the life time of a PCEP session. Similarly for P2MP tunnel, PLSP-ID identify a P2MP TE LSP uniquely. This document adds the following flags to the LSP Object:

N (P2MP bit): If the bit is set to 1, it specifies the message is for P2MP TE LSP which MUST be set in PCRpt or PCUpd message for a P2MP TE LSP.

F (Fragmentation bit): If the bit is set to 1, it specifies the message is fragmented.

If P2MP bit is set, the following P2MP-LSP-IDENTIFIER TLV MUST be present in LSP object.

## 7.2. P2MP-LSP-IDENTIFIER TLV

The P2MP LSP Identifier TLV MUST be included in the LSP object in PCRpt message for RSVP-TE signaled P2MP TE LSPs. If the TLV is missing, the PCE will generate an error with error-type 6 (mandatory object missing) and error-value TBD (P2MP-LSP-IDENTIFIERS TLV missing) and close the PCEP session.

The P2MP LSP Identifier TLV MAY be included in the LSP object in PCUpd message for RSVP-TE signaled P2MP TE LSPs. The special value of all zeros for this TLV is used to refer to all paths pertaining to a particular PLSP-ID.

There are two P2MP LSP Identifier TLVs, one for IPv4 and one for IPv6.

The format of the IPV4-P2MP-LSP-IDENTIFIER TLV is shown in the following figure:

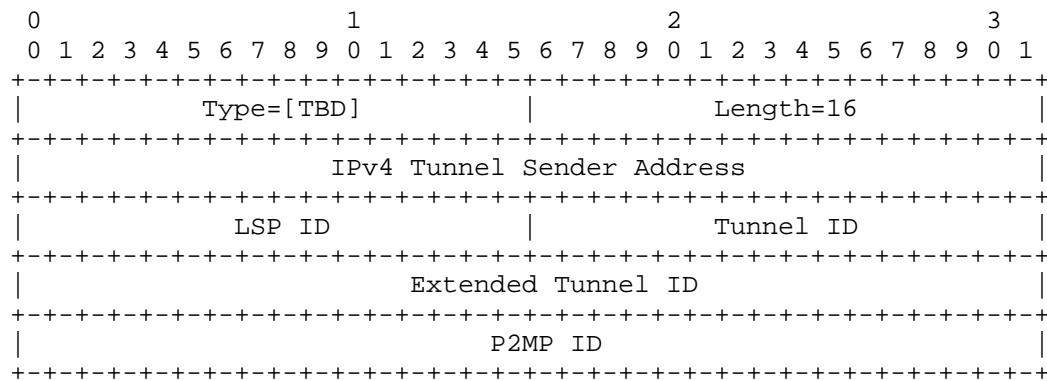


Figure 6: IPV4-P2MP-LSP-IDENTIFIER TLV format

The type (16-bit) of the TLV is [TBD] to be assigned by IANA. The length (16-bit) has a fixed value of 16 octets. The value contains the following fields:

**IPv4 Tunnel Sender Address:** contains the sender node's IPv4 address, as defined in [RFC3209], Section 4.6.2.1 for the LSP\_TUNNEL\_IPv4 Sender Template Object.

**LSP ID:** contains the 16-bit 'LSP ID' identifier defined in [RFC3209], Section 4.6.2.1 for the LSP\_TUNNEL\_IPv4 Sender Template Object.

Tunnel ID: contains the 16-bit 'Tunnel ID' identifier defined in [RFC3209], Section 4.6.1.1 for the LSP\_TUNNEL\_IPv4 Session Object.

Extended Tunnel ID: contains the 32-bit 'Extended Tunnel ID' identifier defined in [RFC3209], Section 4.6.1.1 for the LSP\_TUNNEL\_IPv4 Session Object.

P2MP ID: contains the 32-bit 'P2MP ID' identifier defined in Section 19.1.1 of [RFC4875] for the P2MP LSP Tunnel IPv4 SESSION Object.

The format of the IPV6-P2MP-LSP-IDENTIFIER TLV is shown in the following figure:

