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# PCE Hierarchical SDNs
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## Abstract

This document presents extensions to the Path Computation Element Communication Protocol (PCEP) for supporting a hierarchical SDN control system, which comprises multiple SDN controllers controlling a network with a number of domains.

## 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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This Internet-Draft will expire on May 3, 2018.

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## 1. Introduction

A domain is a collection of network elements within a common sphere of address management or routing procedure which are operated by a single organization or administrative authority. Examples of such domains include IGP (OSPF or IS-IS) areas and Autonomous Systems.

For scalability, security, interoperability and manageability, a big network is organized as a number of domains. For example, a big network running OSPF as routing protocol is organized as a number of OSPF areas. A network running BGP is organized as multiple Autonomous Systems, each of which has a number of IGP areas.

The concepts of Software Defined Networks (SDN) have been shown to reduce the overall network CapEx and OpEx, whilst facilitating the deployment of services and enabling new features. The core principles of SDN include: centralized control to allow optimized usage of network resources and provisioning of network elements across domains.

For a network with a number of domains, it is natural to have multiple SDN controllers, each of which controls a domain in the network. To achieve a centralized control on the network, a hierarchical architecture of controllers is a good fit. At top level of the hierarchy, it is a parent controller that is not a child controller. The parent controller controls a number of child controllers. Some of these child controllers are not parent controllers. Each of them controls a domain. Some other child controllers are also parent controllers, each of which controls multiple child controllers, and so on.

This document presents extensions to the Path Computation Element Communication Protocol (PCEP) for supporting a hierarchical SDN control system, which comprises multiple SDN controllers controlling a network with a number of domains.

## 2. Terminology

The following terminology is used in this document.

ABR: Area Border Router. Router used to connect two IGP areas (Areas in OSPF or levels in IS-IS).

ASBR: Autonomous System Border Router. Router used to connect together ASes of the same or different service providers via one or more inter-AS links.

BN: Boundary Node. A boundary node is either an ABR in the context of inter-area Traffic Engineering or an ASBR in the context of inter-AS Traffic Engineering. A Boundary Node is also called an Edge Node.

Entry BN of domain(n): a BN connecting domain(n-1) to domain(n) along the path found from the source node to the BN, where domain(n-1) is the previous hop (or upstream) domain of domain(n). An Entry BN is also called an in-BN or in-edge node.

Exit BN of domain(n): a BN connecting domain(n) to domain(n+1) along the path found from the source node to the BN, where domain(n+1) is the next hop (or downstream) domain of domain(n). An Exit BN is also called a out-BN or out-edge node.

Source Domain: For a tunnel from a source to a destination, the domain containing the source is the source domain for the tunnel.

Destination Domain: For a tunnel from a source to a destination, the domain containing the destination is the destination domain for the tunnel.

Source Controller: A controller controlling the source domain.

Destination Controller: A controller controlling the destination domain.

Parent Controller: A parent controller is a controller that communicates with a number of child controllers and controls a network with multiple domains through the child controllers. A PCE can be enhanced to be a parent controller.

Child Controller: A child controller is a controller that communicates with one parent controller and controls a domain in a network. A PCE can be enhanced to be a child controller.

Exception list: An exception list for a domain contains the nodes in the domain and its adjacent domains that are on the shortest path tree (SPT) that the parent controller is building.

GTID: Global Tunnel Identifier. It is used to identify a tunnel in a network.

PID: Path Identifier. It is used to identify a path for a tunnel in a network.

Inter-area TE LSP: a TE LSP that crosses an IGP area boundary.

Inter-AS TE LSP: a TE LSP that crosses an AS boundary.

LSP: Label Switched Path

LSR: Label Switching Router

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.

PCE(i): a PCE with the scope of domain(i).

TED: Traffic Engineering Database.

This document uses terminology defined in [RFC5440].

## 3. Conventions Used in This Document

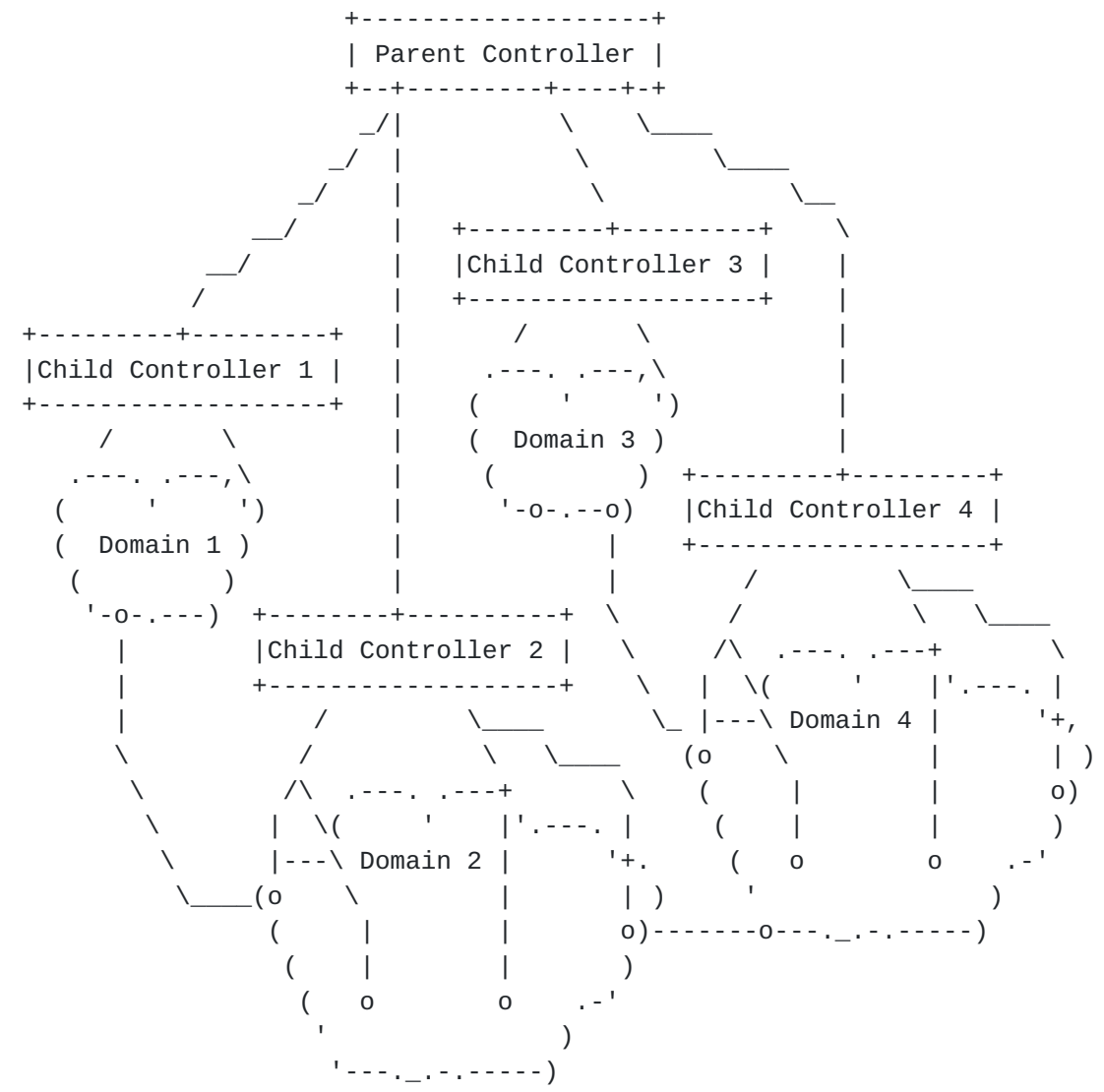
The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

## 4. Requirements

This section summarizes the requirements for Hierarchical SDN Control System (need more text here).

## 5. Overview of Hierarchical SDN Control System

The Figure below illustrates a hierarchical SDN control system. There is one Parent Controller and four Child Controllers: Child Controller 1, Child Controller 2, Child Controller 3 and Child Controller 4.




The parent controller communicates with these four child controllers and controls them, each of which controls (or is responsible for) a domain. Child controller 1 controls domain 1, Child controller 2 controls domain 2, Child controller 3 controls domain 3, and Child controller 4 controls domain 4.

One level of hierarchy of controllers is illustrated in the figure above. There is one parent controller at top level, which is not a child controller. Under the parent controller, there are four child controllers, which are not parent controllers.

In a general case, at top level there is one parent controller that is not a child controller, there are some controllers that are both parent controllers and child controllers, and there are a number of child controllers that are not parent controllers. This is a system

of multiple levels of hierarchies, in which one parent controller controls or communicates with a first number of child controllers, some of which are also parent controllers, each of which controls or communicates with a second number of child controllers, and so on.

Considering one parent controller and its child controllers, each of the child controllers controls a domain and has the topology information on the domain, the parent controller does not have the topology information on any domain controlled by a child controller normally. This is called parent without domain topology.

In some special cases, the parent controller has the topology information on a region consisting of the domains controlled by its child controllers. In other words, the parent controller has the topology information on the domains controlled by its child controllers and the topology/inter-connections among these domains. This is called parent with domain topology.

The parent controller receives requests for creating end to end tunnels from users or applications. For each request, the parent controller is responsible for obtaining a path for the tunnel and creating the tunnel along the path.

For parent without domain topology, the parent controller asks each of its related child controllers to compute path segments from an entry boundary node to exit boundary nodes in the domain it controls or path segments from an exit boundary node in its domain to entry boundary nodes of other adjacent domains just using the inter-domain links attached to the exit boundary node. The details of the segments are hidden from the parent, which sees each of the segments as a link from a boundary node to another boundary node with a cost. The parent controller builds a shortest path tree (SPT) using the path segments computed as links to get the end to end path and then creates the tunnel along the path by asking its related child controllers.

The end to end path does not have any details from the parent's point of view. It can be considered as a sequence of domains containing the shortest path. Along this sequence of domains, the details of the end to end path can be obtained. And then the tunnel along the path with details can be created.

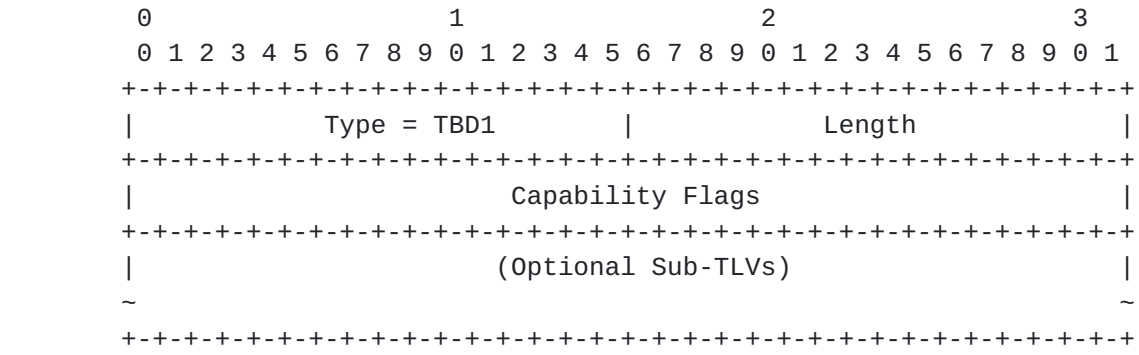
For parent with domain topology, the parent controller computes a path for the tunnel using the topology information on the domains controlled by its child controllers. And then it creates the tunnel along the path computed through asking its related child controllers.

## 6. Extensions to PCEP

This section describes the extensions to PCEP for a Hierarchical SDN Control System (HSCS). The extensions include the definition of a new flag in the RP object, a global tunnel identifier (GTID), a path identifier (PID), a list of path segments and an exception list in the PCReq and PCRep message.

### 6.1. Capability Discovery

During a PCEP session establishment between two PCEP speakers (PCE or PCC), each of them advertises its capabilities for HSCS through the Open Message with the Open Object containing a new TLV to indicate its capabilities for HSCS. This new TLV is called HSCS capability TLV. It has the following format.




The type of the TLV is TBD1. It has a length of 4 octets plus the size of optional Sub-TLVs. The value of the TLV comprises a capability flags field of 32 bits, which are numbered from the most significant as bit zero. Each bit represents a capability.

- PC (Parent Controller - 1 bit): Bit 0 is used as PC flag. It is set to 1 indicating a parent controller.

- CC (Child Controller - 1 bit): Bit 1 is used as PC flag. It is set to 1 indicating a child controller.

- PS (Path Segments - 1 bit): Bit 2 is used as PS flag. It is set to 1 indicating support for computing path segments for HSCS

- TS (Tunnel Segment - 1 bit): Bit 3 is used as TS flag. It is set to 1 indicating support for creating tunnel segment for HSCS

- ET (End to end Tunnel - 1 bit): Bit 4 is used as ET flag. It is set to 1 indicating support for creation and maintenance of end to end LSP tunnels

### 6.2. New Messages for Hierarchical SDN Control System

This section describes the contents and semantics of the new messages, and presents a few of different encodings for the messages.

There are a number of new messages for supporting HSCS. These new messages can be encoded in a few of ways as follows:

- To use a new type at top level for each of the new messages. This is called individual encoding.

- To use a new type at top level for each group of the new messages and a option/operation/sub-type value for every message in the group. This is called group encoding.

- To use/re-use existing messages and a value of options/operations for each new message in an existing message. This is called embedded encoding.

- To combine the ways above. This is called mixed encoding.

Various types of messages for supporting HSCS are listed below. Note that many new messages may not be needed for some procedures/options. For example, four messages Request and Reply for Removing Path Segments and Request and Reply for Keeping Path Segments are not needed if path segments computed are not stored/remembered by a child controller. But in this case, the path segment in each domain along the end to end path computed needs to be re-computed when a tunnel along the path is set up.

Message for Controller Relation Discovery: It is a message exchanged between a parent controller and a child controller for discovering their parent-child relation.

Message for Connections and Accesses Advertisement: It is a message that a child controller sends its parent controller to describe the connections from the domain it controls to its adjacent domains and the access points in the domain to be accessible outside of the domain.

Request for Computing Path Segments: It is a message that a parent controller sends a child controller to request the child controller for computing path segments in the domain the child controller controls.

Reply for Computing Path Segments: It is a message that a child controller sends a parent controller to reply the parent controller for a request message for computing path segments after receiving the request message from the parent controller for computing path segments and computing path segments as requested, which normally contains the path segments computed.

Request for Removing Path Segments: It is a message that a parent controller sends a child controller to request the child controller for removing the path segments computed by the child controller and stored in the child controller.

Reply for Removing Path Segments: It is a message that a child controller sends a parent controller to reply the parent controller for a request message for removing a set of path segments after receiving the request message from the parent controller for removing path segments and removing the path segments as requested, which normally contains a status of removing path segments.

Request for Keeping Path Segments: It is a message that a parent controller sends a child controller to request the child controller for keeping a set of path segments computed by the child controller and stored in the child controller.

Reply for Keeping Path Segments: It is a message that a child controller sends a parent controller to reply the parent controller for a request message for keeping path segments after receiving the request message from the parent controller for keeping path segments and keeping the path segments as requested, which normally contains a status of keeping path segments.

Request for Creating Tunnel Segment: It is a message that a parent controller sends a child controller to request the child controller for creating tunnel segments related to the domain the child controller controls.

Reply for Creating Tunnel Segment: It is a message that a child controller sends a parent controller to reply the parent controller for a request message for creating tunnel segment after receiving the request message from the parent controller for creating tunnel segment and creating tunnel segment as requested, which normally contains a status of creating tunnel segment and a label and an interface.

Request for Removing Tunnel Segment: It is a message that a parent controller sends a child controller to request the child controller for removing the tunnel segment created by the child controller.

