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PCEP Extensions for Segment Routing  
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## Abstract

Segment Routing (SR) enables any head-end node to select any path without relying on a hop-by-hop signaling technique (e.g., LDP or RSVP-TE). It depends only on "segments" that are advertised by Link-State Interior Gateway Protocols (IGPs). A Segment Routed Path can be derived from a variety of mechanisms, including an IGP Shortest Path Tree (SPT), explicit configuration, or a Path Computation Element (PCE). This document specifies extensions to the Path Computation Element Protocol (PCEP) that allow a stateful PCE to compute and initiate Traffic Engineering (TE) paths, as well as a PCC to request a path subject to certain constraint(s) and optimization criteria in SR networks.

## Requirements Language

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

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## 1. Introduction

SR technology leverages the source routing and tunneling paradigms. A source node can choose a path without relying on hop-by-hop signaling protocols such as LDP or RSVP-TE. Each path is specified as a set of "segments" advertised by link-state routing protocols (IS-IS or OSPF). [I-D.filsfils-rtgwg-segment-routing] provides an introduction to SR architecture. The corresponding IS-IS and OSPF extensions are specified in [I-D.ietf-isis-segment-routing-extensions] and [I-D.ietf-ospf-segment-routing-extensions], respectively. SR architecture defines a "segment" as a piece of information advertised by a link-state routing protocols, e.g. an IGP prefix or an IGP adjacency. Several types of segments are defined. A Node segment represents an ECMP-aware shortest-path computed by IGP to a specific node, and is always global within SR/IGP domain. An Adjacency Segment represents unidirectional adjacency. An Adjacency Segment is local to the node which advertises it. Both Node segments and Adjacency segments can be used for SR Traffic Engineering (SR-TE).

The SR architecture can be applied to the MPLS forwarding plane without any change, in which case an SR path corresponds to an MPLS Label Switching Path (LSP). This document is relevant to only MPLS forwarding plane, and assumes that a 32-bit Segment Identifier (SID) represents an absolute value of MPLS label entry. In this document, "Node-SID" and "Adjacency-SID" denote Node Segment Identifier and Adjacency Segment Identifier respectively.

A Segment Routed path (SR path) can be derived from an IGP Shortest Path Tree (SPT). SR-TE paths may not follow IGP SPT. Such paths may be chosen by a suitable network planning tool and provisioned on the source node of the SR-TE path.

[RFC5440] describes Path Computation Element Protocol (PCEP) for communication between a Path Computation Client (PCC) and a Path Computation Element (PCE) or between one a pair of PCEs. A PCE or a PCC operating as a PCE (in hierarchical PCE environment) computes paths for MPLS Traffic Engineering LSPs (MPLS-TE LSPs) based on various constraints and optimization criteria. [I-D.ietf-pce-stateful-pce] specifies extensions to PCEP that allow a stateful PCE to compute and recommend network paths in compliance

with [RFC4657] and defines objects and TLVs for MPLS-TE LSPs. Stateful PCEP extensions provide synchronization of LSP state between a PCC and a PCE or between a pair of PCEs, delegation of LSP control, reporting of LSP state from a PCC to a PCE, controlling the setup and path routing of an LSP from a PCE to a PCC. Stateful PCEP extensions are intended for an operational model in which LSPs are configured on the PCC, and control over them is delegated to the PCE.

A mechanism to dynamically initiate LSPs on a PCC based on the requests from a stateful PCE or a controller using stateful PCE is specified in [I-D.ietf-pce-pce-initiated-lsp]. Such mechanism is useful in Software Driven Networks (SDN) applications, such as demand engineering, or bandwidth calendaring.

It is possible to use a stateful PCE for computing one or more SR-TE paths taking into account various constraints and objective functions. Once a path is chosen, the stateful PCE can initiate an SR-TE path on a PCC using PCEP extensions specified in [I-D.ietf-pce-pce-initiated-lsp] using the SR specific PCEP extensions described in this document. Additionally, using procedures described in this document, a PCC can request an SR path from either stateful or a stateless PCE. This specification relies on the PATH-SETUP-TYPE TLV and procedures specified in [I-D.sivabalan-pce-lsp-setup-type].