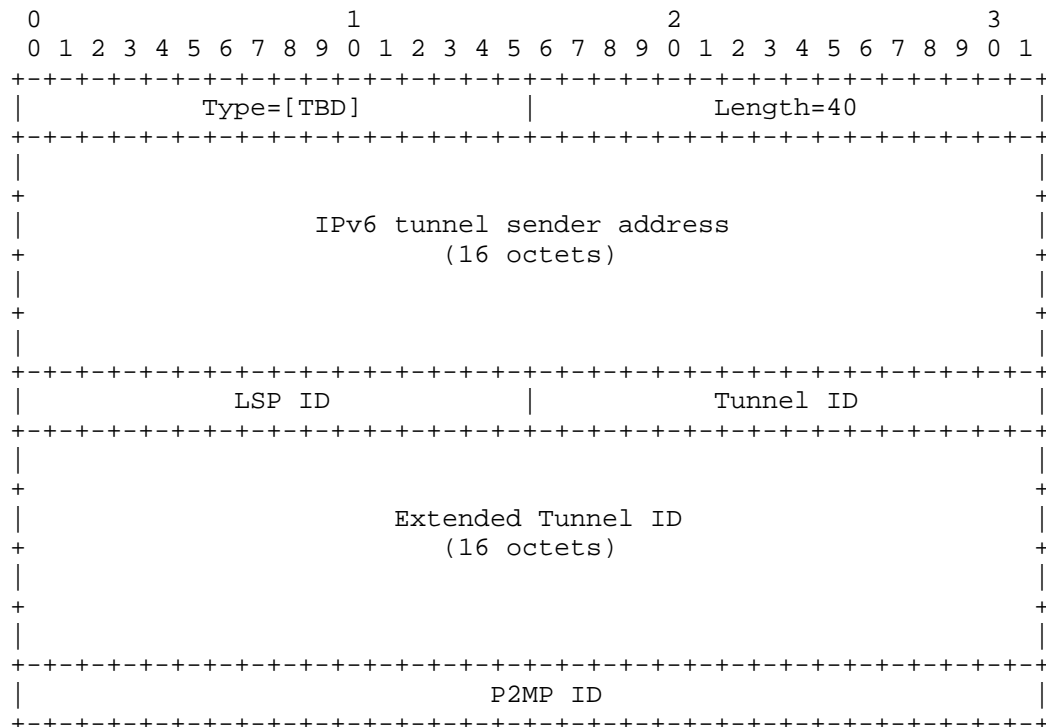


Figure 7: IPV6-P2MP-LSP-IDENTIFIER TLV format

The type of the TLV is [TBD] to be assigned by IANA. The length (16-bit) has a fixed length of 40 octets. The value contains the following fields:

IPv6 Tunnel Sender Address: contains the sender node's IPv6 address, as defined in [RFC3209], Section 4.6.2.2 for the LSP\_TUNNEL\_IPv6 Sender Template Object.

LSP ID: contains the 16-bit 'LSP ID' identifier defined in [RFC3209], Section 4.6.2.2 for the LSP\_TUNNEL\_IPv6 Sender Template Object.

Tunnel ID: contains the 16-bit 'Tunnel ID' identifier defined in [RFC3209], Section 4.6.1.2 for the LSP\_TUNNEL\_IPv6 Session Object.

Extended Tunnel ID: contains the 128-bit 'Extended Tunnel ID' identifier defined in [RFC3209], Section 4.6.1.2 for the LSP\_TUNNEL\_IPv6 Session Object.

P2MP ID: As defined above in IPV4-P2MP-LSP-IDENTIFIERS TLV.

Tunnel ID remains constant over the life time of a tunnel.

### 7.3. S2LS Object

The S2LS (Source-to-Leaves) Object is used to report RSVP-TE state of one or more destinations (leaves) encoded within the END-POINTS object for a P2MP TE LSP. It MUST be carried in PCRpt message along with END-POINTS object when N bit is set in LSP object.

S2LS Object-Class is [TBD].

S2LS Object-Types is 1.

The format of the S2LS object is shown in the following figure:

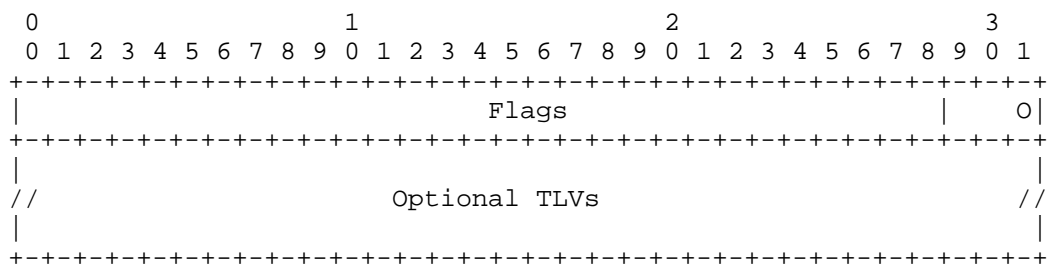


Figure 8: S2LS object format

Flags (32 bits):

O(Operational - 3 bits) the O Field represents the operational status of the group of destinations. The values are as per Operational field in LSP object defined in Section 7.3 of [I-D.ietf-pce-stateful-pce].

When N bit is set in LSP object then the O field in LSP object represents the operational status of the full P2MP TE LSP and the O field in S2LS object represents the operational status of a group of destinations encoded within the END-POINTS object.