Reply for Removing Tunnel Segment: It is a message that a child controller sends a parent controller to reply the parent controller for a request message for removing tunnel segment after receiving the request message from the parent controller for removing tunnel segment and removing the tunnel segment as requested, which normally contains a status of removing tunnel segment.

#### 6.2.1. Contents of Messages

This section describes the contents in each of the messages and gives the format of each of messages in individual encoding, which is the same as in group encoding. Some of the objects in the messages are defined in the following sections.

##### 6.2.1.1. Message for Controller Relation Discovery

A message for controller relation discovery is exchanged between a parent controller and a child controller for discovering their parent-child relation.

A message for controller relation discovery (CRDis message for short) sent from a local controller to a remote controller comprises:

- Local controller attributes
- Remote controller attributes after the local controller receives the remote controller attributes from a remote end and determines that the relation between the local controller and the remote controller can be formed.

The format of the CRDis message is as follows:

```
<CRDis Message> ::= <Common Header>
                    <CRP>
                    <Local-Controller>
                    [<Remote-Controller>]
```

where CRP (Controller Request Parameters) object is defined in section Objects and TLVs.

#### 6.2.1.2. Message for Connections and Accesses Advertisement

After a child controller discovers its parent controller, it sends its parent controller a message for connections and accesses advertisement.

A message for connections and accesses advertisement (CAAdv message for short) from a child controller comprises:

- Inter-domain links from the domain the child controller controls to its adjacent domains.
- The addresses in the domain to be accessible to the outside of the domain.
- Attributes of each of the boundary nodes of the domain.

The format of the CAAdv message is as follows:

```
<CAAdv Message> ::= <Common Header>
                    <CRP>
                    <Inter-Domain-Link-List>
                    [<Access-Address-List>]
where:
<Inter-Domain-Link-List> ::= <Inter-Domain-Link>
                             [<Inter-Domain-Link-List>]
<Access-Address-List> ::= <Access-Address>
                          [<Access-Address-List>]
```

#### 6.2.1.3. Request for Computing Path Segments

After receiving a request for creating an end to end tunnel from source A to destination Z for a given set of constraints, a parent controller allocates a global tunnel identifier (GTID) for the end to end tunnel crossing domains and a path identifier (PID) for an end to end path to be computed for the tunnel. The parent controller sends a request message to each of its related child controllers for computing a set of path segments in the domain the child controller controls in a special order. The parent controller builds a shortest path tree (SPT) using these path segments and obtains a shortest path from source A to destination Z that satisfies the constraints.

Note: The details of the path segments are hidden from the parent, which sees each of the segments as a link from one (boundary) node to another (boundary) node with a cost. The end to end path does not have any details from the parent's point of view, which may be considered as a domain path.

A request message for computing path segments (PSReq message for short) from a parent controller to a child controller comprises:

- The address or identifier of the start-node (saying X) in the domain controlled by the child controller. From this node, a number of path segments are to be computed.

- The global tunnel identifier (GTID) and the path identifier (PID). For the path of the tunnel, a number of path segments are to be computed.

- An exception list containing the nodes that are on the SPT and in the domain controlled by the child controller or its adjacent domains.

- The constraints for the path such as bandwidth constraints and color constraints.

- A destination node Z. If Z is in the domain controlled by the child controller, the child controller computes a shortest path segment satisfying the constraints from node X to node Z within the domain.

- Options for computing path segments:

  E: E set to 1 indicating computing a shortest path segment satisfying the constraints from node X to each of the edge nodes of the domain controlled by the child controller except for the nodes in the exception list. E is set to 1 if there is not any previous hop of node X in the domain.

After receiving the request message, the child controller computes a shortest path segment satisfying the constraints from node X to each of the edge nodes of the domain controlled by the child controller except for the nodes in the exception list if E is 1. In addition, it computes a shortest path segment satisfying the constraints from node X to each of the edge nodes of the adjacent domains except for the edge nodes in the exception list just using the inter-domain links attached to node X if node X is an edge node of the domain and an end point of an inter-domain link.

The format of the PSReq message is as follows:

```
<PSReq Message> ::= <Common Header>
                    [<svec-list>]
                    <path-segment-request-list>
where:
  <svec-list>::=<SVEC>[<svec-list>]
  <path-segment-request-list> ::=
                    <path-segment-request>
                    [<path-segment-request-list>]

  <path-segment-request> ::=
                    <CRP>
                    <Start-Node> <Tunnel-ID> <Path-ID>
                    [<Destination>]
                    [<OF>] [<LSPA>] [<BANDWIDTH>]
                    [<metric-list>] [<RRO>[<BANDWIDTH>]] [<IRO>]
                    [<LOAD-BALANCING>]
                    <exception-list>
```

#### 6.2.1.4. Reply for Computing Path Segments

After receiving a request message from a parent controller for computing path segments, a child controller computes the path segments as requested in the message and sends the parent controller a reply message to reply the request message, which contains the path segments computed. The details of the path segments are hidden from the parent, which sees each of the path segments as a link with a cost.

A reply message for computing path segments (PSRep message for short) comprises:

- The global tunnel identifier (GTID) and the path identifier (PID). For the path of the tunnel, the path segments are computed.

- The address or identifier of the start-node (saying X) in the domain controlled by the child controller. From this node, the path segments are computed.

- For each shortest path segment from node X to node Y computed, the address or identifier of node Y and the cost of the shortest path segment from node X to node Y.

The child controller stores the details about every shortest path segment computed under the global tunnel identifier (GTID) and the path identifier (PID) when it sends the reply message containing the path segments to the parent controller.

The child controller may delete the path segments computed for the global tunnel identifier (GTID) and the path identifier (PID) if it does not receive any request for keeping them from the parent controller for a given period of time.

The format of the PSRep message is as follows:

```
<PSRep Message> ::= <Common Header>
                    <path-segment-reply-list>
where:
  <path-segment-reply-list> ::=
                    <path-segment-reply>
                    [<path-segment-reply-list>]

  <path-segment-reply> ::=
                    <CRP>
                    <Tunnel-ID> <Path-ID>
                    <Start-Node>
                    [ <NO-PATH> | <segment-end-List> ]
                    [<metric-list>]
```

#### 6.2.1.5. Request for Removing Path Segments

After a shortest path satisfying a set of constraints from source A to destination Z is computed, a parent controller may delete the path segments computed and stored in the related child controllers, which are not any part of the shortest path. A parent controller may send a child controller a request message for removing the path segments computed by the child controller and stored in the child controller.

1). A request message for removing path segments (RPSReq message for short) comprises:

o The global tunnel identifier (GTID).

All the path segments stored under GTID in the child controller are to be removed.

2). A request message for removing path segments comprises:

o The global tunnel identifier (GTID) and the path identifier (PID).

All the path segments stored under GTID and PID in the child controller are to be removed.

3). A request message for removing path segments comprises:

- The global tunnel identifier (GTID) and the path identifier (PID)

- A list of start point (or node) addresses or identifiers.

All the path segments stored in the child controller under GTID and PID and with a start point or node from the list of start point (or node) addresses or identifiers are to be removed.

4). A request message for removing path segments comprises:

- The global tunnel identifier (GTID) and the path identifier (PID)

- A list of start point (or node) addresses or identifiers

- A list of pairs (start point, a list of end points), which identifies the path segments from start point of each pair to each of the end points in the list of the pairs.

In addition to the path segments as described in the previous message, the path segments stored in the child controller under GTID and PID and identified by the list of pairs are to be removed.

The format of the RPSReq message is as follows:

```
<RPSReq Message> ::= <Common Header>
                     <remove-path-segment-request-list>
where:
  <remove-path-segment-request-list> :: =
                     <remove-path-segment-request>
                     [<remove-path-segment-request-list>]

  <remove-path-segment-request> ::=
                     <CRP>
                     <Tunnel-ID> [<Path-ID>]
                     [<start-node-list>]
                     [<branch-List>]

  <start-node-list> ::= <Start-Node> [<start-node-list>]

  <branch-list> ::= <Branch> [<branch-list>]
  <Branch> ::= <Start-Node> <branch-end-list>

  <branch-end-list> ::= <Branch-End> [<branch-end-list>]
```

#### 6.2.1.6. Reply for Removing Path Segments

After removing the path segments as requested by a request message for removing path segments from a parent controller, a child controller sends the parent controller a reply message for removing path segments.

A reply message for removing path segments (RPSRep message for short) comprises:

- The global tunnel identifier (GTID) and the path identifier (PID)
- Status of the path segments removal:

  Success: The path segments requested for removal are removed successfully.

  Fail: The path segments requested for removal can not be removed.

- Error code and reasons for failure if the status is Fail.

The format of the RPSRep message is as follows:

```
<RPSRep Message> ::= <Common Header>
                     <remove-path-segment-reply-list>
where:
  <remove-path-segment-reply-list> ::=
                     <remove-path-segment-reply>
                     [<remove-path-segment-reply-list>]

  <remove-path-segment-reply> ::=
                     <CRP>
                     <Tunnel-ID> [<Path-ID>]
                     <Status>
                     [<Reasons>]
```

#### 6.2.1.7. Request for Keeping Path Segments

After a shortest path satisfying a set of constraints from source A to destination Z is computed, a parent controller may send a request message for keeping path segments to each of the related child controllers to keep the path segments on the shortest path.

A request message for keeping path segments (KPSReq message for short) comprises:

- The global tunnel identifier (GTID) and the path identifier (PID).

- A list of pairs (start point, end point), each of which identifies the path segment from the start point of the pair to the end point of the pair.

The child controller will keep the path segments given by the list of pairs (start point, end point) stored under GTID and PID. It will remove all the other path segments stored under GTID and PID.

The format of the KPSReq message is as follows:

```
<KPSReq Message> ::= <Common Header>
                     <keep-path-segment-request-list>
where:
  <keep-path-segment-request-list> :: =
                     <keep-path-segment-request>
                     [<keep-path-segment-request-list>]

  <keep-path-segment-request> ::=
                     <CRP>
                     <Tunnel-ID> <Path-ID>
                     <segment-list>

  <segment-list> ::= <Segment> [<segment-list>]
  <Segment> ::= <Segment-Start> <Segment-End>
```

#### 6.2.1.8. Reply for Keeping Path Segments

After keeping path segments as requested by a request message for keeping path segments from a parent controller, a child controller sends the parent controller a reply message for keeping path segments.

A reply message for keeping path segments (KPSRep message for short) comprises:

- The global tunnel identifier (GTID) and the path identifier (PID).

- Status of the path segment retention:

  Success: The path segments requested for retention are retained successfully.

Fail: The path segments requested for retention can not be retained.

o Error code and reasons for failure if the status is Fail.

The format of the KPSRep message is as follows:

```
<KPSRep Message> ::= <Common Header>
                     <keep-path-segment-reply-list>
where:
  <keep-path-segment-reply-list> ::=
                     <keep-path-segment-reply>
                     [<keep-path-segment-reply-list>]

  <keep-path-segment-reply> ::=
                     <CRP>
                     <Tunnel-ID> <Path-ID>
                     <Status>
                     [<Reasons>]
```

#### 6.2.1.9. Request for Creating Tunnel Segment

After obtaining the end to end shortest point to point (P2P) path, a parent controller creates a tunnel along the path crossing multiple domains through sending a request message for creating tunnel segment to each of the child controllers along the path in a reverse direction to create a tunnel segment.

A request message for creating tunnel segment (CTSReq message for short) comprises:

o The global tunnel identifier (GTID) and the path identifier (PID).

o A path segment from a start point to an end point for parent without domain topology or a path segment details/ERO for parent with domain topology.

o A label and an interface if the domain controlled by the child control is not a destination domain.

For parent without domain topology, the child controller allocates and reserves link bandwidth along the path segment identified by the start point and end point, assigns labels along the path segment, and writes cross connects on each of the nodes along the path segment.

For parent with domain topology, the child controller assigns labels along the path segment ERO and writes cross connects on each of the

nodes along the path segment. The link bandwidth along the path segment is allocated and reserved by the parent controller.

For the non destination domain, the child controller writes the cross connect on the edge node to the downstream domain using the label and the interface from the downstream domain in the message.

For the non source domain, the child controller will include a label and an interface in a message to be sent to the parent controller. The interface connects the edge node of the upstream domain along the path. The label is allocated for the interface on the node that is the next hop of the edge node.

The format of the CTSReq message is as follows:

```
  <CTSReq Message> ::= <Common Header>
                      <create-tunnel-segment-request-list>
  where:
    <create-tunnel-segment-request-list> ::=
                      <create-tunnel-segment-request>
                      [<create-tunnel-segment-request-list>]

    <create-tunnel-segment-request> ::=
                      <CRP>
                      <Tunnel-ID> <Path-ID>
                      <Path-Segment>
                      [<Label> <Interface>]

    <Path-Segment> ::= [<Segment-Start> <Segment-End> | <ERO> ]
```

#### 6.2.1.10. Reply for Creating Tunnel Segment

After creating tunnel segment as requested by a request message for creating tunnel segment from a parent controller, a child controller sends the parent controller a reply message for creating tunnel segment.

A reply message for creating tunnel segment (CTSRep message for short) comprises:

- The global tunnel identifier (GTID) and the path identifier (PID).

- Status of the tunnel segment creation:

Success: The tunnel segment requested is created successfully.

Fail: The tunnel segments requested can not be created.

- A label and an interface if the domain controlled by the child controller is not source domain and the status is Success.

- Error code and reasons for failure if the status is Fail.

For the non source domain controlled by the child controller, the interface in the message connects the edge node of the upstream domain along the path, the label is allocated for the interface on the node that is the next hop of the edge node.

The format of the CTSRep message is as follows:

```
<CTSRep Message> ::= <Common Header>
                     <create-tunnel-segment-reply-list>
where:
  <create-tunnel-segment-reply-list> ::=
                     <create-tunnel-segment-reply>
                     [<create-tunnel-segment-reply-list>]

  <create-tunnel-segment-reply> ::=
                     <CRP>
                     <Tunnel-ID> <Path-ID>
                     <Status> [<Label> <Interface>]
                     [<Reasons>]
```

#### 6.2.1.11. Request for Removing Tunnel Segment

When a parent controller receives a request for deleting a tunnel from a user or an application, or receives a reply message for creating tunnel segment with status of Fail from a child controller, the parent controller will delete the tunnel through sending a request message for removing tunnel segment to each of the related child controllers.

A request message for removing tunnel segment (RTSReq message for short) comprises:

- The global tunnel identifier (GTID) and the path identifier (PID).

The child controller releases the labels assigned along the path segments under GTID and PID, and removes the cross connects on each of the nodes along the path segments. If the child controller reserved the link bandwidth along the path segments under GTID and

PID, it releases the link bandwidth reserved.

The format of the RTSReq message is as follows:

```
  <RTSReq Message> ::= <Common Header>
                       <remove-tunnel-segment-request-list>
  where:
    <remove-tunnel-segment-request-list> ::=
                       <remove-tunnel-segment-request>
                       [<remove-tunnel-segment-request-list>]

    <remove-tunnel-segment-request> ::
                       <CRP>
                       <Tunnel-ID> [<Path-ID>]
```

#### 6.2.1.12. Reply for Removing Tunnel Segment

After removing the tunnel segment as requested by a request message for removing tunnel segment from a parent controller, a child controller sends the parent controller a reply message for removing tunnel segment.

A reply message for removing tunnel segment (RTSRep message for short) comprises:

- The global tunnel identifier (GTID) and the path identifier (PID).
- Status of the tunnel segment removal:

  Success: The tunnel segment requested is removed successfully.

  Fail: The tunnel segment requested can not be removed.

- Error code and reasons for failure if the status is Fail.

