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**Multicast Tree Setup via PCEP  
draft-li-pce-multicast-02**

Abstract

Multicast forwarding requires per-tree state on certain nodes. Even with BIER, per-tree state is needed on ingress/egress BIER routers (though not needed on transit BIER routers). This documents specifies PCEP protocol to collect tree information (e.g. root, leaf, constraints) to allow a PCE to calculate a tree, and the procedures to set up per-tree forwarding state on relevant nodes for various multicast trees and various replication technologies.

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## [1.](#) Introduction

Currently, during the establishment of multicast services, multicast management information is mainly signaled by PIM [[RFC2362](#)], mLDP [[RFC6388](#)] or BGP [[RFC6514](#)]. The trees/tunnels are set up using the "receiver-initiated join" technique of PIM/mLDP, hop by hop from downstream routers towards the root. The BGP messages are either sent hop by hop between downstream routers and their upstream neighbors, or can be reflected by Route Reflectors (RRs). The control signaling interaction of multicast information is between routers and cannot be managed in a unified manner.

As an alternative to each hop independently determining its upstream router and signaling upstream towards the root (following PIM/mLDP model), the entire tree can be calculated by a centralized controller, and the signaling can be entirely done from the controller.

[[RFC4655](#)] defines a stateful PCE to be one in which the PCE maintains "strict synchronization between the PCE and not only the network states (in term of topology and resource information), but also the set of computed paths and reserved resources in use in the network." [[RFC8231](#)] specifies a set of extensions to PCEP to support state synchronization between PCCs and PCEs.

The controller can serve as a PCE to centrally manage multicast trees and establish states on all tree nodes serving as PCC. This document defines PCEP objects and TLVs to accomplish the multicast source registration/revocation, receiver discovery, multicast tree state update etc. functions.

## **2. Overview**

### **2.1. Different Multicast Trees**

This section discusses various multicast trees like IP, mLDP, SR-P2MP - each with its own tree identification.

#### **2.1.1. IP Multicast**

As stated in [[RFC1112](#)], an IP multicast packet's destination address is a Multicast Group Address and it follows either a source specific tree rooted at the First Hop Router (FHR) or a shared tree rooted at a Rendezvous Point (RP) [[RFC7761](#)]. Each tree is identified by a (source address, group address) pair, where the source address MAY be a wildcard in case of the shared tree. This identification, which is often referred to as (s, g) or (\*, g), is used in both forwarding plane as well as in control plane that sets up the tree, e.g., using Protocol Independent Multicast (PIM) [[RFC7761](#)] [[RFC5015](#)].

Each node on the tree needs to have corresponding forwarding plane state used to forward corresponding traffic and control plane state that is used to set up a tree. Depending on the number of (s, g) and/or (\*, g) trees that a routing domain need to support, serious scaling/convergence problems MAY result.

#### **2.1.2. mLDP/RSVP-TE P2MP Tunnels**

Quite often, some different multicast trees are used for similar purposes and the tree structure are identical or very similar. For example, in an IPTV application, many channels MAY need to be sent from the same headend router to the same set of edge routers close to receivers.

In that case, a set of IP multicast trees can be transported over a fewer set of MPLS P2MP tunnels - either mLDP [[RFC6388](#)] or RSVP-TE P2MP [[RFC4875](#)] tunnels - across an MPLS domain. Inside the MPLS domain, there is no IP multicast tree state but only fewer state for the P2MP tunnels. Outside the MPLS domain, those IP multicast trees still have their per-tree state on each tree node.

An mLDP tree is identified by an mLDP FEC in the control plane. In the context of PCEP signaling, part of or an entire mLDP tunnel can be set up using PCEP from a PCE instead of using hop-by-hop mLDP signaling. In this case the only relevance to mLDP is that mLDP FEC is used to identify the tunnel.

A RSVP-TE P2MP tree is identified by a RSVP Session object in the control plane. While in theory it can also be set up via PCEP signaling from a PCE, it is outside the scope of this document.

In the forwarding plane, there is no difference between an mLDP tunnel and a RSVP-TE P2MP tunnel. A tree is identified by a label - incoming labeled traffic is replicated to a bunch of downstream nodes with a label that identifies the tree to the downstream nodes.

### **2.1.3. SR-P2MP Tunnels**

Segment Routing (SR) [[RFC8402](#)] has two principles:

1. No per-flow/tunnel state inside an SR domain
2. Optional but preferred use of controllers

When it comes to multicast, the only technologies that sticks to principle #1 is BIER [[RFC8279](#)], which does not use per-tree state for forwarding.

SR-P2MP [[I-D.ietf-pim-sr-p2mp-policy](#)] [[I-D.ietf-spring-sr-replication-segment](#)] sticks to principle #2 only, in that PCEs are used to calculate a multicast tree subject to constraints and then direct signaling from PCEs are used to set up the tree instead of using mLDP/RSVP signaling, but per-tree state is still used.

In the control plane, an SR-P2MP is identified by a (root-id, tree-id) tuple. In an SR-MPLS forwarding plane, an SR-P2MP tunnel is not different from mLDP/RSVP-TE P2MP tunnel at all, though the tree-identifying label is called a tree sid.

In an SRv6 forwarding plane, the tree sid is embedded as part of an IPv6 address.

## **2.2. Different Replication Technologies**

For any kind of multicast trees mentioned above, on a particular tree node A, an incoming packet needs to be replicated to a set of downstream nodes B/C/D/E. Note that the upstream and downstream nodes MAY be directly connected or they can be reached via a set of P2P/MP2P tunnels, P2MP tunnels, or via BIER. In the latter case, intermediate nodes do not maintain the per-tree state but they do need to maintain state for the transporting tunnels or BIER.

Now on node A/B/C/D/E, per-tree replication state needs to be set up. In particular on A, depending on the method used to replicate to B/C/D/E, (a combination of) the following replication branches are needed:

- \* A set of outgoing interfaces for native IP forwarding to directly connected nodes from the B/C/D/E set in case of IP multicast tree, and/or,
- \* A set of P2P/MP2P/P2MP tunnels to reach indirectly connected nodes from the B/C/D/E set, and/or,
- \* A BIER bitstring and relevant BIER information to reach some nodes from the B/C/D/E set

In the latter two cases, the replication branches also need relevant information to identify to B/C/D/E which tree a packet is for (e.g., a label for an mLDP or SR-P2MP tree).