Future documents MAY define optional TLVs that MAY be included in the S2LS Object.

## 8. Message Fragmentation

The total PCEP message length, including the common header, is 16 bytes. In certain scenarios the P2MP report and update request may not fit into a single PCEP message (e.g. initial report or update). The F-bit is used in the LSP object to signal that the initial report, update, or initiate message was too large to fit into a single message and will be fragmented into multiple messages. In order to identify the single report or update each message will use the same PLSP-ID. In order to identify that a series of PCInitiate messages represents a single Initiate, each message will use the same PLSP-ID (in this case 0) and SRP-ID-number.

Fragmentation procedure described below for report or update message is similar to [RFC6006] which describes request and response message fragmentation.

### 8.1. Report Fragmentation Procedure

If the initial report is too large to fit into a single report message, the PCC will split the report over multiple messages. Each message sent to the PCE, except the last one, will have the F-bit set in the LSP object to signify that the report has been fragmented into multiple messages. In order to identify that a series of report messages represents a single report, each message will use the same PLSP-ID.

To indicate P2MP message fragmentation errors associated with a P2MP Report, a Error-Type (18) and a new error-value TBD is used if a PCE has not received the last piece of the fragmented message, it should send an error message to the PCC to signal that it has received an incomplete message (i.e., "Fragmented Report failure").

## 8.2. Update Fragmentation Procedure

Once the PCE computes and updates a path for some or all leaves in a P2MP TE LSP, an update message is sent to the PCC. If the update is too large to fit into a single update message, the PCE will split the update over multiple messages. Each update message sent by the PCE, except the last one, will have the F-bit set in the LSP object to signify that the update has been fragmented into multiple messages. In order to identify that a series of update messages represents a single update, each message will use the same PLSP-ID and SRP-ID-number.

To indicate P2MP message fragmentation errors associated with a P2MP Update request, a Error-Type (18) and a new error-value TBD is used if a PCC has not received the last piece of the fragmented message, it should send an error message to the PCE to signal that it has received an incomplete message (i.e., "Fragmented Update failure").

## 8.3. PCInitiate Fragmentation Procedure

Once the PCE initiates to set up the P2MP TE LSP, a PCInitiate message is sent to the PCC. If the PCInitiate is too large to fit into a single PCInitiate message, the PCE will split the PCInitiate over multiple messages. Each PCInitiate message sent by the PCE, except the last one, will have the F-bit set in the LSP object to signify that the PCInitiate has been fragmented into multiple messages. In order to identify that a series of PCInitiate messages represents a single Initiate, each message will use the same PLSP-ID (in this case 0) and SRP-ID-number.

To indicate P2MP message fragmentation errors associated with a P2MP PCInitiate, a Error-Type (18) and a new error-value TBD is used if a PCC has not received the last piece of the fragmented message, it should send an error message to the PCE to signal that it has received an incomplete message (i.e., "Fragmented Instantiation failure").

## 9. Non-Support of P2MP TE LSPs for Stateful PCE

The PCEP protocol extensions described in this document for stateful PCEs with P2MP capability MUST NOT be used if PCE has not advertised its stateful capability with P2MP as per Section 5.2. If the PCEP Speaker on the PCC supports the extensions of this draft (understands the P2MP flag in the LSP object) but did not advertise this capability, then upon receipt of PCUpd message from the PCE, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD (Attempted LSP Update Request for P2MP if active stateful PCE capability for P2MP was not advertised). If the PCEP

Speaker on the PCE supports the extensions of this draft (understands the P2MP flag in the LSP object) but did not advertise this capability, then upon receipt of a PCRpt message from the PCC, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD (Attempted LSP State Report for P2MP if stateful PCE capability for P2MP was not advertised) and it will terminate the PCEP session.

If a Stateful PCE receives a P2MP TE LSP report message and the PCE does not understand the P2MP flag in the LSP object, and therefore the PCEP extensions described in this document, then the Stateful PCE would act as per [I-D.ietf-pce-stateful-pce].

The PCEP protocol extensions described in this document for PCC or PCE with instantiation capability for P2MP TE LSPs MUST NOT be used if PCC or PCE has not advertised its stateful capability with Instantiation and P2MP capability as per Section 5.2. If the PCEP Speaker on the PCC supports the extensions of this draft (understands the P (P2MP-LSP-INSTANTIATION-CAPABILITY) flag in the LSP object) but did not advertise this capability, then upon receipt of PCInitiate message from the PCE, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD (Attempted LSP Instantiation Request for P2MP if stateful PCE instantiation capability for P2MP was not advertised).

## 10. Manageability Considerations

All manageability requirements and considerations listed in [RFC5440], [RFC6006], [I-D.ietf-pce-stateful-pce], and [I-D.ietf-pce-pce-initiated-lsp] apply to PCEP protocol extensions defined in this document. In addition, requirements and considerations listed in this section apply.