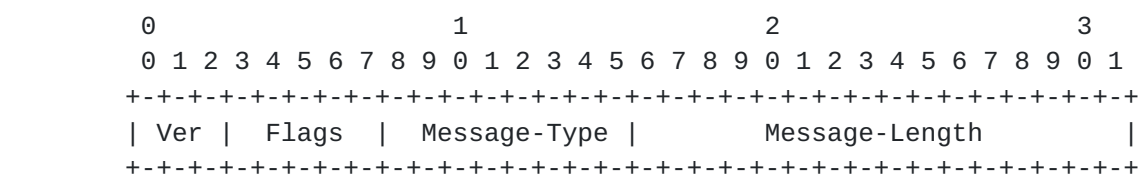
The format of the RTSRep message is as follows:

```
<RTSRep Message> ::= <Common Header>
                     <remove-tunnel-segment-reply-list>
where:
  <reply-tunnel-segment-reply-list> ::=
                     <remove-tunnel-segment-reply>
                     [<remove-tunnel-segment-reply-list>]

  <remove-tunnel-segment-reply> ::=
                     <CRP>
                     <Tunnel-ID> [<Path-ID>]
                     <Status>
                     [<Reasons>]
```

### 6.2.2. Individual Encoding of Messages

The format of PCEP Message Common Header is as follows:




Message-Type (8 bits): The following message types are currently defined (refer to RFC 5440):

| Message-Type | Meaning |
|---|---|
| 1 | Open |
| 2 | Keepalive |
| 3 | Path Computation Request |
| 4 | Path Computation Reply |
| 5 | Notification |
| 6 | Error |
| 7 | Close |

The new message types are defined as follows:

| Message-Type | Meaning |
|---|---|
| mTBD1 | Controller Relation Discovery |
| mTBD2 | Connections and Accesses Advertisement |
| mTBD3 | Path Segment Computation Request |
| mTBD4 | Path Segment Computation Reply |
| mTBD5 | Remove Path Segment Request |
| mTBD6 | Remove Path Segment Reply |
| mTBD7 | Keep Path Segment Request |
| mTBD8 | Keep Path Segment Reply |
| mTBD9 | Create Tunnel Segment Request |
| mTBD10 | Create Tunnel Segment Reply |
| mTBD11 | Remove Tunnel Segment Request |
| mTBD12 | Remove Tunnel Segment Reply |

Ver, Flags and Message-Length are defined as RFC 5440.

### 6.2.3. Group Encoding of Messages

We can encode the tunnel related messages into two groups: one group comprises the request messages related to tunnel and the other comprises the reply messages related to tunnel. Thus we can have four new message types, which are defined in PCEP Message Common Header as follows:

| Message-Type | Meaning |
|---|---|
| mTBD1 | Controller Relation Discovery |
| mTBD2 | Connections and Accesses Advertisement |
| mTBD3 | Tunnel Segment Operation Request |
| mTBD4 | Tunnel Segment Operation Reply |

Ver, Flags, other message types and Message-Length in PCEP Message Common Header are defined as RFC 5440.

The Tunnel Segment Operation can be one of the followings:

Create Tunnel Segment: Create a segment of an end to end tunnel.

Remove Tunnel Segment: Remove a segment of an end to end tunnel.

Compute Path Segments: Compute some path segments to find an end to end path for an end to end tunnel.

Remove Path Segments: Remove some path segments.

Keep Path Segment: Keep path segments on an end to end path for an end to end tunnel.

Each of these operations can be indicated by a value of options field of an object such as CRP object following PCEP Message Common Header in a message.

### 6.2.4. Embedded Encoding of Messages

Each of the request messages can be encoded as a Path Computation Request message with a value of options/operations in an existing object. Each of the reply messages can be encoded as a Path Computation Reply message with a value of options/operations in an existing object.

A new options/operations field of 3 bits may be defined in the existing RP object. Thus each of the five request messages for supporting HSCS can be represented by a Path Computation Request message with a corresponding Options value in the RP object listed below. Each of the five reply messages for supporting HSCS can be represented by a Path Computation Reply message with a corresponding Options value in the RP object listed below.

| Options Value | Meaning |
|---|---|
| oTBD1 | Path Segment Computation Request/Reply |
| oTBD2 | Remove Path Segment Request/Reply |
| oTBD3 | Keep Path Segment Request/Reply |
| oTBD4 | Create Tunnel Segment Request/Reply |
| oTBD5 | Remove Tunnel Segment Request/Reply |

Each request/reply message contains the contents for the message described in the previous section.

The Controller Relation Discovery message may be encoded as a Open message with a flag or a value of options/operations in an existing object. The Open message as a Controller Relation Discovery message contains the contents for the Discovery message described in the previous section.

The Connections and Accesses Advertisement message may be encoded as a Report message with a flag or a value of options/operations in an existing object such as SRP object. The Report message as a Connections and Accesses Advertisement message contains the contents of the Connections and Accesses Advertisement message described in the previous section.

### 6.2.5. Mixed Encoding of Messages

Some of the above encodings can be combined to form a mixed encoding of the messages for supporting HSCS. For example, one mixed encoding of the messages is as follows:

- Using Individual Encoding for Connections and Accesses Advertisement message and
- Using Embedded Encoding for Controller Relation Discovery, all the request and reply messages for supporting HSCS.

Another mixed encoding of messages is below:

- Using Embedded Encoding for Controller Relation Discovery;
- Using Individual Encoding for Connections and Accesses Advertisement message and
- Using Group Encoding for all the request and reply messages for supporting HSCS.

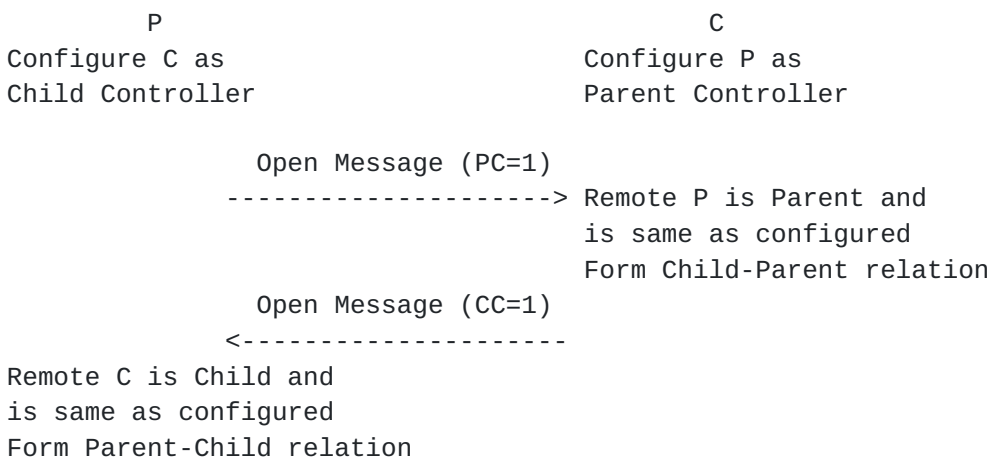
## 6.3. Controller Relation Discovery

This section presents two approaches for discovering controller relation. One uses the Open Message with some simple extensions. The other uses a new message for Controller Relation Discovery, called a discovery message.

### 6.3.1. Using Open Message

For a parent controller P and a child controller C connected by a PCE session and having a normal PCE peer adjacency, their parent-child relation is discovered through Open Messages exchanged between the parent controller and the child controller. The following is a sequence of events related to a controller relation discovery.

Controller P sends controller C an Open Message containing a capability TLV with parent flag PC set to 1 after controller C is configured as a child controller over the PCE session between P and C.




When C receives the Open Message from P and determines that PC=1 in the message is consistent with the parent controller configured locally, it forms Child-Parent relation between C and P. It sends controller P an Open Message containing a capability TLV with child controller flag CC set to 1 after controller P is configured as a parent controller over the PCE session between C and P.

When P receives the Open Message from C and determines that CC=1 in the message is consistent with the Child controller configured locally, it forms Parent-Child relation between P and C.

After the Parent-Child relation between P and C is formed, this relation is broken if the configuration "C as Child Controller" on parent controller P is deleted or "P as Parent Controller" on child controller C is removed.

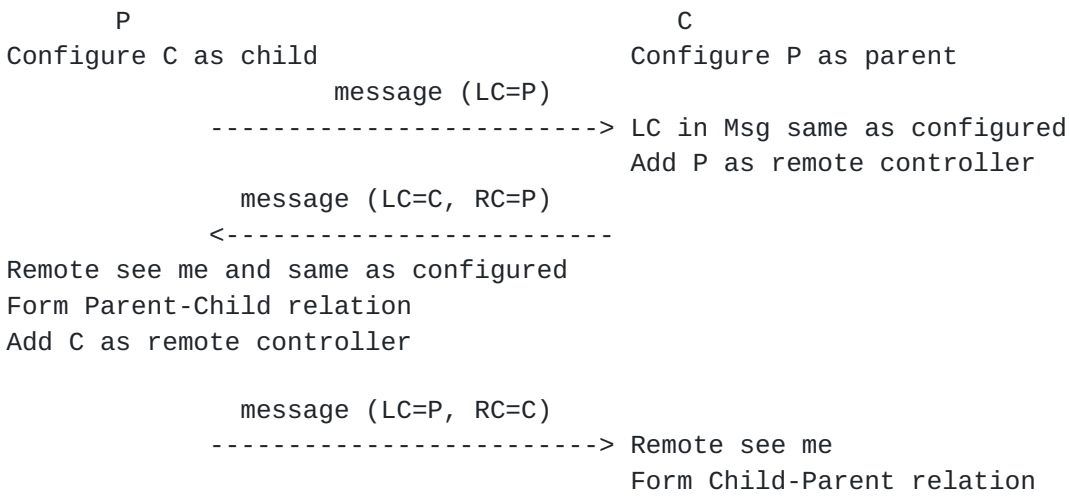
When the configuration "C as Child Controller" is deleted from parent controller P, P breaks/removes the Parent-Child relation between P and C and sends C an Open Message with PC = 0. When child controller C receives the Open Message with PC = 0 from P, it determines that the remote end P is no longer its parent controller as configured locally and breaks/removes the Child-Parent relation between C and P.

When the configuration "P as Parent Controller" is deleted from child controller C, C breaks/removes the Child-Parent relation between C and P and sends P an Open Message with CC = 0. When parent controller P receives the Open Message with CC = 0 from C, it determines that the remote end C is no longer its child controller as configured locally and breaks/removes the Parent-Child relation between P and C.

### 6.3.2. Using Discovery Message

For a parent controller P and a child controller C connected by a PCE session and having a normal PCE peer adjacency, their parent-child relation is discovered through messages for controller relation discovery exchanged between the parent controller and the child controller. The following is a sequence of events related to a controller relation discovery.

Controller P sends controller C a message containing a local controller (LC=) P with a parent flag set to 1 after controller C is configured as a child controller over a PCE session between P and C.




When C receives the message from P and determines that the local controller (LC=) P in the message is the same as the parent controller configured locally, it sends controller P a message containing local controller (LC=) C and remote controller (RC=) P.

When P receives the message from C and determines that the local controller (LC=) C in the message is the same as the child controller configured locally and the remote controller C sees me controller P (RC=P in the message), it forms a parent-child relation between P and C and sends controller C another message containing local controller (LC=) P and remote controller (RC=) C.

When C receives the message from P and determines that the local controller (LC=) P in the message is the same as the parent controller configured locally and the remote controller P sees me controller C (RC=C in the message), it forms a child-parent relation between C and P.

### 6.4. Connections and Accesses Advertisement

A child controller sends its parent controller a message for connections and accesses, which contains the connections (i.e., inter-domain links) connecting the domain that the child controller controls to other adjacent domains, and the addresses/prefixes (i.e., the access points) in the domain to be accessible from outside of the domain.

When there is a change on the connections and the accesses of the domain, the child controller sends its parent controller a updated message for the connections and accesses, which contains the latest connections and accesses of the domain.

A parent controller stores the connections and accesses for each of its child controllers according to the messages for connections and accesses received from the child controllers. For a updated message, it updates the connections and accesses accordingly.

When a child controller is down, its parent controller may remove the connections and accesses of the domain controlled by the child controller.

After connections and accesses advertisement, a parent controller has the exterior information about all the domains controlled by its child controllers. In other words, a parent controller has the connections among the domains (i.e., the inter-domain links connecting the domains) controlled by its child controllers and the addresses/prefixes (i.e., access points) in the domains to be accessible.

A connection comprises: the attributes for a link connecting domains and the attributes for the end points of the link. The attributes for an end point of a link comprises the type of the end point node such as ABR or ASBR, and the domain of the end point such AS number and area number.

An access point comprises an address or a prefix of a domain to be accessible outside of the domain.

### 6.5. Tunnel Creation

This section describes a couple of procedures for computing a shortest end to end path for a tunnel, and then a procedure for creating the tunnel along the path. One procedure for computing a end to end path takes two rounds of computations. The first round obtains an end to end path without any details on any of the path segments along the path. This path can be considered as a domain

path. In the second round, the details on each of the path segments along the domain path are computed. The other procedure is to get an end to end path in one round.

### 6.5.1. Computing Path in Two Rounds

After a parent controller receives a request for creating an end to end tunnel from source A to destination Z for a given set of constraints, it computes an end to end path in two rounds as follows:

Round 1: Obtain a domain path

Roughly speaking, obtaining a domain path consists of the following three steps:

Step 1: The parent controller sends a request message to each of its related child controllers for computing a set of path segments in the domain the child controller controls in a special order.

Step 2: After a child controller receives the request message, it computes the path segments as requested and sends the parent controller a reply message with the path segments computed as links. It does not store any details about the path segments it computes. The details of the path segments are hidden from the parent controller, which sees each of the segments as a link from one (boundary) node to another (boundary) node with a cost.

Step 3: The parent controller builds a shortest path tree (SPT) using these path segments and obtains a shortest path from source A to destination Z that satisfies the constraints.

Details for obtaining a domain path are described below:

Step 1: The parent controller selects the node just added to the SPT (Initially, it selects the source).

Step 2: After selecting the node just added into the SPT, the parent controller chooses the child controller controlling the domain containing the node, and determines whether the node is destination.

For destination node, the parent controller stops computing path since the end to end (domain) path from source to destination is in the SPT, which is from the root of the SPT to the node (destination node) in the SPT.

For non-destination node X, the parent controller sends the child controller a request message for computing path segments in the domain controlled by the child controller.

- o After receiving the request message, the child controller computes the path segments as requested and sends the parent controller a reply message with the path segments computed as links. It does not store any details about the path segments it computes. The details of the path segments are hidden from the parent controller, which sees each of the segments as a link from one (boundary) node to another (boundary) node with a cost.

Step 3: After receiving the reply message from the child controller, the parent controller updates the candidate list with the links, picks up a node in the candidate list with the minimum cost and adds it into the SPT. Repeat step 1.

Round 2: Obtain the path details

After obtaining a domain path, the parent controller may initiate a BRPC procedure along the domain path to get the end to end path. Each of the child controllers controlling the domains along the domain path may store the details of the path segment it computes using a path key.

### 6.5.2. Computing Path in One Round

For a top level parent without domain topology, the parent controller computes a shortest point to point (P2P) path for a tunnel from a source to a destination satisfying a set of constraints given to the tunnel through building a shortest path tree (SPT). The SPT is built from the source as the root of the SPT with an empty candidate list in the following steps.

Step 1: The parent controller selects the node just added to the SPT (Initially, it selects the source).

Step 2: After selecting the node just added into the SPT, the parent controller chooses the child controller controlling the domain containing the node, and determines whether the node is destination.

For destination node, the parent controller stops computing path since the end to end path from source to destination is in the SPT, which is from the root of the SPT to the node (destination node) in the SPT.