### **2.3. Tree Information Discovery**

When a PCE calculates a multicast tree, it needs to collect the tree information like root, leaves and calculation constraints. This MAY be provided to the PCE via a southbound (wrt the PCE) interface from an orchestrator or via northbound PCEP signaling from some PCC nodes (e.g. the root and leaf nodes of the tree). The PCE MAY also participate overlay signaling protocols to collect the information (e.g., [[I-D.zzhang-mvpn-evpn-controller](#)]).

This document only covers the northbound PCEP signaling. The two other methods mentioned above are out of scope of this document.

Whether it is an IP Multicast or mLDP/SR-P2MP Tree, the root, leaves and calculation constraints are encoded the same way but associated with different tree identifications in the PCEP signaling. Specifically, the root and leaves are encoded as IP addresses.

The leaf information can be encoded as a full set of leaves or as addition/removal delta.

#### **2.3.1. Root node Discovery**

When a multicast source accesses to a First Hop Router (FHR), the FHR originates a PCRpt message carrying the Multicast Source Registration (MSR) object defined in [Section 3.3](#), which provides FHR information. FHR, as PCC, delegate the controller as PCE to calculate multicast tree. In the sent PCRpt message, the D bit of LSP Object is set to 1.

### **2.3.2. Leaf node Discovery**

For IP multicast, Last Hop Router (LHR) MAY convert the multicast source and group address carried in the IGMP Join/Leave messages sent by local hosts and VPN information corresponding to local hosts into PCRpt messages and report these information to the controller. Similar to IGMP messages, PIM messages from other domains can also be used as receiver information and be converted into PCRpt messages to be reported to the controller.

For mLDP and SR-P2MP multicast, The corresponding tree identifiers can also be carried in PCRpt messages and reported to the controller.

When the first receiver accesses a Last Hop Router (LHR) to join a multicast tree, or when the last receiver leaves the LHR, the LHR originates a PCRpt message carrying the Multicast Receiver Information (MRI) object defined in [Section 3.4](#), which provides LHR information.

If the receivers locate in different VPN domains, the VPN information associated with the multicast source and multicast destination should also be reported by the LHR and FHR. The VPN information reported by LHRs SHOULD be consistent.

### **2.4. Multicast Tree**

The multicast trees are established with the FHRs of the multicast source as the root of the multicast trees. According to different multicast technologies, the types of multicast trees include labeled tree and BIER tree. Different multicast trees correspond to different processing. This section describes the state update of different multicast operations.

No matter which forwarding technology is used, there is a case that local multicast receivers directly access to FHRs. In this case, FHRs need to forward multicast data for local receivers in the way of native IP without other control information.

In some scenarios, the egresses node needs a VPN forwarding identifier to determine which VRF to forward the packet to. The allocation of VPN forwarding identifier is performed by controller. The scenario of egress assigning VPN tags has not been considered yet. Controller sends the VPN forwarding identifier to ingress and instructs ingress to encapsulate it. The VPN Forwarding Label may be MPLS label or SRv6 segment.

### **2.4.1. Labeled Tree**

For a Labeled multicast tree, whether the forwarding is based on native IP, mLDP or SR-P2MP tunnel, each node needs a tree label to identify a multicast tree. There are three options for tree label assignment:

- \* From each router's SRLB that the controller learns
- \* From the common SRGB that the controller learns
- \* From the controller's local label space

The detailed instruction is as per [\[I-D.ietf-bess-bgp-multicast-controller\]](#). [Section 3.5.1](#) defines two new TLVs to extend the CCI Object-Type support the tree label and VPN Label.

The operations for initiating multicast tree LSPs and downloading labels are consistent with [\[I-D.ietf-pce-sr-p2mp-policy\]](#).

### **2.4.2. BIER Tree**

Different from other forwarding technologies, BIER does not need the transit nodes to maintain the multicast state, and only needs to forward and encapsulate the packets according to the BitString and BIFT. BIFT information can be learned by IGP. For each node of a sub-domain, the BIFT can be configured locally or allocated by BGP controller or PCE. Allocation by PCE is as per [\[I-D.chen-pce-pcep-extension-pce-controller-bier\]](#).

After receiving the BFR information reported from LHRs, the controller combine BFR information of LHRs into a BitString to guide multicast data forwarding.

The controller (PCE) sends the BitString to the FHR via PCInitiate or PCUpd message carrying Tree Forwarding State Synchronization (TFSS) object defined in [Section 3.6](#) to inform the FHR to forward multicast data for a specific multicast tree according to the BitString, and the tree identifier is (\*, g) or (s, g) tuple. Controller also needs to inform FHR to encapsulate VPN forwarding identifier so that LHRs can forward multicast data to specific VRF accordingly.

## **2.5. Multicast Statistics**

Multicast statistics are helpful for multicast service analysis and business development. This section describes how to collect statistics about multicast users.



For each LHR, the statistics consist of two parts, one is the number of local users in the its managed domain, and the other is the number of other managed domains. The sum of these two parts is the number of multicast data that the one LHR needs to duplicate.

LHRs send this information to the controller via PCRpt message carrying Multicast Receiver Statistics (MRS) object. LHRs need report this information to the controller periodically. Once the statistics information of a LHR change, the LHR also needs reports to the controller.

Controller collects the statistics reported by LHRs and MAY periodically informs the FHR of the statistics via PCRpt messages carrying MRS object so that the FHR can feed the statistics back to the multicast source.

### **3. PCEP Object Formats**

#### **3.1. OPEN Object**

##### **3.1.1. STATEFUL-PCE-CAPABILITY TLV**

During the PCEP initialization phase, PCEP speakers advertise stateful capability via the STATEFUL-PCE-CAPABILITY TLV in the OPEN object. Various flags are defined for the STATEFUL-PCE-CAPABILITY TLV defined in [[RFC8231](#)] and updated in [[RFC8232](#)] and [[RFC8281](#)].

A new flag is added in this document, whose code point is TBD1:

MULTICAST-STATE-CAPABILITY bit, if this bit is set to 1 by a PCEP speaker, it indicates that the PCEP speaker supports the capability of these new extensions as specified in this document.

To support the multicast tree state management capabilities described in this document, both PCE and PCC need to set MULTICAST-STATE-CAPABILITY bit. If a PCEP speaker receivers PECP message with the newly defined object, but without the MULTICAST-STATE-CAPABILITY bit set in STATEFUL-PCE-CAPABILITY TLV in the OPEN object, it MUST:

- \* Send a PCErr message with Error-Type=10(Reception of an invalid object) and Error-Value TBD2(MULTICAST-STATE-CAPABILITY bit is not set).
- \* Terminate the PCEP session.

### 3.1.2. PCECC Capability sub-TLV

The PCECC-CAPABILITY sub-TLV is an optional TLV for use in the OPEN Object for PCECC capability advertisement in PATH-SETUP-TYPE-CAPABILITY TLV as specified in [RFC9050].