## 2. Terminology

The following terminologies are used in this document:

ERO: Explicit Route Object

IGP: Interior Gateway Protocol

IS-IS: Intermediate System to Intermediate System

LSR: Label Switching Router

MSD: Maximum SID Depth

NAI: Node or Adjacency Identifier

OSPF: Open Shortest Path First

PCC: Path Computation Client

PCE: Path Computation Element

PCEP: Path Computation Element Protocol

RRO: Record Route Object

SID: Segment Identifier

SR: Segment Routing

SR-TE: Segment Routed Traffic Engineering

TED: Traffic Engineering Database

### 3. Overview of PCEP Operation in SR Networks

In SR networks, an ingress node of an SR path appends all outgoing packets with an SR header consisting of a list of SIDs (or MPLS labels in the context of this document). The header has all necessary information to guide the packets from the ingress node to the egress node of the path, and hence there is no need for any signaling protocol.

In a PCEP session, LSP information is carried in the Explicit Route Object (ERO), which consists of a sequence of subobjects. Various types of ERO subobjects have been specified in [RFC3209], [RFC3473], and [RFC3477]. In SR networks, an ingress node of an SR path appends all outgoing packets with an SR header consisting of a list of SIDs (or MPLS labels in the context of this document). SR-TE LSPs computed by a PCE can be represented in one of the following forms:

- o An ordered set of IP address(es) representing network nodes/links: In this case, the PCC needs to convert the IP address(es) into the corresponding MPLS labels by consulting its Traffic Engineering Database (TED).
- o An ordered set of SID(s).
- o An ordered set of both MPLS label(s) and IP address(es): In this case, the PCC needs to convert the IP address(es) into the corresponding SID(s) by consulting its TED.

This document defines a new ERO subobject denoted by "SR-ERO subobject" capable of carrying a SID as well as the identity of the node/adjacency represented by the SID. SR-capable PCEP speakers should be able to generate and/or process such ERO subobject. An ERO containing SR-ERO subobjects can be included in the PCEP Path Computation Reply (PCRep) message defined in [RFC5440], the PCEP LSP Initiate Request message (PCInitiate) defined in [I-D.ietf-pce-pce-initiated-lsp], as well as in the PCEP LSP Update Request (PCUpd) and PCEP LSP State Report (PCRpt) messages defined in [I-D.ietf-pce-stateful-pce].

When a PCEP session between a PCC and a PCE is established, both PCEP speakers exchange information to indicate their ability to support SR-specific functionality. Furthermore, an LSP initially established via RSVP-TE signaling can be updated with SR-TE path. This capability is useful when a network is migrated from RSVP-TE to SR-TE technology. Similarly, an LSP initially created with SR-TE path can be updated to signal the LSP using RSVP-TE if necessary.

A PCC MAY include an RRO object containing the recorded LSP in PCReq and PCRpt messages as specified in [RFC5440] and [I-D.ietf-pce-stateful-pce] respectively. This document defines a new RRO subobject for SR networks. Methods used by a PCC to record SR-TE LSP are outside the scope of this document.

In summary, this document:

- o Defines a new PCEP capability, new ERO subobject, new RRO subobject, a new TLV, and new PCEP error codes.
- o Specifies how two PCEP speakers can establish a PCEP session that can carry information about SR-TE paths.
- o Specifies processing rules of ERO subobject.
- o Defines a new path setup type carried in the PATH-SETUP-TYPE TLV for SR-TE LSP.

The extensions specified in this document are applicable to the stateless PCE model defined in [RFC5440], as well as for the active stateful and passive stateful PCE models defined in [I-D.ietf-pce-stateful-pce].

#### 4. SR-Specific PCEP Message Extensions

As defined in [RFC5440], a PCEP message consists of a common header followed by a variable length body made up of mandatory and/or optional objects. This document does not require any changes in the format of PCReq and PCRep messages specified in [RFC5440], PCInitiate message specified in [I-D.ietf-pce-pce-initiated-lsp], and PCRpt and PCUpd messages specified in [I-D.ietf-pce-stateful-pce]. However, PCEP messages pertaining to SR-TE LSP MUST include PATH-SETUP-TYPE TLV in the RP or SRP object to clearly identify that SR-TE LSP is intended. In other words, a PCEP speaker MUST not infer whether or not a PCEP message pertains to SR-TE LSP from any other object or TLV.