For non-destination node X, the parent controller sends the child controller a request message for computing path segments related to the domain controlled by the child controller. The request contains the exception list for the domain and flag E.

- o After receiving the request message, the child controller computes a shortest path segment from node X to each of the edge nodes of the domain not in the exception list if E is 1.

- o In addition, it computes a shortest path segment from node X to each of the edge nodes of the adjacent domains not in the exception list just using the inter-domain links attached to node X if node X is an edge node and there is an inter-domain link attached to it.

- o If node X is in the destination domain, it computes a shortest path segment from node X to the destination.

- o It sends the parent controller a reply message with the path segments computed as links and stores the details of the path segments temporarily.

Step 3: After receiving the reply message from the child controller, the parent controller updates the candidate list with the links, picks up a node in the candidate list with the minimum cost and adds it into the SPT. Repeat step 1.

For a parent without domain topology, if the parent controller is also a child controller of another upper level parent controller, after receiving a request for computing path segments from the upper level parent controller, the parent controller computes each of the path segments as requested in the same way as described above. It records and maintains the path segments computed under the GTID and PID in the request message received from the upper level parent controller.

In addition, for each path segment to be computed, it allocates a new GTID and PID for the path segment and computes the path segment through sending a request message for computing path segments to each of its related child controllers using the new GTID and PID.

When the parent as a child controller receives a request message for removing path segments from the upper level parent controller, it removes the path segments computed by each of its related child controllers through sending a request message for removing path segments to each of the related child controllers, and then it removes the path segments crossing multiple domains controlled by its

child controllers.

### 6.5.3. Creating Tunnel along Path

After obtaining the end to end shortest point to point (P2P) path, the parent controller creates a tunnel along the path crossing multiple domains through requesting the child controllers along the path in a reverse direction.

For a parent without domain topology, the following is the procedure for creating the tunnel along the path, which is initiated by the parent controller starting from domain X = destination domain.

Step 1: The parent controller sends the child controller controlling domain X a request message for creating tunnel segment in domain X.

- After receiving the request message from the parent controller, the child controller creates the tunnel segment in domain X it controls through reserving the resources such as link bandwidth, allocating labels along the path segment and writing a cross connect on every node in the domain along the path.

- If the child controller is not destination controller, the request message contains an label and interface for the next hop of the edge node of domain X. The label is allocated by the controller that controls the downstream domain of domain X. The child controller uses this label and an incoming label allocated for the incoming interface on the edge node to write a cross connect on the edge node.

- The child controller sends the parent controller a reply message with the status of the tunnel segment creation. The reply message contains an incoming label and interface for the next hop of the edge node of the upstream domain of domain X if domain X is not source domain.

Step 2: The parent controller receives the reply message from child controller C. If the status in the message is Fail, then it removes the tunnel segments created for the tunnel and return with failure for creating the tunnel.

Step 3: If child controller C is the source controller, then the end to end tunnel is created, and the parent controller and the child controllers along the tunnel maintain the information of the tunnel with the GTID and PID. The parent controller returns with success for creating the tunnel.

Step 4: Child controller C is not source controller. The reply message contains the label and interface, the parent controller repeats step 1 with domain X = the upstream domain of domain X. (In other words, it sends a request message to the child controller that controls the domain which is the upstream domain of the domain in which a tunnel segment is just created. The request contains the label and interface.)

For a parent with domain topology, the procedure for creating the tunnel along the path initiated by the parent controller is similar to the one described above, but has a few of changes to it, which are listed as follows:

- The request message for creating tunnel segment sent to a child controller from the parent controller contains the detailed information about the path segment (such as ERO comprising every hop of the path segment) along which the tunnel segment to be created.

- The child controller does not check or reserve resources such as link bandwidth along the path segment if the parent controller is responsible for allocating and reserving the resources along the path for the tunnel.

- The child controller does not assign any labels along the path segment if the parent controller is responsible for assigning labels along the path for the tunnel. In this case, the request message for creating tunnel segment contains an label for every hop of the path segment. The reply message from the child controller to the parent controller does not contain any label or interface.

When the parent as a child controller receives a request message for creating tunnel segment along a path segment from the upper level parent controller, it gets the path segments for its related child controllers from the path segment in the message.

For the parent with domain topology, it obtains the detailed hop to hop information crossing multiple domains about the path segment stored by the parent controller using the GTID, PID and start point and end point of the path segment in the message received. The parent controller creates the tunnel segments in the multiple domains through sending a request message for creating tunnel to each of its related child controllers along the path in a reverse direction.

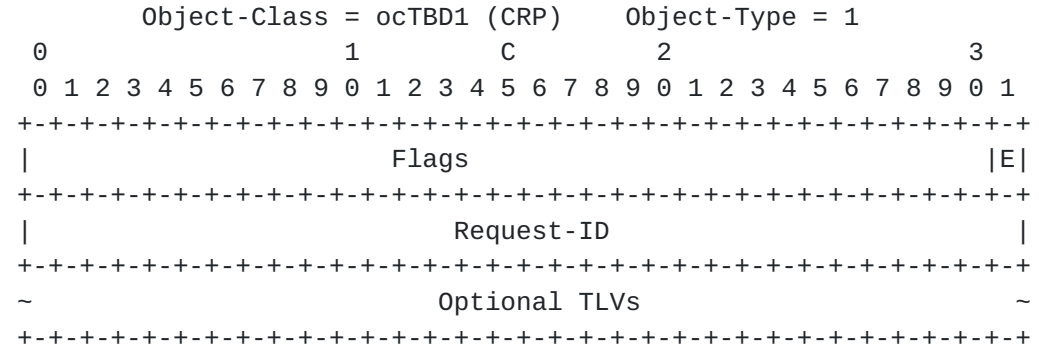
For the parent without domain topology, it obtains the detailed information about the path segment stored by the parent controller using the GTID, PID and start point and end point of the path segment

in the message received. The detailed information includes multiple path segments, each of which crosses a domain controlled by one of its related child controllers. These multiple path segments constitute the path segment in the message, which crosses multiple domains. The parent controller creates the tunnel segments in the multiple domains through sending a request message for creating tunnel to each of its related child controllers along the path in a reverse direction. For each of the path segments crossing a domain, the parent controller creates a tunnel segment along the path segment through sending a request message for creating tunnel to its child controller controlling the domain.

## 6.6. Objects and TLVs

### 6.6.1. CRP Objects

A Controller Request Parameters (CRP) object carried within each of the new messages for supporting HSCS is used to specify various parameters of a tunnel related operation request. The CRP object has Object-Class ocTBD1 and CRP Object-Type = 1. The format of the CRP body is as follows




The following flags are currently defined:

- E (Edges of Domain): E set to 1 indicating computing a shortest path segment satisfying a given set of constraints from a start node to each of the edge nodes of the domain controlled by a child controller except for the nodes in a given exception list.

For Group Encoding of messages, a new Options field of 3 bits is defined in the flags field of the CRP object to tell the receiver of a message that the request/reply is for one of the five request/reply messages for supporting HSCS as follows:

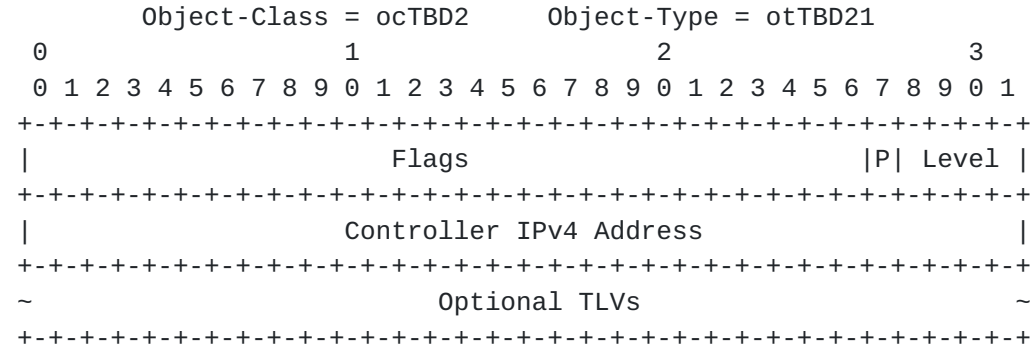
| Options | Meaning |
|---|---|
| 1 | Path Segment Computation Request/Reply |
| 2 | Remove Path Segment Request/Reply |
| 3 | Keep Path Segment Request/Reply |
| 4 | Create Tunnel Segment Request/Reply |
| 5 | Remove Tunnel Segment Request/Reply |

### 6.6.2. LOCAL-CONTROLLER Object

A LOCAL-CONTROLLER (LC) Object is carried within a Controller Relation Discovery message. Two LC objects are defined: one for IPv4 and the other for IPv6. These two objects have the same Object-Class ocTBD2 but have different Object-Types.

#### 6.6.2.1. LOCAL-CONTROLLER Object for IPv4

The LOCAL-CONTROLLER Object for IPv4 (LC-IPv4 for short) has Object-Class ocTBD2 and Object-Type otTBD21. The format of the LC-IPv4 body is as follows:




The LC-IPv4 object body has a 32-bit Flags field and a 32-bit Controller IPv4 Address. It may contain additional TLVs. No TLVs are currently defined.

The following flags are currently defined:

- P (Parent Controller): P set to 1 indicating that the local controller is a Parent controller.

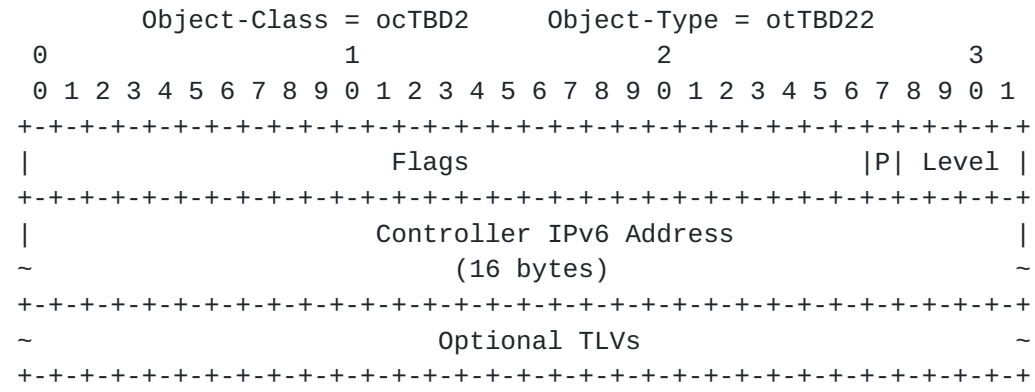
- Level (Level as Parent): Level indicates the level of a controller as a parent controller. Level 0 means the highest (i.e., top) level as a parent controller. Level i (i > 0) for a parent controller C means that C as a child controller has a parent controller of level (i - 1).

Unassigned bits in the Flags field are considered reserved. They MUST be set to zero on transmission and MUST be ignored on receipt.

The Controller IPv4 Address indicates an IPv4 address of the local controller.

### 6.6.2.2. LOCAL-CONTROLLER Object for IPv6

The LOCAL-CONTROLLER Object for IPv6 (LC-IPv6 for short) has Object-Class ocTBD2 and Object-Type otTBD22. The format of the LC-IPv6 body is as follows:




The LC-IPv6 object body has a 32-bit Flags field and a 128-bit Controller IPv6 Address. It may contain additional TLVs. No TLVs are currently defined.

The flag P (1 bit) and Level (4 bits) in the 32-bit Flags are the same as those defined in the LOCAL-CONTROLLER Object for IPv4.

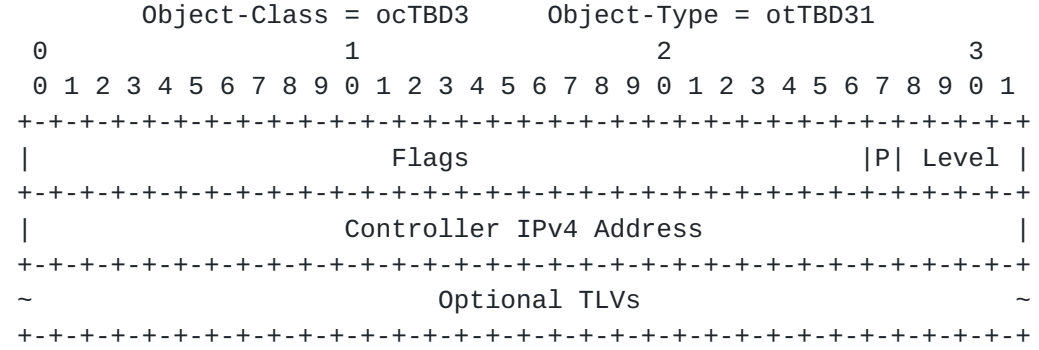
The Controller IPv6 Address indicates an IPv6 address of the local controller.

### 6.6.3. REMOTE-CONTROLLER Object

When a local controller receives a Controller Relation Discovery message from a remote controller, the local controller MUST include a REMOTE-CONTROLLER (RC) Object with the remote controller in a Controller Relation Discovery message to be sent to the remote controller. Two RC objects are defined: one for IPv4 and the other for IPv6. These two objects have the same Object-Class ocTBD3 but have different Object-Types.

#### 6.6.3.1. REMOTE-CONTROLLER Object for IPv4

The REMOTE-CONTROLLER Object for IPv4 (RC-IPv4 for short) has Object-Class ocTBD3 and Object-Type otTBD31. The format of the RC-IPv4 body is as follows:




The RC-IPv4 object body has a 32-bit Flags field and a 32-bit Controller IPv4 Address. It may contain additional TLVs. No TLVs are currently defined.

The following flags are currently defined:

- P (Parent Controller): P set to 1 indicating that the remote controller is a Parent controller.

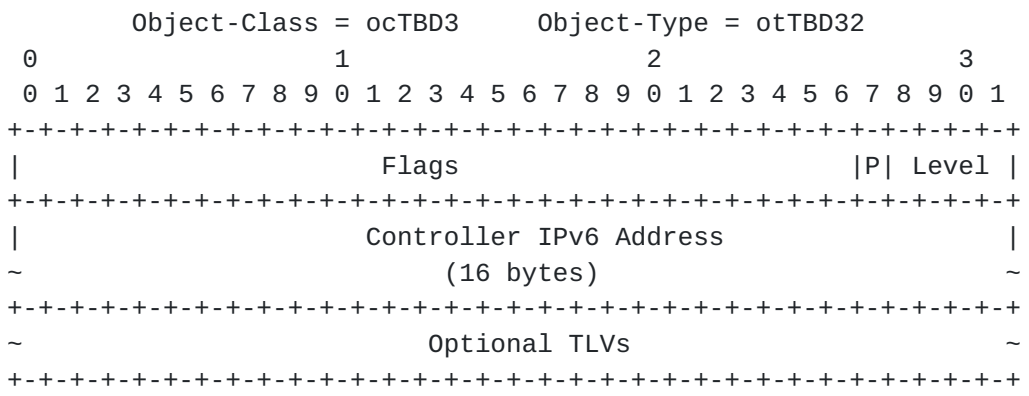
- Level (Level as Parent): Level indicates the level of a controller as a parent controller. Level 0 means the highest (i.e., top) level as a parent controller. Level i (i > 0) for a parent controller C means that C as a child controller has a parent controller of level (i - 1).

Unassigned bits in the Flags field are considered reserved. They MUST be set to zero on transmission and MUST be ignored on receipt.

The Controller IPv4 Address indicates an IPv4 address of the remote controller.