[I-D.dhody-pce-pcep-extension-pce-controller-p2mp] adds a new flag (M Bit) in the PCECC-CAPABILITY sub-TLV to indicate the support for P2MP in PCECC, which is applicable for multicast tree described in this document as well.

### 3.2. PATH-SETUP-TYPE TLV

The PATH-SETUP-TYPE TLV is defined in [RFC8408]; [RFC9050] defines a PST value for PCECC as '2', which is applicable for multicast tree described in this document as well.

### 3.3. Multicast Source Registration Object

The MSR object is optional and SHOULD contain multicast source information and FHR information. The MSR object SHOULD be carried within a PCRpt message sent by PCC to PCE for registration. The MSR object SHOULD be carried within a PCUpd message sent by PCE to PCC in response to registration.

MSR Object-Class is TBD3. MSR Object-Type is 1. The format of the MSR object body is:

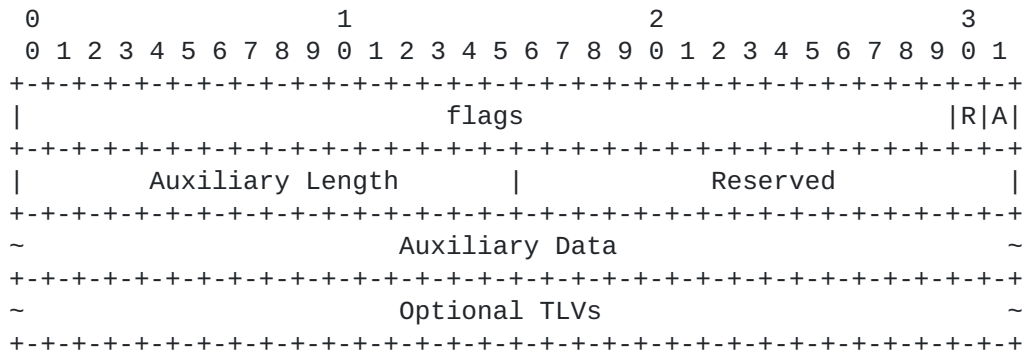


Figure 1: MSR Object Body Format

R (Register flag, 1 bit): The R flag set to 1 indicates that the PCC is registering multicast information to the PCE. The R flag set to 0 indicates that the PCC revokes the registration.

A (Authentication flag, 1 bit): The A flag set to 1 indicates success of registration. The A flag set to 0 indicates failure of registration or revocation of registration. If there is no authentication information, A flag SHOULD also be set to 0.

Auxiliary Length (1 Octet): indicates the length of Auxiliary Data.

Auxiliary Data (Variable length): contains functional data such as authentication information.

MSR object MAY include Multicast Address TLV, mLDP FEC TLV, P2MP SR Policy Association Group Policy Identifiers TLV, and VPN Information TLV. P2MP SR Policy Association Group Policy Identifiers TLV are defined in [I-D.ietf-pce-sr-p2mp-policy]. MSR object carries different TLVs depending on the multicast tree.

3.3.1. Multicast Address TLV

In IP multicast scenarios, Multicast Address TLV SHOULD be included.

The format of the Multicast Address TLV is:

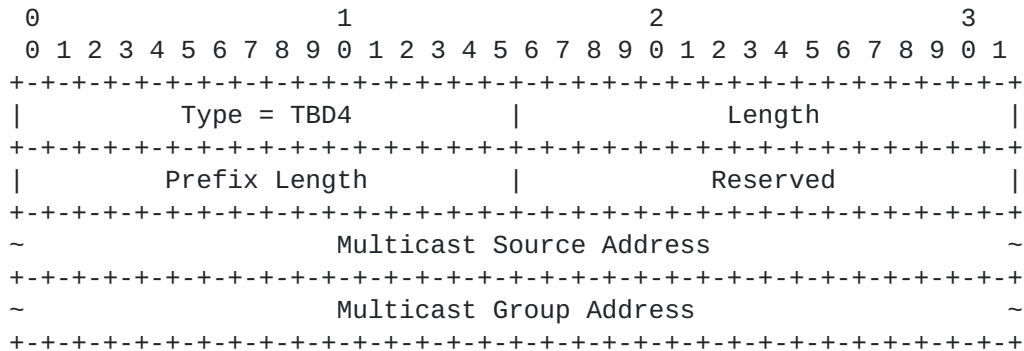


Figure 2: Multicast Address TLV Format

Prefix Length (2 Octets): indicates the length of multicast addresses. the length MAY be 4 Octets, 8 Octets, 16 Octets, or 32 Octets. The multicast source address can be empty, but the multicast group address must be filled. If both the multicast source address and multicast group address exist, they must be both IPv4 and IPv6 addresses.

Multicast Source Address (Variable length): contains IPv4 or IPv6 address of the multicast source.

Multicast Group Address (Variable length): contains IPv4 or IPv6 address of the multicast group.

**3.3.2. mLDP FEC TLV**

In mLDP multicast scenarios, Multicast Address TLV SHOULD be included.

The format of the mLDP FEC TLV is:

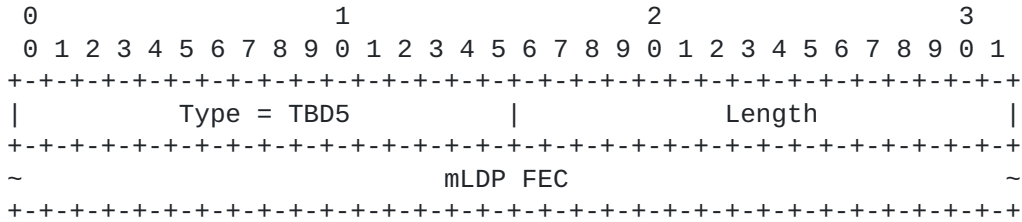


Figure 3: mLDP FEC TLV Format

mLDP FEC (Variable length): carries mLDP FEC.

**3.3.3. VPN Information TLV**

VPN Information TLV is used to report VPN information about multicast sources and receivers. The format of the VPN Information TLV is:

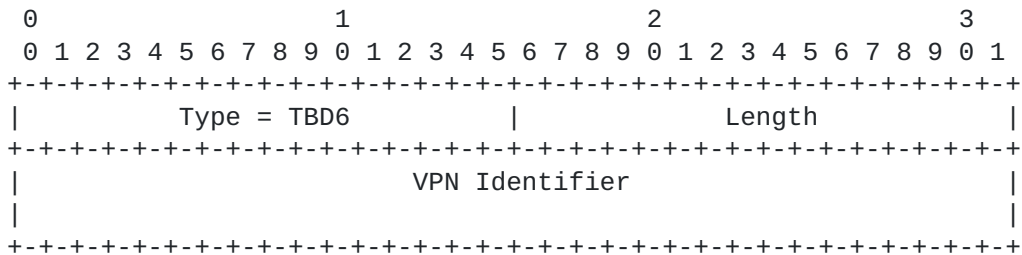


Figure 4: VPN Information TLV Format

VPN Identifier (8 Octets): indicates the VPN which the receiver used.