### 10.1. Control of Function and Policy

A PCE or PCC implementation MUST allow configuring the stateful PCEP capability, the LSP Update capability, and the LSP Initiation capability for P2MP LSPs.

### 10.2. Information and Data Models

The PCEP MIB module SHOULD be extended to include advertised P2MP stateful capabilities, P2MP synchronization status, and P2MP delegation status etc.



### 10.3. Liveness Detection and Monitoring

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

### 10.4. Verify Correct Operations

Mechanisms defined in this document do not imply any new operation verification requirements in addition to those already listed in [RFC5440], [RFC6006], [I-D.ietf-pce-stateful-pce], and [I-D.ietf-pce-pce-initiated-lsp].

### 10.5. Requirements On Other Protocols

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

### 10.6. 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], [RFC6006], [I-D.ietf-pce-stateful-pce], and [I-D.ietf-pce-pce-initiated-lsp].

## 11. IANA Considerations

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

### 11.1. PCE Capabilities in IGP Advertisements

IANA is requested to allocate new bits in "PCE Capability Flags" registry for stateful PCE with P2MP capability as follows:

Bit	Meaning	Reference
TBD	Active Stateful PCE with P2MP	[This I-D]
TBD	Passive Stateful PCE with P2MP	[This I-D]
TBD	Stateful PCE Initiation with P2MP	[This I-D]

### 11.2. STATEFUL-PCE-CAPABILITY TLV

The following values are defined in this document for the Flags field in the STATEFUL-PCE-CAPABILITY-TLV (defined in [I-D.ietf-pce-stateful-pce]) in the OPEN object:

Bit	Description	Reference
TBD	P2MP-CAPABILITY	This.I-D
TBD	P2MP-LSP-UPDATE-CAPABILITY	This.I-D
TBD	P2MP-LSP-INSTANTIATION-CAPABILITY	This.I-D

### 11.3. Extension of LSP Object

This document requests that a registry is created to manage the Flags field of the LSP object (defined in [I-D.ietf-pce-stateful-pce]). New values are to be assigned by Standards Action [RFC5226]. Each bit should be tracked with the following qualities:

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

The following values are defined in this document:

Bit	Description	Reference
TBD	P2MP	This.I-D
TBD	Fragmentation	This.I-D

### 11.4. Extension of PCEP-Error Object

A new 19 (recommended values) defined in section 8.5 of [I-D.ietf-pce-stateful-pce]. The error-type 6 is defined in [RFC5440] and error-type 18 in [RFC6006]. This document extend the

new Error-Values for those error types for the following error conditions:

Error-Type	Meaning
6	Mandatory Object missing Error-value=TBD: S2LS object missing Error-value=TBD: P2MP-LSP-IDENTIFIER TLV missing
18	P2MP Fragmentation Error Error-value= TBD. Fragmented Report failure Error-value= TBD. Fragmented Update failure Error-value= TBD. Fragmented Instantiation failure
19	Invalid Operation Error-value= TBD. Attempted LSP State Report for P2MP if stateful PCE capability for P2MP was not advertised Error-value= TBD. Attempted LSP Update Request for P2MP if active stateful PCE capability for P2MP was not advertised Error-value= TBD. Attempted LSP Instantiation Request for P2MP if stateful PCE instantiation capability for P2MP was not advertised

Upon approval of this document, IANA is requested to make the assignment of a new error value for the existing "PCEP-ERROR Object Error Types and Values" registry located at <http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-error-object>.

#### 11.5. PCEP TLV Type Indicators

Upon approval of this document, IANA is requested to make the assignment of a new value for the existing "PCEP TLV Type Indicators" registry located at <http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators>. This document defines the following new PCEP TLVs:

Value	Meaning	Reference
TBD	P2MP-IPV4-LSP-IDENTIFIERS	This.I-D
TBD	P2MP-IPV6-LSP-IDENTIFIERS	This.I-D

## 12. Security Considerations

The stateful operations on P2MP TE LSP are more CPU-intensive and also utilize more link bandwidth. In the event of an unauthorized stateful P2MP operations, or a denial of service attack, the subsequent PCEP operations may be disruptive to the network. Consequently, it is important that implementations conform to the relevant security requirements of [RFC5440], [RFC6006] and [I-D.ietf-pce-stateful-pce], and [I-D.ietf-pce-pce-initiated-lsp]. Further [I-D.ietf-pce-pceps] discusses an experimental approach to provide secure transport for PCEP.

## 13. Acknowledgments

Thanks to Quintin Zhao, Avantika and Venugopal Reddy for his comments.

## 14. References

### 14.1. Normative References

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