#### 6.6.3.2. REMOTE-CONTROLLER Object for IPv6

The REMOTE-CONTROLLER Object for IPv6 (RC-IPv6 for short) has Object-Class ocTBD3 and Object-Type otTBD32. The format of the RC-IPv6 body is as follows:




The LC-IPv6 object body has a 32-bit Flags field and a 128-bit Controller IPv6 Address. It may contain additional TLVs. No TLVs are currently defined.

The flag P (1 bit) and Level (4 bits) in the 32-bit Flags are the same as those defined in the REMOTE-CONTROLLER Object for IPv4.

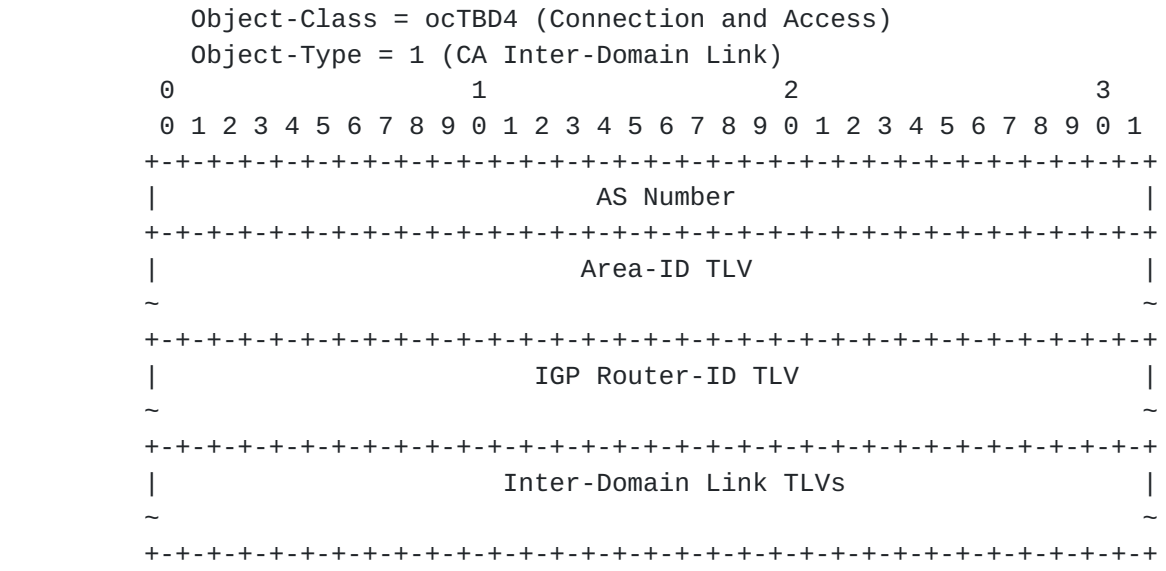
The Controller IPv6 Address indicates an IPv6 address of the remote controller.

### 6.6.4. CONNECTION and ACCESS Object

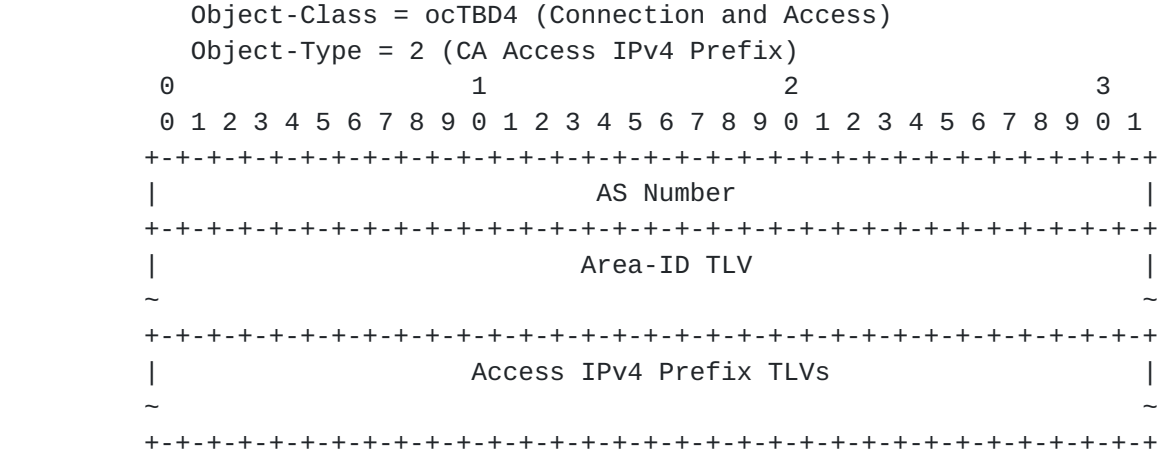
The CONNECTION and ACCESS Object (CA for short) has Object-Class ocTBD4. Three Object-Types are defined under CA object:

- CA Inter-Domain Link: CA Object-Type is 1.
- CA Access IPv4 Prefix: CA Object-Type is 2.
- CA Access IPv6 Prefix: CA Object-Type is 3.

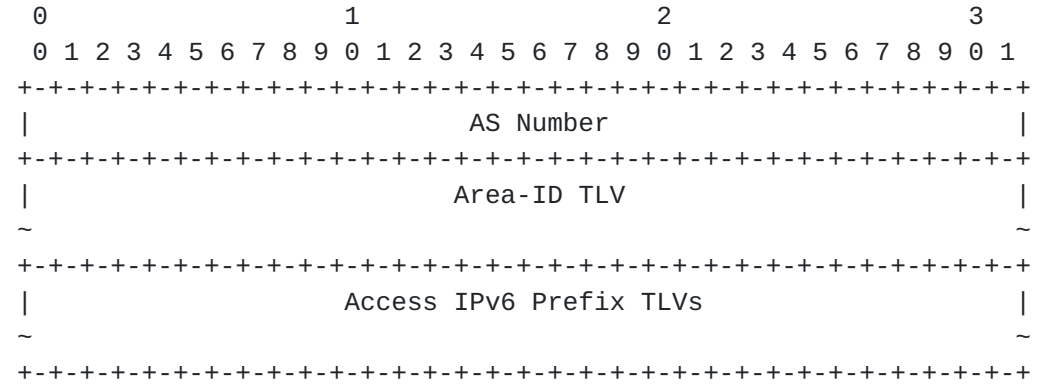
The format of each of these object bodies is as follows:



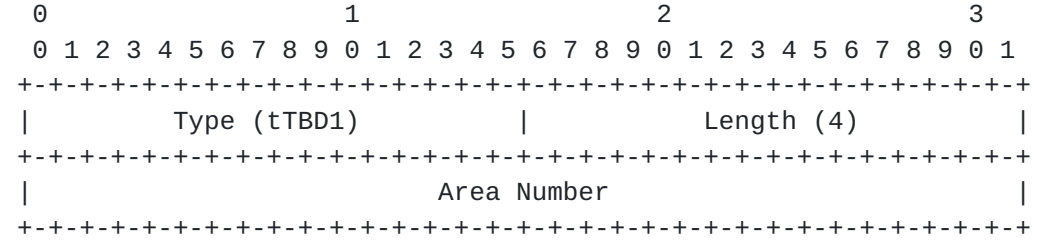

Each of the Inter-Domain Link TLVs describes an inter-domain link and comprises a number of inter-domain link Sub-TLVs.



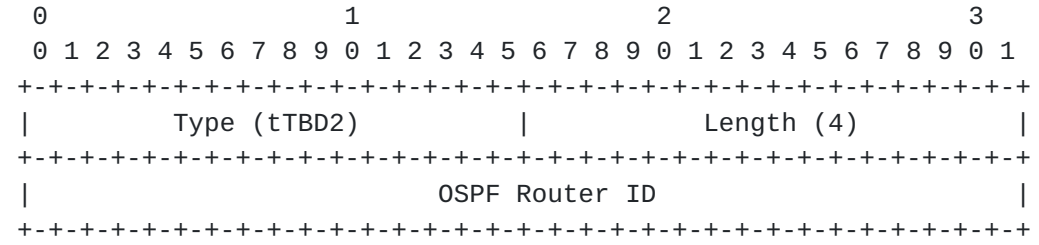
Object-Class = ocTBD4 (Connection and Access)
Object-Type = 3 (CA Access IPv6 Prefix)



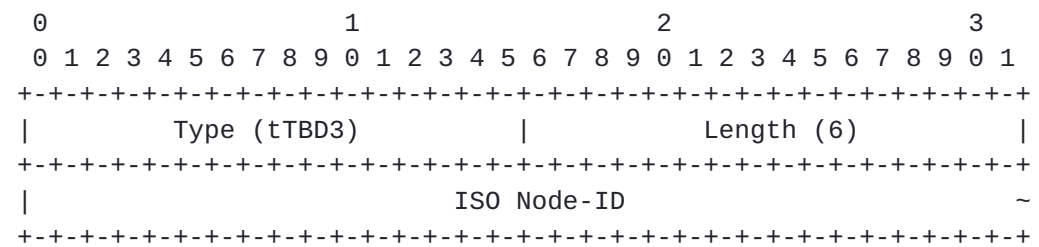

The format of the Area-ID TLV is shown below:



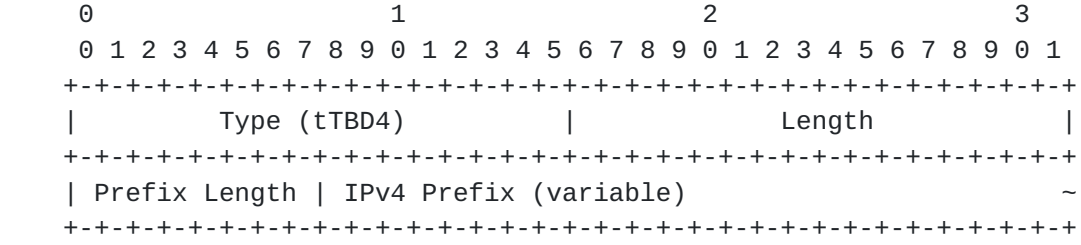

The format of the OSPF Router-ID TLV is shown below:



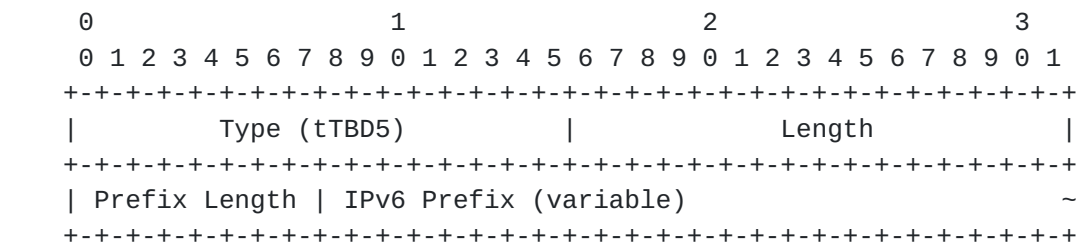

The format of the ISIS Router-ID TLV is shown below:



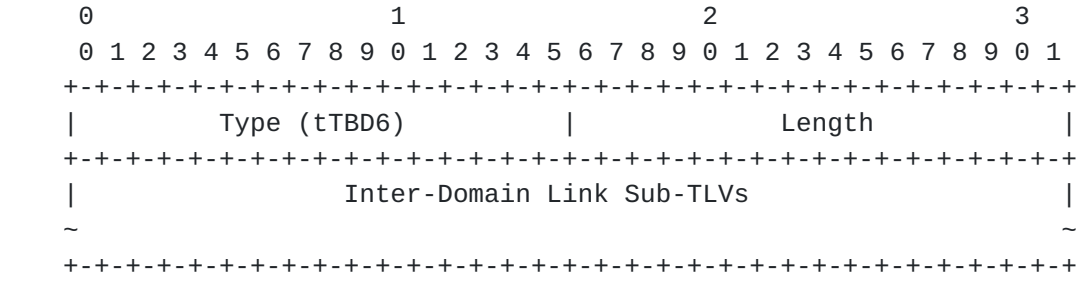
The format of the Access IPv4 Prefix TLV is shown as follows:



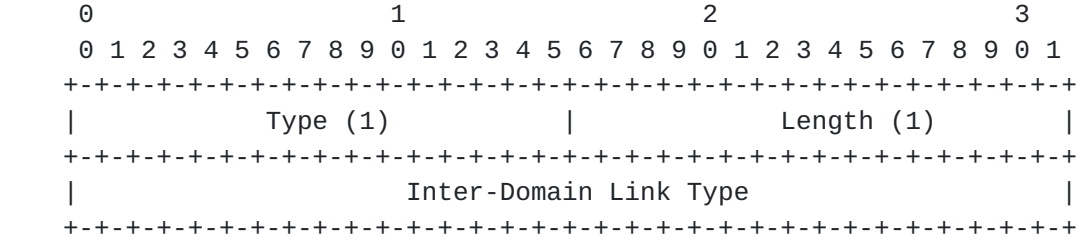

The format of the Access IPv6 Prefix TLV is illustrated below:




The format of the Inter-Domain link TLV is illustrated below:




The format of the Inter-Domain Link Type Sub-TLV is illustrated below:



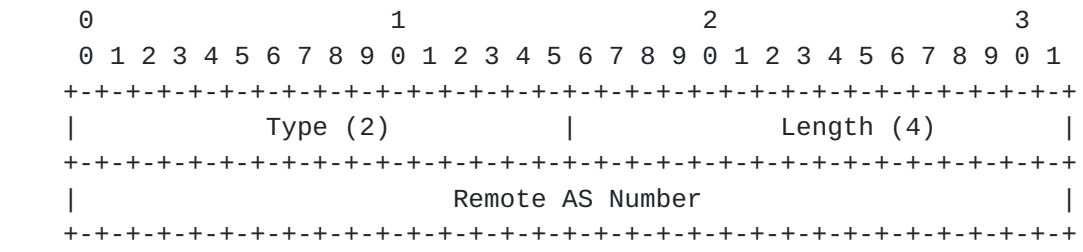

The Inter-Domain Link Type sub-TLV defines the type of the inter-domain link:

1 - Point-to-point

2 - Multi-access

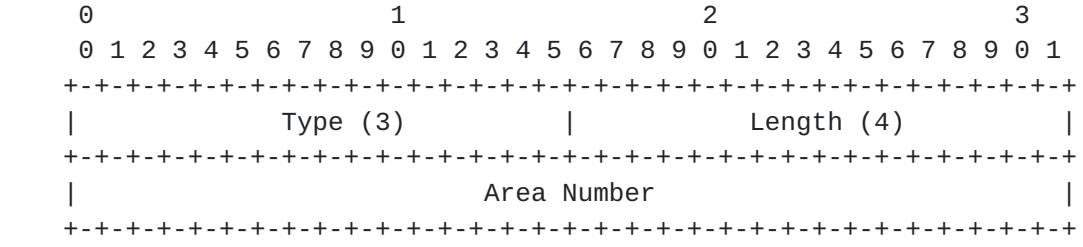
The Inter-Domain Link Type sub-TLV is TLV type 1, and is one octet in length.

The format of the Remote AS Number ID Sub-TLV is illustrated below:

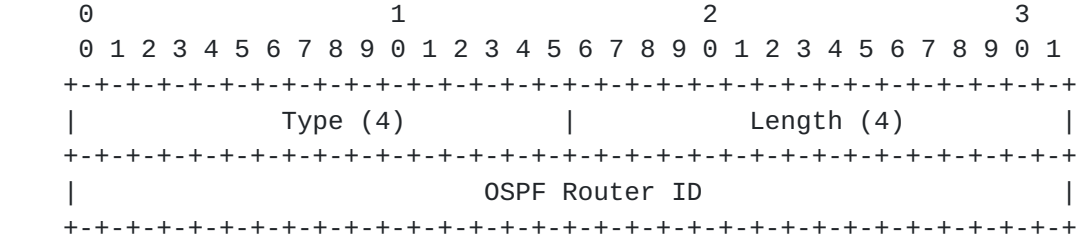



The Remote AS Number field has 4 octets. When only two octets are used for the AS number, as in current deployments, the left (high-order) two octets MUST be set to zero.