**3.4. Multicast Receiver Information Object**

The MRI object is optional and SHOULD contain receivers' information for matching the multicast registration information. The MRI object SHOULD be carried within a PCRpt message sent by PCC to PCE for multicast joining or leaving.

MRI Object-Class is TBD7. MRI Object-Type is 1. The format of the MRI object body is:

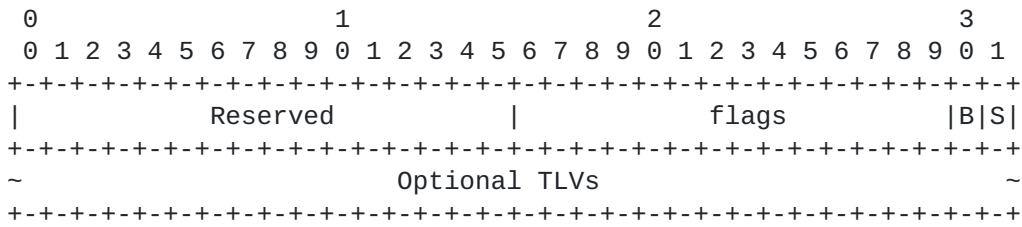


Figure 5: MRI Object Body Format

B(BIER multicast flag, 1 bit): The B flag set to 1 indicates that multicast protocol is BIER. If the B flag set to 1, MRI object SHOULD include BFR information TLV defined in [Section 3.4.1](#).

S(Subscribe flag, 1 bit): The S flag set to 1 indicates that PCC delivers the message requesting to join PCE. The S flag set to 0 indicates that PCC delivers the message requesting to leave to PCE.

MRI object MAY include Multicast Address TLV, mLDP FEC TLV, P2MP SR Policy Association Group Policy Identifiers TLV, VPN Information TLV, and BFR information TLV.

**3.4.1. BFR Information TLV**

BFR Information TLV is used to report router location information in the BIER domain. The format of the BFR Information TLV is:

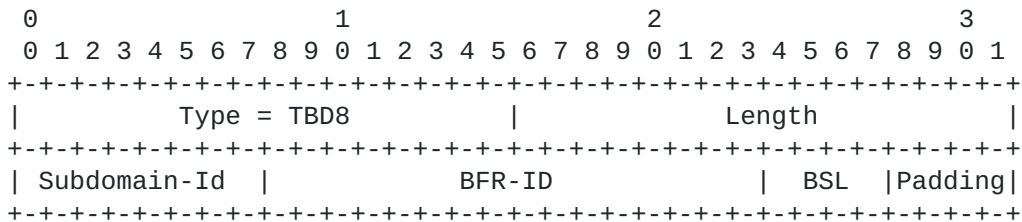


Figure 6: BFR Information TLV Format

Subdomain-Id (1 Octet): Unique value identifying the BIER subdomain.

BFR-ID (2 Octets): Identification of BFR in a subdomain.

BSL (BitString Length, 4 bits): encodes the length in bits of the BitString as per [RFC8296](#), the maximum length of the BitString is 7, it indicates the length of BitString is 4096. It is used to refer to the number of bits in the BitString.

**3.5. CCI Object**

The CCI object [RFC9050] is used by the PCE to specify the forwarding instructions to the PCC and MAY be carried within a PCInitiate or PCRpt message for control information download/report.

The CCI Object Type 1 for MPLS Label is defined in [RFC9050], which is used for the P2MP LSPs as well. For mLDP multicast trees, in addition to forwarding labels, corresponding tree labels or label stacks are required. Therefore, a new TLV is needed to carry tree labels or label stacks. In addition, in order to meet the needs of VPN scenarios, a new TLV with VPN forwarding Identifier is also defined.

**3.5.1. Tree Label TLV**

The format of Tree Label TLV is:

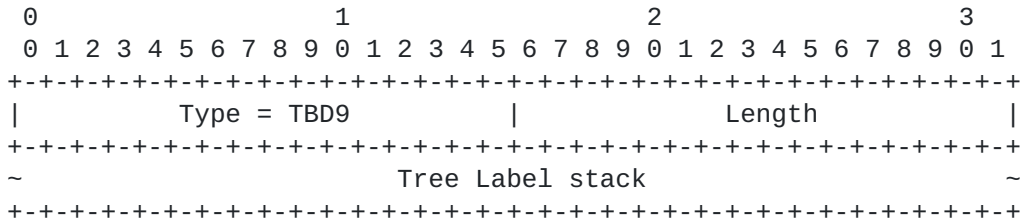


Figure 7: Tree Label TLV Format

Tree Label stack (Variable length): contains tree labels used to identify multicast trees. There are three application scenarios, as per [I-D.ietf-bess-bgp-multicast-controller].

**3.5.2. VPN Forwarding Identifier TLV**

The format of VPN Forwarding Identifier TLV is:

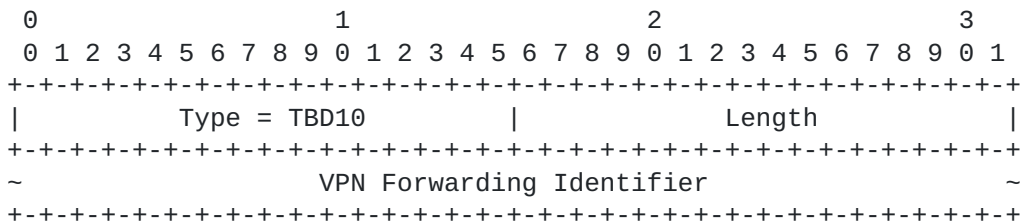


Figure 8: VPN Forwarding Identifier TLV Format

VPN Forwarding Identifier (Variable length): contains MPLS label or IPv6 Segment Identifier with 16 Octets.

**3.6. Tree Forwarding State Synchronization Object**

The TFSS object is optional and SHOULD contain the forwarding state of control plane that the tree node needs to synchronize. The TFSS object SHOULD be carried within a PCInitiate or PCUpd message sent by PCE to PCC, or a PCRpt message sent by PCC to PCE for response.

TFSS Object-Class is TBD11. TFSS Object-Type is 1. The format of the TFSS object body is:

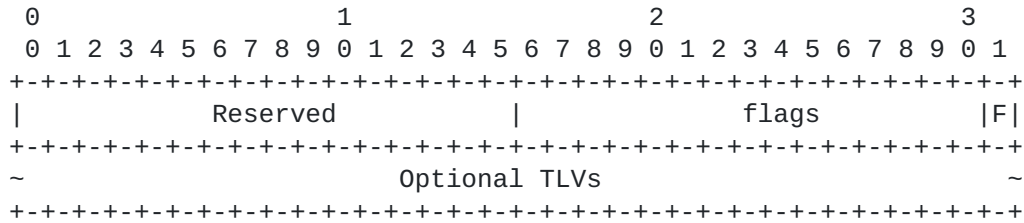


Figure 9: TFSS Object Body Format

F (Forwarding flag, 1 bit): The F flag set to 1 indicates that the node MAY start forwarding multicast packets. The F flag set to 0 indicates that the node SHOULD stop forwarding multicast packets.

TFSS object MAY include Multicast Address TLV, VPN Forwarding Identifier TLV, and BIER Attribute TLV. When TT=1, BIER Attribute TLV SHOULD be included.

**3.6.1. BIER Attribute TLV**

BIER Attribute TLV is used to instruct the FHR to forward multicast packets to the users according to the BitString specified by the controller. The format of BIER Attribute TLV is:

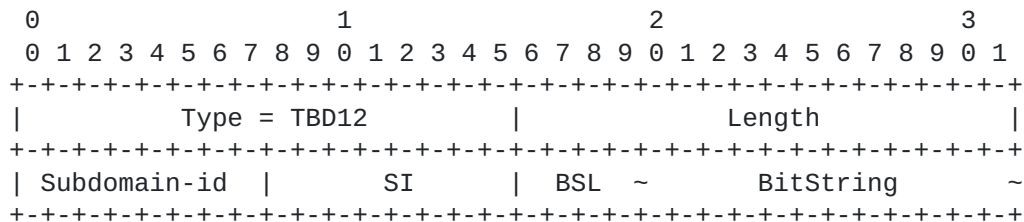


Figure 10: BIER Attribute TLV Format

Subdomain-id (1 Octet): Unique value identifying the BIER subdomain.

SI (Set Identifier, 1 Octet): encoding the Set Identifier used in the encapsulation for this BIER subdomain for this BitString length.

BSL (BitString Length, 4 bits): encodes the length in bits of the BitString as per [RFC8296], the maximum length of the BitString is 7, it indicates the length of BitString is 4096. It is used to refer to the number of bits in the BitString.

BitString(Variable length): indicates the path of multicast data packets forwarding for headend.

**3.7. Multicast Receiver Statistics Object**

The MRS object is optional and used to inform PCE of the number of receivers. The MRS object SHOULD be carried within a PCRpt or a PCUpd message for synchronize receiver information periodically, or PCRpt message for the leaving of receivers.

MRS Object-Class is TBD13. MRS Object-Type is 1. The format of the MRS object body is:

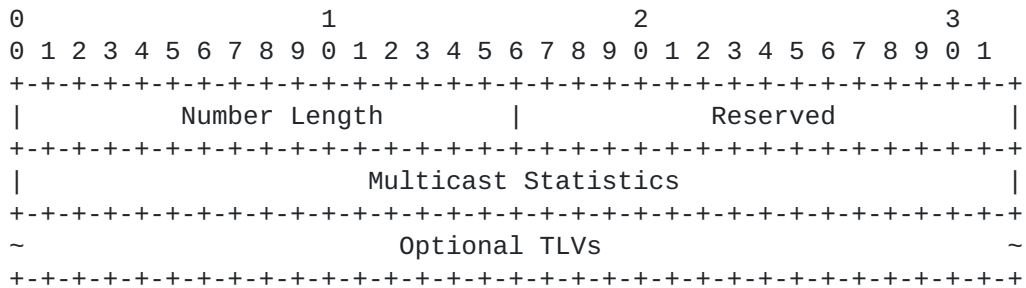


Figure 11: MRS Object Body Format

Number Length (2 Octets): indicates the length of receiver number.

Multicast Statistics (4 Octets): indicates the statistics information for a particular multicast tree of a controller or a LHR.

MRS object MAY include Multicast Address TLV, mLDP FEC TLV, P2MP SR Policy Association Group Policy Identifiers TLV.

**4. Message Formats**

**4.1. PCRpt message**

The definition of the PCRpt message from [RFC8231] and [RFC9050] is extended to optionally include MSR object, MRI object, TFSS object, and MRS object after the path object. The encoding will become:



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

Where:

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

```
<state-report> ::= [<SRP>]
                    <LSP>
                    <path>
                    [<MSR>]
                    [<MRI>]
                    [<TFSS>]
                    [<MRS>]
```

Where:

<path> is as per [\[RFC8231\]](#) and the LSP and SRP object are also defined in [\[RFC8231\]](#).

#### **4.2. PCInitiate message**

The definition of the PCInitiate message from [\[RFC8281\]](#) is extended to optionally include TFSS object after the path object. The encoding will become:

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

Where:

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

```
<update-request> ::= <SRP>
                    <LSP>
                    [<TFSS>]
```

Where:

LSP and SRP object are defined in [\[RFC8231\]](#).

#### **4.3. PCUpd message**

The definition of the PCUpd message from [\[RFC8231\]](#) is extended to optionally include MSR object, TFSS object and MRS object after the path object. The encoding will become:

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

Where:

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

```
<update-request> ::= <SRP>
                        <LSP>
                        <path>
                        [<MSR>]
                        [<TFSS>]
                        [<MRS>]
```

Where:

<path> is as per [\[RFC8231\]](#) and the LSP and SRP object are also defined in [\[RFC8231\]](#).