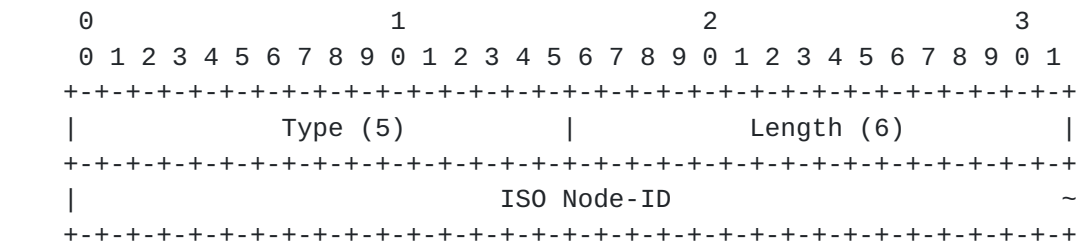
The format of the Remote Area-ID Sub-TLV is shown below:



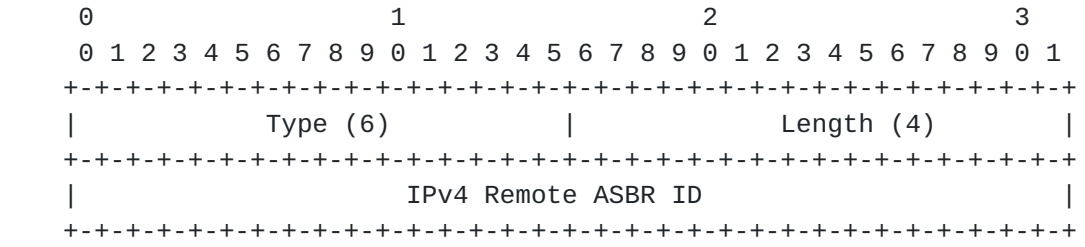

The format of the Remote OSPF Router-ID Sub-TLV is shown below:




The format of the Remote ISIS Router-ID Sub-TLV is shown below:

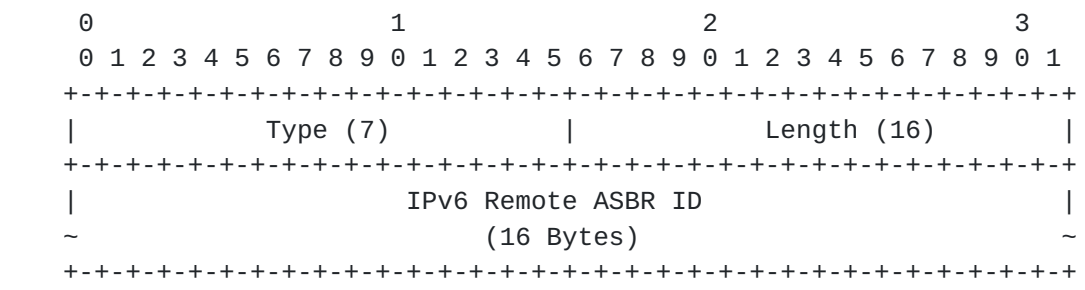



The format of the IPv4 Remote ASBR ID Sub-TLV is illustrated below:



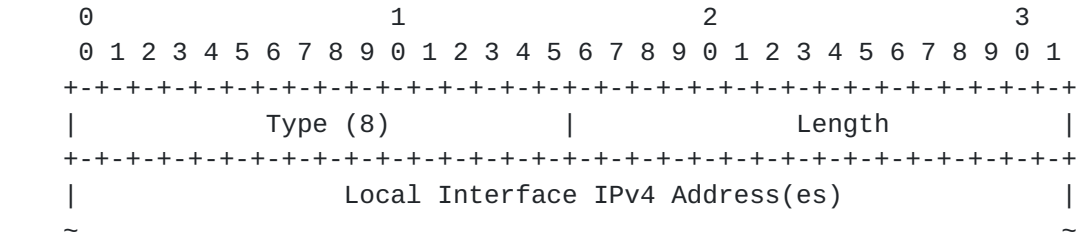

The IPv4 Remote ASBR ID sub-TLV MUST be included if the neighboring ASBR has an IPv4 address.

The format of the IPv6 Remote ASBR ID Sub-TLV is illustrated below:




The IPv6 Remote ASBR ID sub-TLV MUST be included if the neighboring ASBR has an IPv6 address.

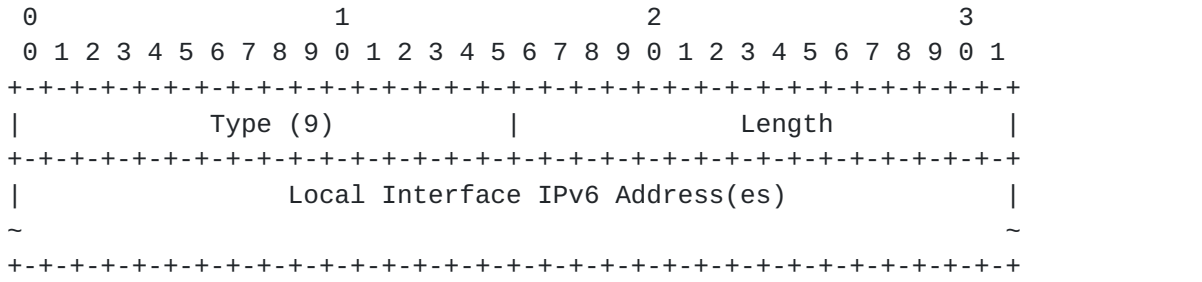
The format of the Local Interface IPv4 Address Sub-TLV is shown below:



The Local Interface IPv4 Address sub-TLV specifies the IPv4 address(es) of the interface corresponding to the inter-domain link. If there are multiple local addresses on the link, they are all listed in this sub-TLV.

The Local Interface IPv4 Address sub-TLV is TLV type 8, and is 4N octets in length, where N is the number of local IPv4 addresses.

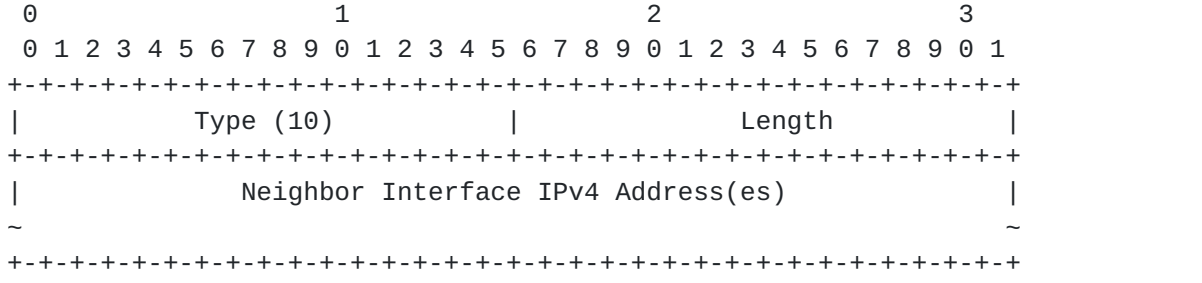
The format of the Local Interface IPv6 Address Sub-TLV is illustrated below:




The Local Interface IPv6 Address sub-TLV specifies the IPv6 address(es) of the interface corresponding to the inter-domain link. If there are multiple local addresses on the link, they are all listed in this sub-TLV.

The Local Interface IPv6 Address sub-TLV is TLV type 9, and is 16N octets in length, where N is the number of local IPv6 addresses.

The format of the Remote Interface IPv4 Address Sub-TLV is illustrated below:

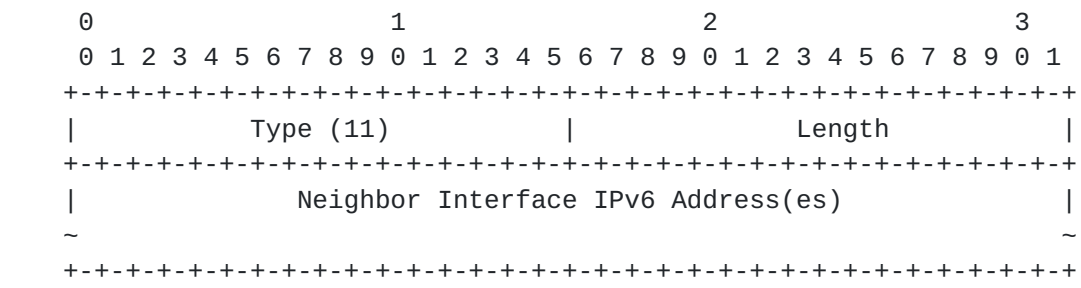



The Remote Interface IPv4 Address sub-TLV specifies the IPv4 address(es) of the neighbor's interface corresponding to the inter-domain link. This and the local address are used to discern multiple

parallel links between systems. If there are multiple remote addresses on the link, they are all listed in this sub-TLV.

The Remote Interface IPv4 Address sub-TLV is TLV type 10, and is 4N octets in length, where N is the number of neighbor IPv4 addresses.

The format of the Remote Interface IPv6 Address Sub-TLV is illustrated below:




The Remote Interface IPv6 Address sub-TLV specifies the IPv6 address(es) of the neighbor's interface corresponding to the inter-domain link. If there are multiple neighbor addresses on the link, they are all listed in this sub-TLV.

The Remote Interface IPv6 Address sub-TLV is TLV type 11, and is 16N octets in length, where N is the number of neighbor IPv6 addresses.

### 6.6.5. NODE Object

The NODE Object has Object-Class ocTBD5. A nuber of Object-Types are defined under NODE object below:

1. IPv4 START-NODE: NODE Object-Type is 1.

2. IPv6 START-NODE: NODE Object-Type is 2.

3. IPv4 DESTINATION-NODE-LIST: NODE Object-Type is 3.

4. IPv6 DESTINATION-NODE-LIST: NODE Object-Type is 4.

5. IPv4 SEGMENT-END-NODE-LIST: NODE Object-Type is 5.

6. IPv6 SEGMENT-END-NODE-LIST: NODE Object-Type is 6.

7. IPv4 EXCEPTION-NODE-LIST: NODE Object-Type is 7.

8. IPv6 EXCEPTION-NODE-LIST: NODE Object-Type is 8.

9. NODE-IGP-METRIC-LIST: NODE Object-Type is 9.

10. NODE-TE-METRIC-LIST: NODE Object-Type is 10.

11. NODE-HOP-COUNT-LIST: NODE Object-Type is 11.

The format of NODE object body for IPv4 START-NODE is as follows:

```
    Object-Class = ocTBD5 (NODE)
    Object-Type = 1 (IPv4 START-NODE)
  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
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                   Start Node IPv4 Address                     |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

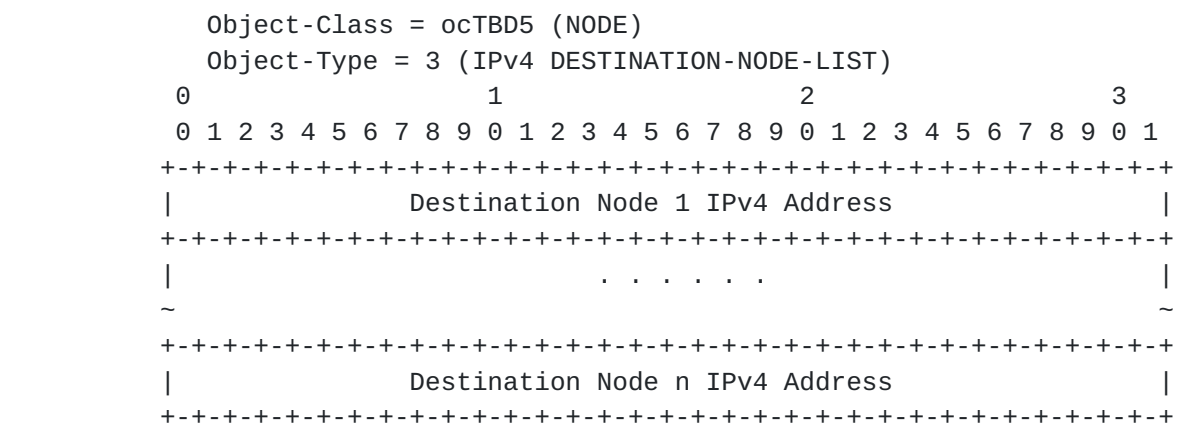
The Start Node IPv4 Address is the IPv4 address of a start node.

The format of NODE object body for IPv6 START-NODE is as follows:

```
    Object-Class = ocTBD5 (NODE)
    Object-Type = 2 (IPv6 START-NODE)
  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
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                   Start Node IPv6 Address                     |
 ~                        (16 bytes)                             ~
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

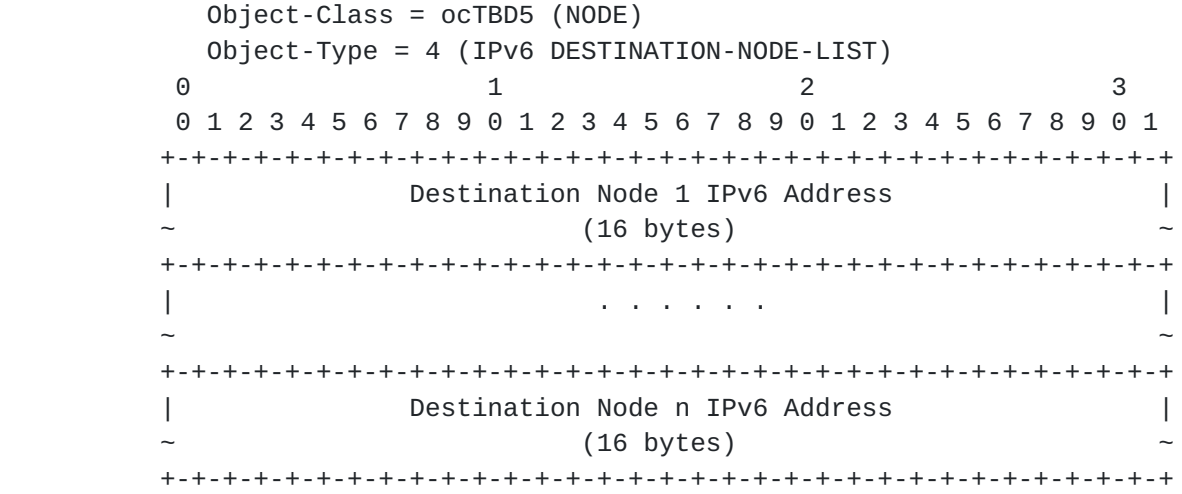
The Start Node IPv6 Address is the IPv6 address of a start node.