## 5. Example Workflow

### 5.1. Multicast Tree Discovery

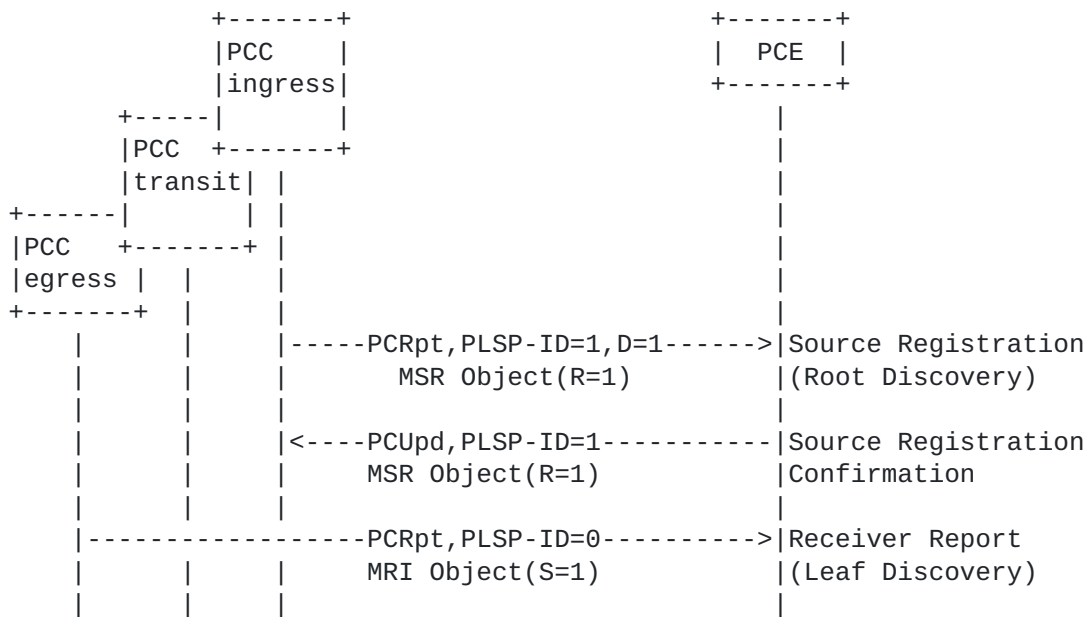


Figure 11: Workflow of Multicast Tree Discovery

### 5.2. Multicast Tree Path Establishment and Update

#### 5.2.1. Labeled Tree

The workflow of Labeled Tree are as per [\[I-D.ietf-pce-sr-p2mp-policy\]](#).

5.2.2. BIER Tree

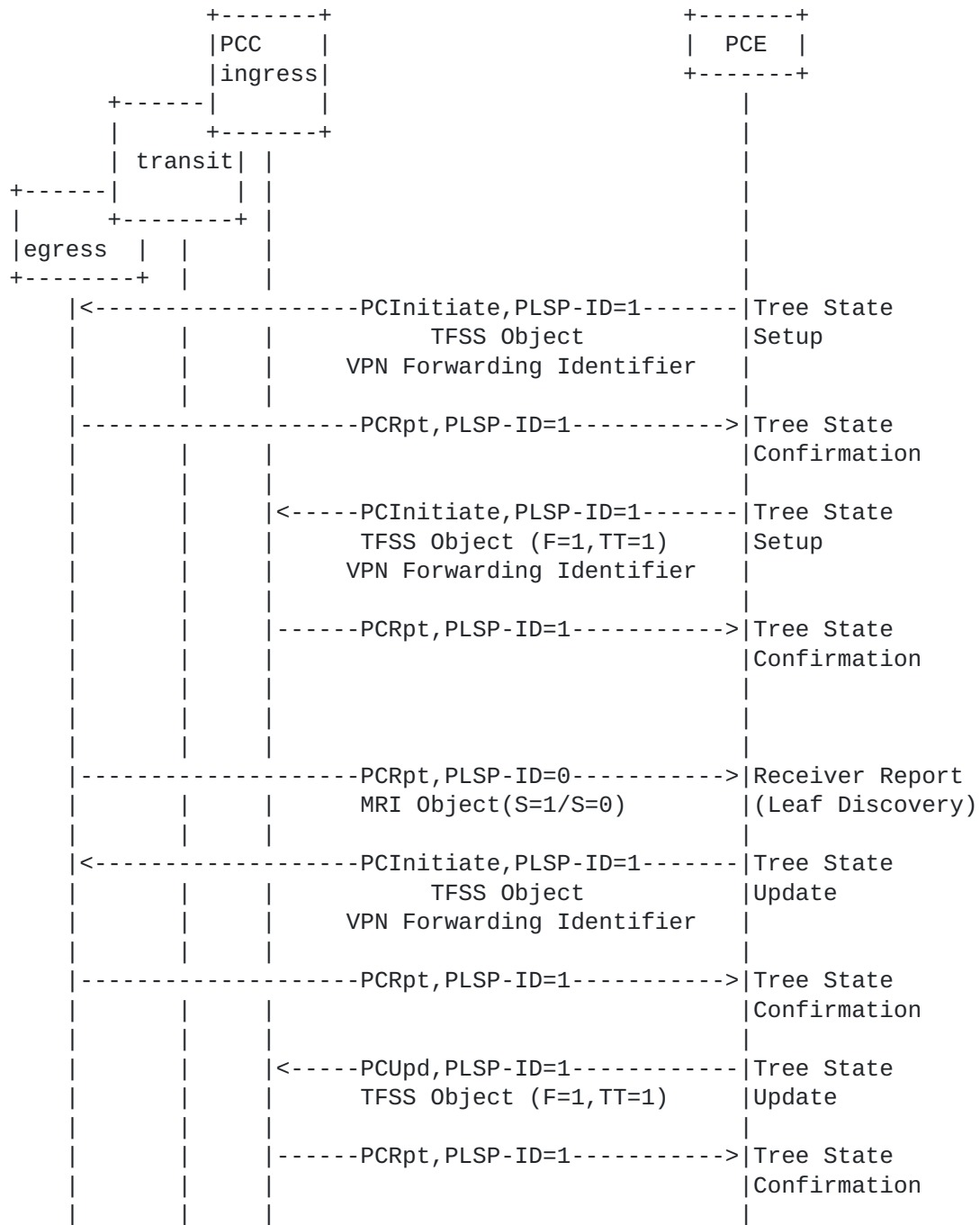


Figure 12: Workflow of BIER Tree Setup/Update

In the previous multicast tree discovery process, ingress has delegated the PCE to calculate the multicast path. Therefore, during the establishment of the multicast tree, PCE informs the ingress to forward multicast data for (S,G)/(\*,G) via PCInitiate message carrying TFSS object according to the delegation. The PLSP-ID is the value specified by the ingress. PCE also sends VPN forwarding identifier to ingress and egresses, so that multicast packets can be forwarded to specified VPN.

Ingress then updates the tree state and responds to the PCE. At this point, the BIER tree is formally established and the ingress starts forwarding for the multicast according to the BitString specified by PCE.

If the topology of the BIER tree changes, the corresponding egresses will send PCRpt messages carrying MRI object to PCE to inform PCE of their changes. PCE needs to send VPN forwarding identifier to these egresses.

The PCE updates the BitString based on changes of the egresses and informs the ingress to update. State update process is similar to state setup process, except for the type of message sent by the PCE.

**5.3. Multicast Statistics Synchronization**

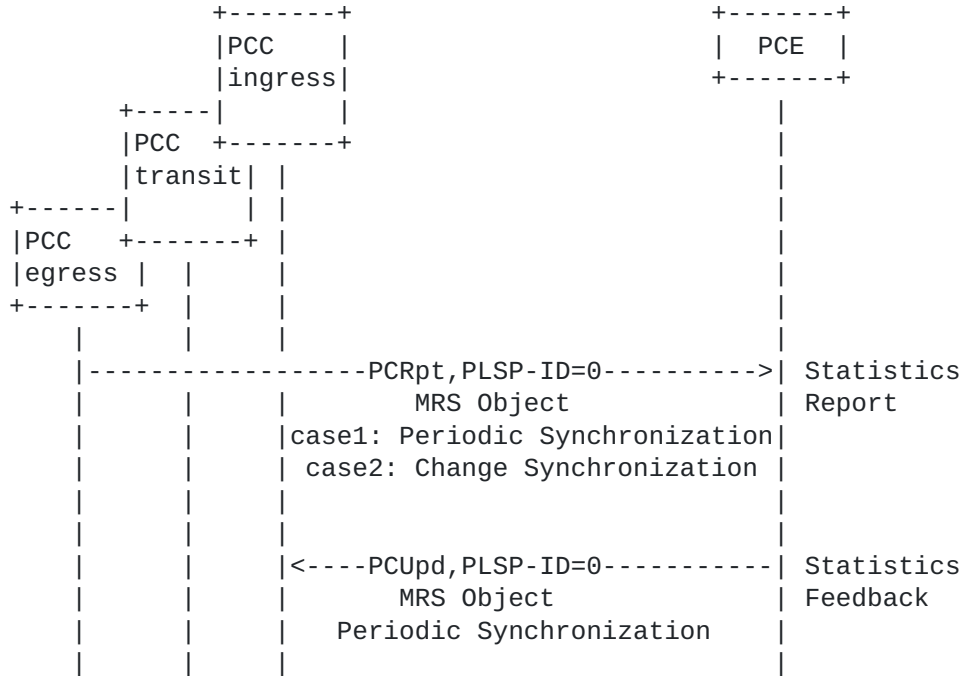


Figure 13: Workflow of Multicast Statistics Synchronization

**6. Security Considerations**

To be added.

**7. IANA Considerations**

**7.1. MULTICAST-STATE-CAPABILITY**

IANA is requested to allocate a new code point within registry "STATEFUL-PCE-CAPABILITY TLV Flag Field" under "Path Computation Element Protocol (PCEP) Numbers" as follows:

Value	Description	Reference
TBD1	MULTICAST-STATE-CAPABILITY	This document

**7.2. PCEP-ERROR Object**

IANA is requested to allocate code-points in the "PCEP-ERROR Object Error Types and Values" sub-registry for the following new error-type and error-value:

Error-Type	Description	Reference
10	Error-value = TBD2 MULTICAST-STATE-CAPABILITY bit is not set	This document

**7.3. New Objects**

IANA is requested to allocate the following Object-Class Values in the "PCEP Objects" sub-registry under the "Path Computation Element Protocol (PCEP) Numbers" registry:

Object-Class Value	Description	Reference
TBD3	Multicast Source Registration	This document
TBD7	Multicast Receiver Information	This document
TBD11	Tree Forwarding State Synchronization	This document
TBD13	Multicast Receiver Statistics	This document

IANA is requested to allocate the following Object-Type Value of CCI object in the "PCEP Objects" sub-registry under the "Path Computation Element Protocol (PCEP) Numbers" registry:

#### 7.4. New TLVs

IANA is requested to allocate the following TLVs:

Type	Description	Reference
TBD4	Multicast Source Address	This document
TBD5	mLDP FEC	This document
TBD6	VPN Information	This document
TBD8	BFR Information	This document
TBD9	Tree Label	This document
TBD10	VPN Forwarding Identifier TLV	This document
TBD12	BIER Attribute	This document

#### 8. Acknowledgements

The author thanks ... for their review and comments.

#### 9. References

##### 9.1. Normative References

- [I-D.ietf-pce-sr-p2mp-policy]  
 Bidgoli, H., Voyer, D., Rajarathinam, S., Hemmati, E., Saad, T., and S. Sivabalan, "PCEP extensions for p2mp sr policy", Work in Progress, Internet-Draft, [draft-ietf-pce-sr-p2mp-policy-01](https://www.ietf.org/archive/id/draft-ietf-pce-sr-p2mp-policy-01), 7 July 2022, <<https://www.ietf.org/archive/id/draft-ietf-pce-sr-p2mp-policy-01.txt>>.
- [RFC1112] Deering, S., "Host extensions for IP multicasting", STD 5, [RFC 1112](https://www.rfc-editor.org/info/rfc1112), DOI 10.17487/RFC1112, August 1989, <<https://www.rfc-editor.org/info/rfc1112>>.
- [RFC2362] Estrin, D., Farinacci, D., Helmy, A., Thaler, D., Deering, S., Handley, M., Jacobson, V., Liu, C., Sharma, P., and L. Wei, "Protocol Independent Multicast-Sparse Mode (PIM-SM): Protocol Specification", [RFC 2362](https://www.rfc-editor.org/info/rfc2362), DOI 10.17487/RFC2362, June 1998, <<https://www.rfc-editor.org/info/rfc2362>>.
- [RFC4655] Farrel, A., Vasseur, J.-P., and J. Ash, "A Path Computation Element (PCE)-Based Architecture", [RFC 4655](https://www.rfc-editor.org/info/rfc4655), DOI 10.17487/RFC4655, August 2006, <<https://www.rfc-editor.org/info/rfc4655>>.
- [RFC4875] Aggarwal, R., Ed., Papadimitriou, D., Ed., and S. Yasukawa, Ed., "Extensions to Resource Reservation Protocol - Traffic Engineering (RSVP-TE) for Point-to-