The format of NODE object body for IPv4 DESTINATION-NODE-LIST is as follows:



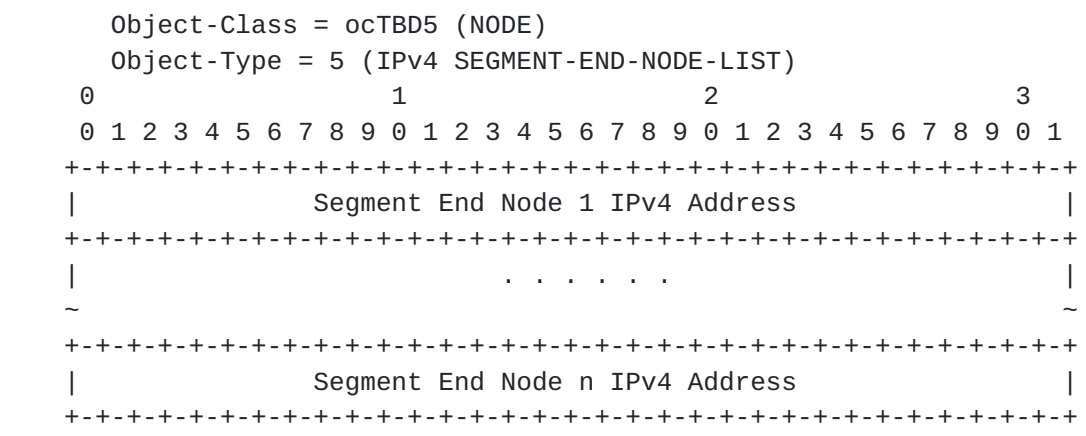

The IPv4 DESTINATION-NODE-LIST contains n destination node IPv4 addresses. An IPv4 DESTINATION-NODE-LIST is also called an IPv4 DESTINATION-NODES.

The format of NODE object body for IPv6 DESTINATION-NODE-LIST is as follows:



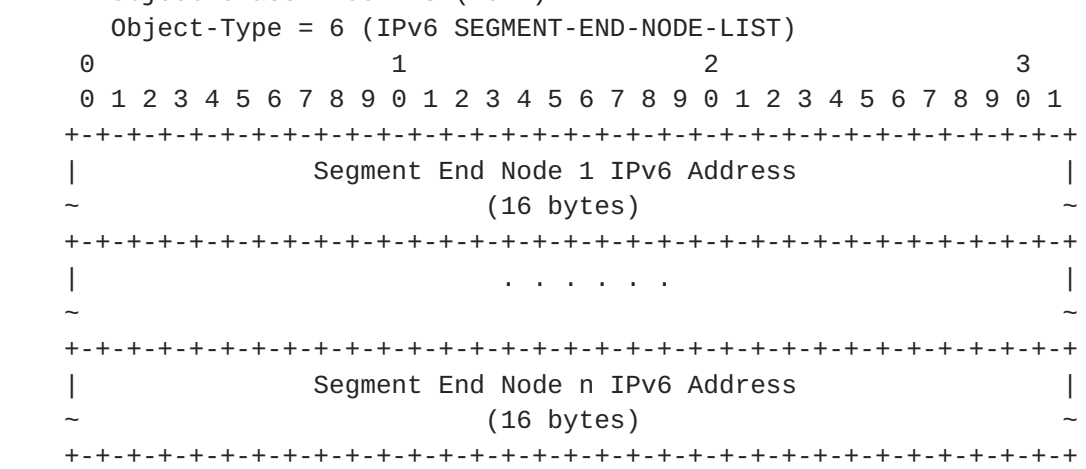

The IPv6 DESTINATION-NODE-LIST contains n destination node IPv6 addresses. An IPv6 DESTINATION-NODE-LIST is also called an IPv6 DESTINATION-NODES.

The format of NODE object body for IPv4 SEGMENT-END-NODE-LIST is as follows:



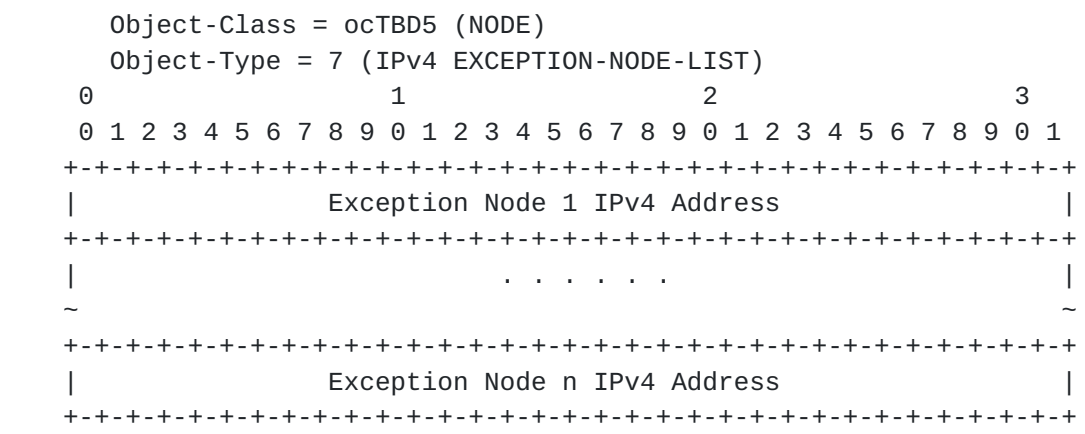

The IPv4 SEGMENT-END-NODE-LIST contains n segment node IPv4 addresses. An IPv4 SEGMENT-END-NODE-LIST is also called an IPv4 SEGMENT-END-NODES.

The format of NODE object body for IPv6 SEGMENT-END-NODE-LIST is as follows:



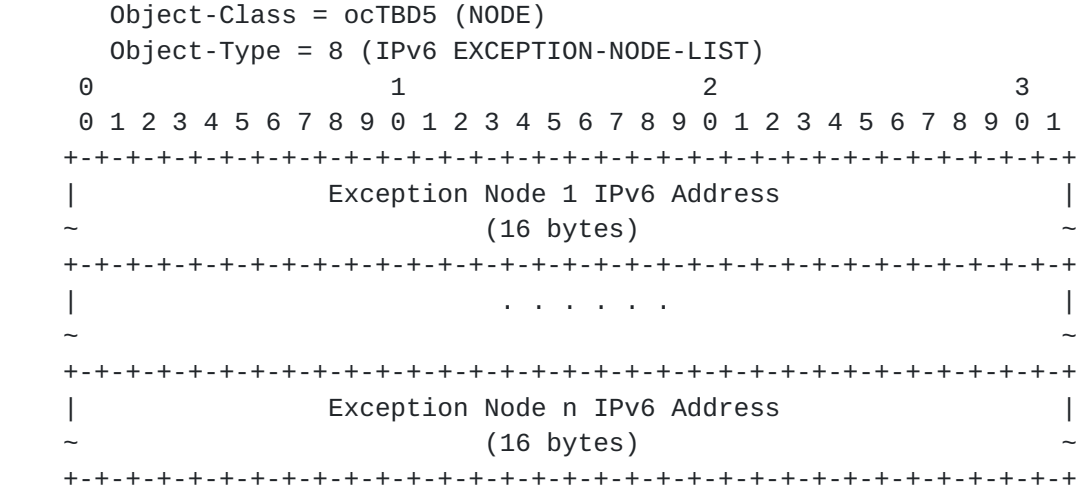

The IPv6 SEGMENT-END-NODE-LIST contains n segment end node IPv6 addresses. An IPv6 SEGMENT-END-NODE-LIST is also called an IPv6 SEGMENT-END-NODES.

The format of NODE object body for IPv4 EXCEPTION-NODE-LIST is as follows:



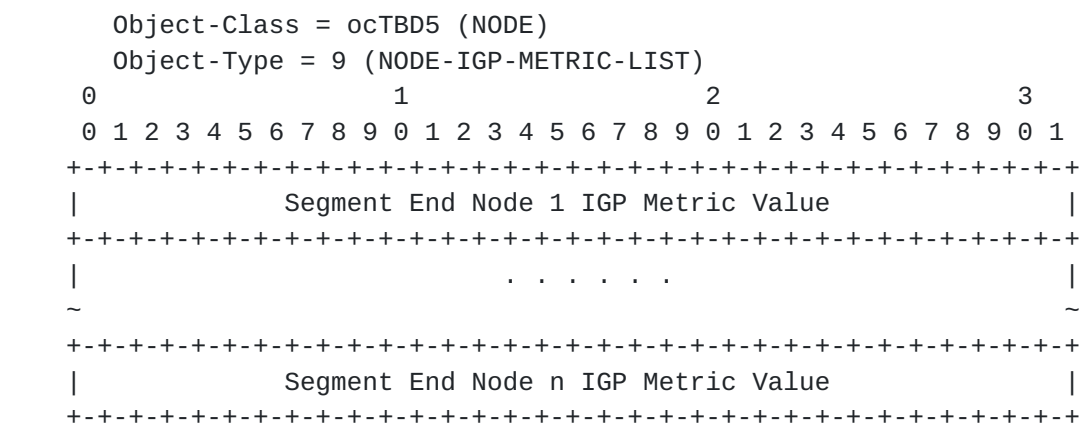

The IPv4 SEGMENT-END-NODE-LIST contains n node IPv4 addresses in an exception list. An IPv4 EXCEPTION-NODE-LIST is also called an IPv4 EXCEPTION-LIST.

The format of NODE object body for IPv6 EXCEPTION-NODE-LIST is as follows:



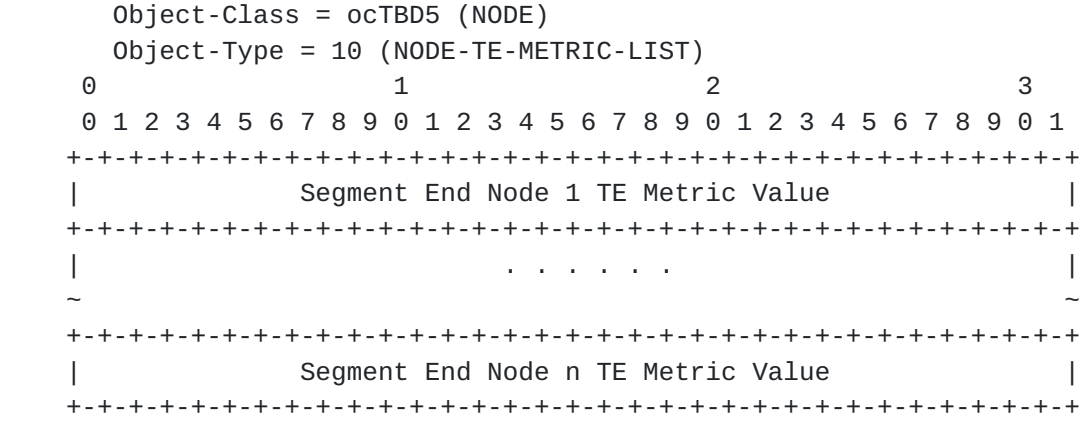

The IPv6 EXCEPTION-NODE-LIST contains n node IPv6 addresses in an exception list. An IPv6 EXCEPTION-NODE-LIST is also called an IPv6 EXCEPTION-LIST.

The format of NODE object body for NODE-IGP-METRIC-LIST is as follows:




The NODE-IGP-METRIC-LIST contains n IGP metrics for n segment end nodes.

The format of NODE object body for NODE-TE-METRIC-LIST is as follows:




The NODE-TE-METRIC-LIST contains n TE metrics for n segment end nodes.

The format of NODE object body for NODE-HOP-COUNT-LIST is as follows:

```
    Object-Class = ocTBD5 (NODE)
    Object-Type = 11 (NODE-HOP-COUNT-LIST)
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Segment End Node 1 Hop Counts Value              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           . . . . . .                         |
~                                                               ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Segment End Node n Hop Counts Value              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The NODE-HOP-COUNT-LIST contains n hop counts values for n segment end nodes.

### 6.6.6. TUNNEL Object

The TUNNEL Object has Object-Class ocTBD6. Two Object-Types are defined under TUNNEL object:

1. TUNNEL-ID: TUNNEL Object-Type is 1.

2. TUNNEL-PATH-ID: TUNNEL Object-Type is 2.

The format of TUNNEL object body for TUNNEL-ID is as follows:

```
    Object-Class = ocTBD6 (TUNNEL)
    Object-Type = 1 (TUNNEL-ID)
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Tunnel ID                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The Tunnel ID in the body is a 32-bit unique number for identifying a tunnel globally.