- Multipoint TE Label Switched Paths (LSPs)", [RFC 4875](#), DOI 10.17487/RFC4875, May 2007, <<https://www.rfc-editor.org/info/rfc4875>>.
- [RFC5015] Handley, M., Kouvelas, I., Speakman, T., and L. Vicisano, "Bidirectional Protocol Independent Multicast (BIDIR-PIM)", [RFC 5015](#), DOI 10.17487/RFC5015, October 2007, <<https://www.rfc-editor.org/info/rfc5015>>.
- [RFC6388] Wijnands, IJ., Ed., Minei, I., Ed., Kompella, K., and B. Thomas, "Label Distribution Protocol Extensions for Point-to-Multipoint and Multipoint-to-Multipoint Label Switched Paths", [RFC 6388](#), DOI 10.17487/RFC6388, November 2011, <<https://www.rfc-editor.org/info/rfc6388>>.
- [RFC6514] Aggarwal, R., Rosen, E., Morin, T., and Y. Rekhter, "BGP Encodings and Procedures for Multicast in MPLS/BGP IP VPNs", [RFC 6514](#), DOI 10.17487/RFC6514, February 2012, <<https://www.rfc-editor.org/info/rfc6514>>.
- [RFC7761] Fenner, B., Handley, M., Holbrook, H., Kouvelas, I., Parekh, R., Zhang, Z., and L. Zheng, "Protocol Independent Multicast - Sparse Mode (PIM-SM): Protocol Specification (Revised)", STD 83, [RFC 7761](#), DOI 10.17487/RFC7761, March 2016, <<https://www.rfc-editor.org/info/rfc7761>>.
- [RFC8231] Crabbe, E., Minei, I., Medved, J., and R. Varga, "Path Computation Element Communication Protocol (PCEP) Extensions for Stateful PCE", [RFC 8231](#), DOI 10.17487/RFC8231, September 2017, <<https://www.rfc-editor.org/info/rfc8231>>.
- [RFC8232] 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", [RFC 8232](#), DOI 10.17487/RFC8232, September 2017, <<https://www.rfc-editor.org/info/rfc8232>>.
- [RFC8279] Wijnands, IJ., Ed., Rosen, E., Ed., Dolganow, A., Przygienda, T., and S. Aldrin, "Multicast Using Bit Index Explicit Replication (BIER)", [RFC 8279](#), DOI 10.17487/RFC8279, November 2017, <<https://www.rfc-editor.org/info/rfc8279>>.

- [RFC8281] Crabbe, E., Minei, I., Sivabalan, S., and R. Varga, "Path Computation Element Communication Protocol (PCEP) Extensions for PCE-Initiated LSP Setup in a Stateful PCE Model", [RFC 8281](#), DOI 10.17487/RFC8281, December 2017, <<https://www.rfc-editor.org/info/rfc8281>>.
- [RFC8296] Wijnands, IJ., Ed., Rosen, E., Ed., Dolganow, A., Tantsura, J., Aldrin, S., and I. Meilik, "Encapsulation for Bit Index Explicit Replication (BIER) in MPLS and Non-MPLS Networks", [RFC 8296](#), DOI 10.17487/RFC8296, January 2018, <<https://www.rfc-editor.org/info/rfc8296>>.
- [RFC8402] Filsfils, C., Ed., Previdi, S., Ed., Ginsberg, L., Decraene, B., Litkowski, S., and R. Shakir, "Segment Routing Architecture", [RFC 8402](#), DOI 10.17487/RFC8402, July 2018, <<https://www.rfc-editor.org/info/rfc8402>>.
- [RFC9050] Li, Z., Peng, S., Negi, M., Zhao, Q., and C. Zhou, "Path Computation Element Communication Protocol (PCEP) Procedures and Extensions for Using the PCE as a Central Controller (PCECC) of LSPs", [RFC 9050](#), DOI 10.17487/RFC9050, July 2021, <<https://www.rfc-editor.org/info/rfc9050>>.

## **9.2. Informative References**

- [I-D.chen-pce-pcep-extension-pce-controller-bier] Chen, R., Xu, B., Chen, H., and A. Wang, "PCEP Procedures and Protocol Extensions for Using PCE as a Central Controller (PCECC) of BIER", Work in Progress, Internet-Draft, [draft-chen-pce-pcep-extension-pce-controller-bier-03](#), 7 March 2022, <<https://www.ietf.org/archive/id/draft-chen-pce-pcep-extension-pce-controller-bier-03.txt>>.
- [I-D.dhody-pce-pcep-extension-pce-controller-p2mp] Li, Z., Peng, S., Geng, X., and M. S. Negi, "Path Computation Element Communication Protocol (PCEP) Extensions for Using the PCE as a Central Controller (PCECC) of point-to-multipoint (P2MP) LSPs", Work in Progress, Internet-Draft, [draft-dhody-pce-pcep-extension-pce-controller-p2mp-09](#), 10 July 2022, <<https://www.ietf.org/archive/id/draft-dhody-pce-pcep-extension-pce-controller-p2mp-09.txt>>.
- [I-D.ietf-bess-bgp-multicast-controller] Zhang, Z., Raszuk, R., Pacella, D., and A. Gulko, "Controller Based BGP Multicast Signaling", Work in Progress, Internet-Draft, [draft-ietf-bess-bgp-multicast-](#)



controller-09, 11 April 2022,  
<<https://www.ietf.org/archive/id/draft-ietf-bess-bgp-multicast-controller-09.txt>>.

[I-D.ietf-pim-sr-p2mp-policy]  
(editor), D. V., Filsfils, C., Parekh, R., Bidgoli, H.,  
and Z. Zhang, "Segment Routing Point-to-Multipoint  
Policy", Work in Progress, Internet-Draft, [draft-ietf-pim-sr-p2mp-policy-05](https://www.ietf.org/archive/id/draft-ietf-pim-sr-p2mp-policy-05), 2 July 2022,  
<<https://www.ietf.org/archive/id/draft-ietf-pim-sr-p2mp-policy-05.txt>>.

[I-D.ietf-spring-sr-replication-segment]  
(editor), D. V., Filsfils, C., Parekh, R., Bidgoli, H.,  
and Z. Zhang, "SR Replication Segment for Multi-point  
Service Delivery", Work in Progress, Internet-Draft,  
[draft-ietf-spring-sr-replication-segment-08](https://www.ietf.org/archive/id/draft-ietf-spring-sr-replication-segment-08), 1 July 2022,  
<<https://www.ietf.org/archive/id/draft-ietf-spring-sr-replication-segment-08.txt>>.

[I-D.zzhang-mvpn-evpn-controller]  
Zhang, Z., Parekh, R., Zhang, Z., and H. Bidgoli, "MVPN  
and EVPN BUM Signaling with Controllers", Work in  
Progress, Internet-Draft, [draft-zzhang-mvpn-evpn-controller-01](https://www.ietf.org/archive/id/draft-zzhang-mvpn-evpn-controller-01), 25 October 2021,  
<<https://www.ietf.org/archive/id/draft-zzhang-mvpn-evpn-controller-01.txt>>.

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