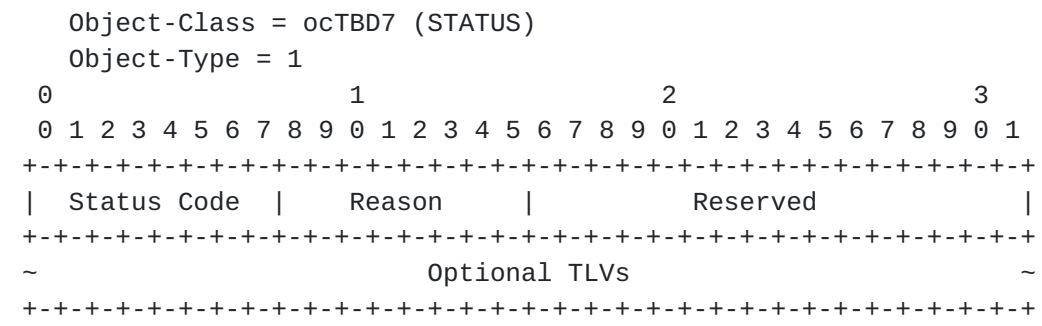
The format of TUNNEL object body for TUNNEL-PATH-ID is as follows:

```
    Object-Class = ocTBD6 (TUNNEL)   Object-Type = 2 (PATH-ID)
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Path ID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The Path ID in the body is a 16-bit number for uniquely identifying a path under a tunnel.

### 6.6.7. STATUS Object

The STATUS Object has Object-Class ocTBD7. The format of STATUS object body has following format:




The status code (or status for short) in a STATUS may be one of the followings:

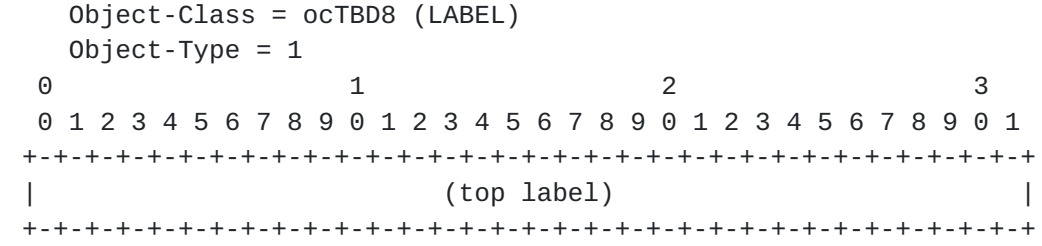
1 (SUCCESS): Indicating a request is successfully finished.

2 (FAIL): Indicating a request can not be finished.

When the status is FAIL, the Reason gives a reason for the failure and the Optional TLVs give some more details about failure.

### 6.6.8. LABEL Object

The LABEL Object has Object-Class ocTBD8. The format of LABEL object body has following format:




The contents of a LABEL is a single label, encoded in 4 octets.

### 6.6.9. INTERFACE Object

The INTERFACE Object has Object-Class ocTBD9. Three Object-Types are defined under INTERFACE object:

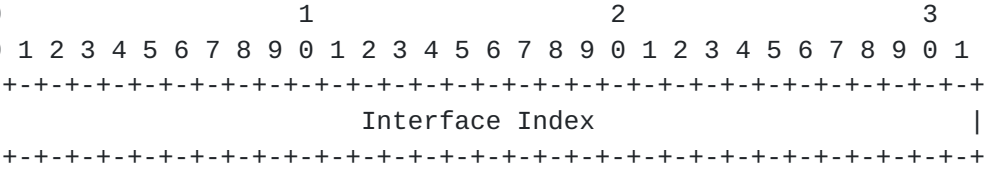
1. Index: Object-Type is 1.

2. IPv4 Address: Object-Type is 2.

3. IPv6 Address: Object-Type is 3.

The format of INTERFACE object body for interface index has following format:

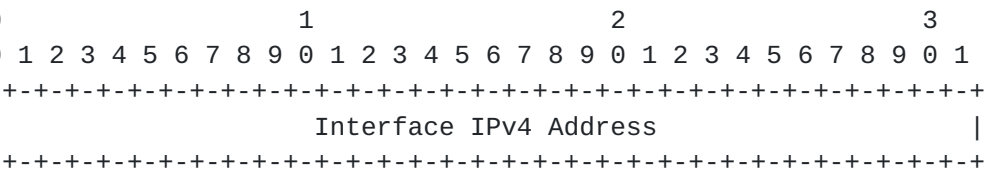
Object-Class = ocTBD9 (INTERFACE)
Object-Type = 1 (Index)




The Interface Index is a single interface index, encoded in 4 octets.

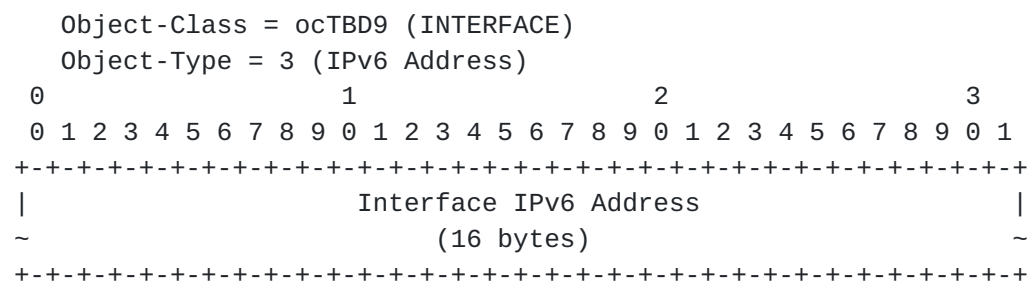
The format of INTERFACE object body for interface IPv4 address has following format:

Object-Class = ocTBD9 (INTERFACE)
Object-Type = 2 (IPv4 Address)




The Interface IPv4 Address is a single interface IPv4 address, encoded in 4 octets.

The format of INTERFACE object body for interface IPv6 address has following format:




The Interface IPv6 Address is a single interface IPv6 address, encoded in 16 octets.

## 7. Security Considerations

The mechanism described in this document does not raise any new security issues for the PCEP protocols.

## 8. IANA Considerations

This section specifies requests for IANA allocation.

## 9. Acknowledgement

The authors would like to thank people for their valuable comments on this draft.

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## 10.2. Informative References

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## Appendix A. Details on Embedded Encoding of Messages

A new options field of 3 bits is defined in the flags field of the RP object to tell the receiver of the message that the request/reply is for one of the five request/reply messages for supporting HSCS as follows:

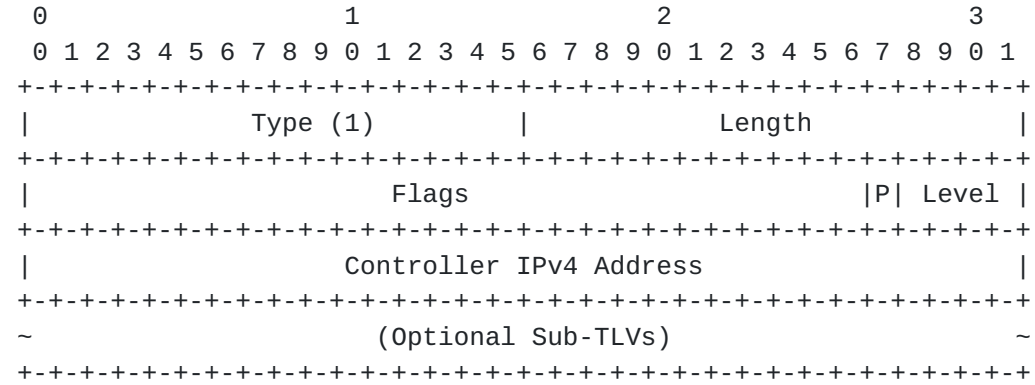
| Options | Meaning |
|---|---|
| 1 | Path Segment Computation Request/Reply |
| 2 | Remove Path Segment Request/Reply |
| 3 | Keep Path Segment Request/Reply |
| 4 | Create Tunnel Segment Request/Reply |
| 5 | Remove Tunnel Segment Request/Reply |

A new flag E of 1 bit is defined in the flags field of the RP object. Flag E set to 1 indicating computing a shortest path segment satisfying a given set of constraints from a start node to each of the edge nodes of the domain controlled by a child controller except for the nodes in a given exception list.

### A.1. Message for Controller Relation Discovery

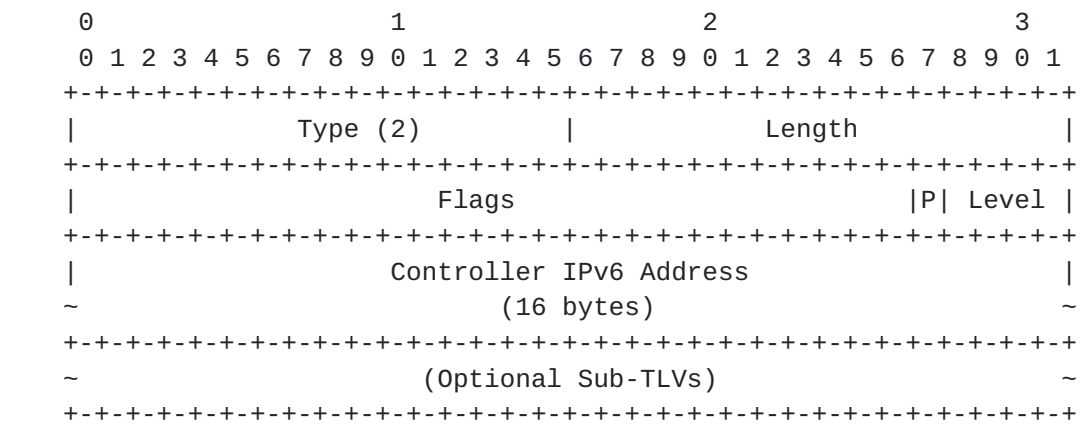
The new TLV defined in the Open Object in section Capability Discovery is extended to contain Sub-TLVs for local controller and remote controller. Thus Open Message with the Open Object containing the new TLV can be used as Message for Controller Relation Discovery. Four optional Sub-TLVs are defined as follows:

1. Local Controller IPv4 Sub-TLV



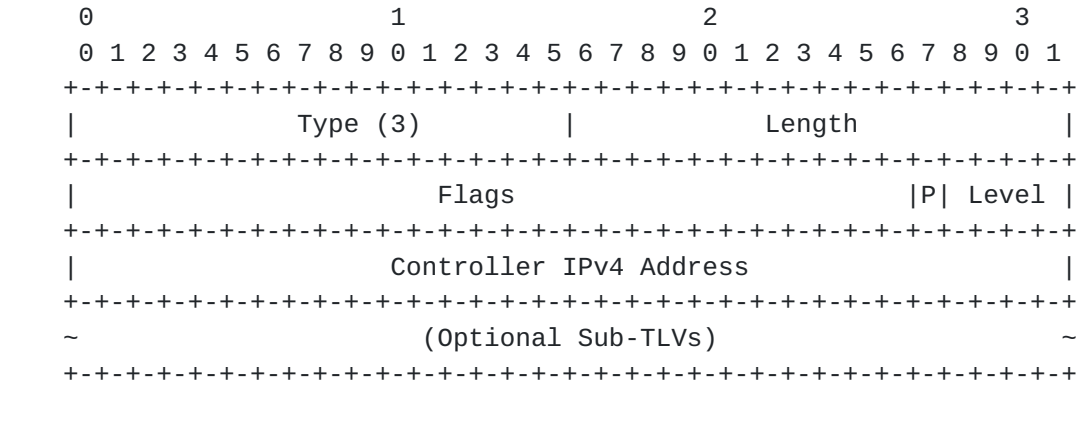
The meanings of each field in the Sub-TLV is the same as described in section LOCAL-CONTROLLER Object for IPv4.

2. Local Controller IPv6 Sub-TLV



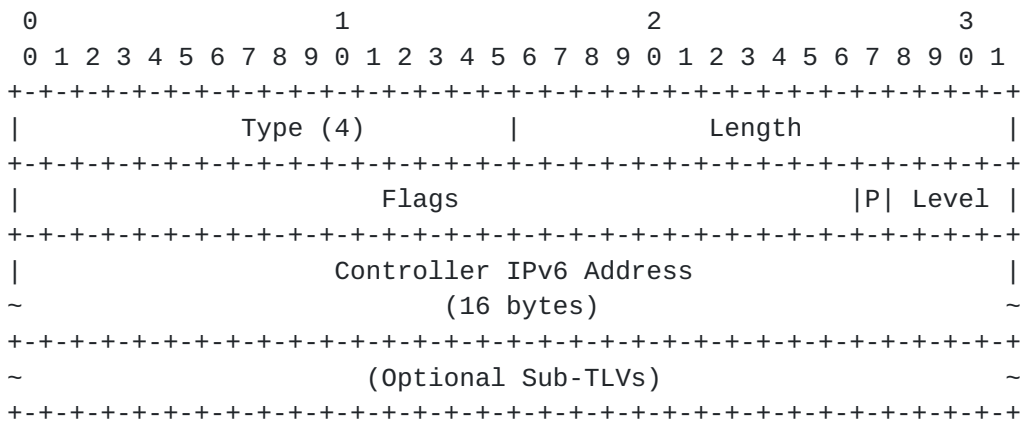

The meanings of each field in the Sub-TLV is the same as described in section LOCAL-CONTROLLER Object for IPv6.

3. Remote Controller IPv4 Sub-TLV




The meanings of each field in the Sub-TLV is the same as described in section REMOTE-CONTROLLER Object for IPv4.

4. Remote Controller IPv6 Sub-TLV




The meanings of each field in the Sub-TLV is the same as described in section REMOTE-CONTROLLER Object for IPv6.

## A.2. Message for Connections and Accesses Advertisement

The format of the CAAdv message is as follows:

```
<CAAdv Message> ::= <Common Header>
                    <SRP>
                    <Inter-Domain-Link-List>
                    [<Access-Address-List>]
where:
<Inter-Domain-Link-List> ::= <Inter-Domain-Link>
                             [<Inter-Domain-Link-List>]
<Access-Address-List> ::= <Access-Address>
                          [<Access-Address-List>]
```

## A.3. Request for Computing Path Segments

The format of the PSReq message is as follows:

```
<PSReq Message> ::= <Common Header>
                    [<svec-list>]
                    <path-segment-request-list>
where:
  <svec-list>::=<SVEC>[<svec-list>]
  <path-segment-request-list> ::=
                    <path-segment-request>
                    [<path-segment-request-list>]

  <path-segment-request> ::=
                    <RP> <END-POINTS> [<OF>] [<LSPA>] [<BANDWIDTH>]
                    <Tunnel-ID> <Path-ID>
                    [<metric-list>] [<RRO>[<BANDWIDTH>]] [<IRO>]
                    [<LOAD-BALANCING>]
                    <exception-list>
```

### A.4. Reply for Computing Path Segments

The format of the PSRep message is as follows:

```
<PSRep Message> ::= <Common Header>
                    <path-segment-reply-list>
where:
  <path-segment-reply-list> ::=
                    <path-segment-reply>
                    [<path-segment-reply-list>]

  <path-segment-reply> ::=
                    <RP> [<NO-PATH>] [<attribute-list>]
                    <Tunnel-ID> <Path-ID>
                    <Start-Node>
                    [ <NO-PATH> | <segment-end-List> ]
                    [<attribute-list>]
```

### A.5. Request for Removing Path Segments

The format of the RPSReq message is as follows:

```
<RPSReq Message> ::= <Common Header>
                     <remove-path-segment-request-list>
where:
  <remove-path-segment-request-list> :: =
                     <remove-path-segment-request>
                     [<remove-path-segment-request-list>]

  <remove-path-segment-request> ::=
                     <RP>
                     <Tunnel-ID> [<Path-ID>]
                     [<start-node-list>]
                     [<branch-List>]

  <start-node-list> ::= <Start-Node> [<start-node-list>]

  <branch-list> ::= <Branch> [<branch-list>]
  <Branch> ::= <Start-Node> <branch-end-list>

  <branch-end-list> ::= <Branch-End> [<branch-end-list>]
```

### A.6. Reply for Removing Path Segments

The format of the RPSRep message is as follows:

```
<RPSRep Message> ::= <Common Header>
                     <remove-path-segment-reply-list>
where:
  <remove-path-segment-reply-list> ::=
                     <remove-path-segment-reply>
                     [<remove-path-segment-reply-list>]

  <remove-path-segment-reply> ::=
                     <RP>
                     <Tunnel-ID> [<Path-ID>]
                     <Status>
                     [<Reasons>]
```

### A.7. Request for Keeping Path Segments

The format of the KPSReq message is as follows:

```
<KPSReq Message> ::= <Common Header>
                     <keep-path-segment-request-list>
where:
  <keep-path-segment-request-list> :: =
                     <keep-path-segment-request>
                     [<keep-path-segment-request-list>]

  <keep-path-segment-request> ::=
                     <RP>
                     <Tunnel-ID> <Path-ID>
                     <segment-list>

  <segment-list> ::= <Segment> [<segment-list>]
  <Segment> ::= <Segment-Start> <Segment-End>
```

### A.8. Reply for Keeping Path Segments

The format of the KPSRep message is as follows:

```
<KPSRep Message> ::= <Common Header>
                     <keep-path-segment-reply-list>
where:
  <keep-path-segment-reply-list> ::=
                     <keep-path-segment-reply>
                     [<keep-path-segment-reply-list>]

  <keep-path-segment-reply> ::=
                     <RP>
                     <Tunnel-ID> <Path-ID>
                     <Status>
                     [<Reasons>]
```

### A.9. Request for Creating Tunnel Segment

The format of the CTSReq message is as follows:

```
<CTSReq Message> ::= <Common Header>
                     <create-tunnel-segment-request-list>
where:
  <create-tunnel-segment-request-list> ::=
                     <create-tunnel-segment-request>
                     [<create-tunnel-segment-request-list>]

  <create-tunnel-segment-request> ::=
                     <RP>
                     <Tunnel-ID> <Path-ID>
                     <Path-Segment>
                     [<Label> <Interface>]

  <Path-Segment> ::= [<Segment-Start> <Segment-End> | <ERO> ]
```

### A.10. Reply for Creating Tunnel Segment

The format of the CTSRep message is as follows:

```
<CTSRep Message> ::= <Common Header>
                     <create-tunnel-segment-reply-list>
where:
  <create-tunnel-segment-reply-list> ::=
                     <create-tunnel-segment-reply>
                     [<create-tunnel-segment-reply-list>]

  <create-tunnel-segment-reply> ::=
                     <RP>
                     <Tunnel-ID> <Path-ID>
                     <Status> [<Label> <Interface>]
                     [<Reasons>]
```

### A.11. Request for Removing Tunnel Segment

The format of the RTSReq message is as follows:

```
<RTSReq Message> ::= <Common Header>
                     <remove-tunnel-segment-request-list>
where:
  <remove-tunnel-segment-request-list> ::=
                     <remove-tunnel-segment-request>
                     [<remove-tunnel-segment-request-list>]

  <remove-tunnel-segment-request> ::
                     <RP>
                     <Tunnel-ID> [<Path-ID>]
```

### A.12. Reply for Removing Tunnel Segment

The format of the RTSRep message is as follows:

```
<RTSRep Message> ::= <Common Header>
                     <remove-tunnel-segment-reply-list>
where:
  <reply-tunnel-segment-reply-list> ::=
                     <remove-tunnel-segment-reply>
                     [<remove-tunnel-segment-reply-list>]

  <remove-tunnel-segment-reply> ::=
                     <RP>
                     <Tunnel-ID> [<Path-ID>]
                     <Status>
                     [<Reasons>]
```

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