## 5. Object Formats

### 5.1. The OPEN Object

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

#### 5.1.1. The SR PCE Capability TLV

The SR-PCE-CAPABILITY TLV is an optional TLV associated with the OPEN Object to exchange SR capability of PCEP speakers. The format of the SR-PCE-CAPABILITY TLV is shown in the following figure:

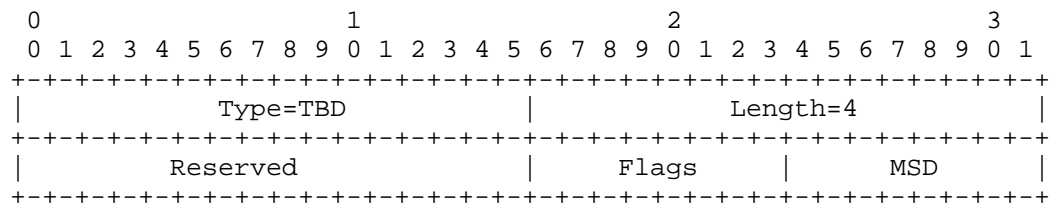


Figure 1: SR-PCE-CAPABILITY TLV format

The code point for the TLV type is to be defined by IANA. The TLV length is 4 octets.

The 32-bit value is formatted as follows. The "Maximum SID Depth" (1 octet) field (MSD) specifies the maximum number of SIDs that a PCC is capable of imposing on a packet. The "Flags" (1 octet) and "Reserved" (2 octets) fields are currently unused, and MUST be set to zero on transmission and ignored on reception.

##### 5.1.1.1. Exchanging SR Capability

By including the SR-PCE-CAPABILITY TLV in the OPEN message destined to a PCE, a PCC indicates that it is capable of supporting the head-end functions for SR-TE LSP. By including the TLV in the OPEN message destined to a PCC, a PCE indicates that it is capable of computing SR-TE paths.

The number of SIDs that can be imposed on a packet depends on PCC's data plane's capability. The default value of MSD is 0 meaning that a PCC does not impose any limitation on the number of SIDs included in any SR-TE path coming from PCE. Once an SR-capable PCEP session is established with a non-default MSD value, the corresponding PCE cannot send SR-TE paths with SIDs exceeding that MSD value. If a PCC needs to modify the MSD value, the PCEP session MUST be closed and re-established with the new MSD value. If a PCEP session is

established with a non-default MSD value, and the PCC receives an SR-TE path containing more SIDs than specified in the MSD value, the PCC MUST send a PCErr message with Error-Type 10 (Reception of an invalid object) and Error-value 3 (Unsupported number of Segment ERO).

The SR Capability TLV is meaningful only in the OPEN message sent from a PCC to a PCE. As such, a PCE does not need to set MSD value in outbound message to a PCC. Similarly, a PCC ignores any MSD value received from a PCE. If a PCE receives multiple SR-PCE-CAPABILITY TLVs in an OPEN message, it processes only the first TLV is processed.

## 5.2. The RP/SRP Object

In order to setup an SR-TE LSP using SR, RP or SRP object MUST PATH-SETUP-TYPE TLV specified in [I-D.sivabalan-pce-lsp-setup-type]. This document defines a new Path Setup Type (PST) for SR as follows:

- o PST = 1: Path is setup using Segment Routing Traffic Engineering technique.

## 5.3. ERO Object

An SR-TE path consists of one or more SID(s) where each SID MAY be associated with the identifier that represents the node or adjacency corresponding to the SID. This identifier is referred to as the 'Node or Adjacency Identifier' (NAI). As described later, a NAI can be represented in various formats (e.g., IPv4 address, IPv6 address, etc). Furthermore, a NAI is used only for troubleshooting purposes, and MUST NOT be used to replace or modify any fields in a data packet header.

The ERO object specified in [RFC5440] is used to carry SR-TE path information. In order to carry SID and/or NAI, this document defines a new ERO subobject referred to as "SR-ERO subobject" whose format is specified in the following section. An ERO object carrying an SR-TE path consists of one or more ERO subobject(s), and MUST carry only SR-ERO subobject. Note that an SR-ERO subobject does not need to have both SID and NAI. However, at least one of them MUST be present.

When building the MPLS label stack from ERO, a PCC MUST assume that SR-ERO subobjects are organized as a last-in-first-out stack. The first subobject relative to the beginning of ERO contains the information about the topmost label. The last subobject contains information about the bottommost label.



## 5.3.1. SR-ERO Subobject

An SR-ERO subobject consists of a 32-bit header followed by the SID and the NAI associated with the SID. The SID is a 32-bit number. The size of the NAI depends on its respective type, as described in the following sections.

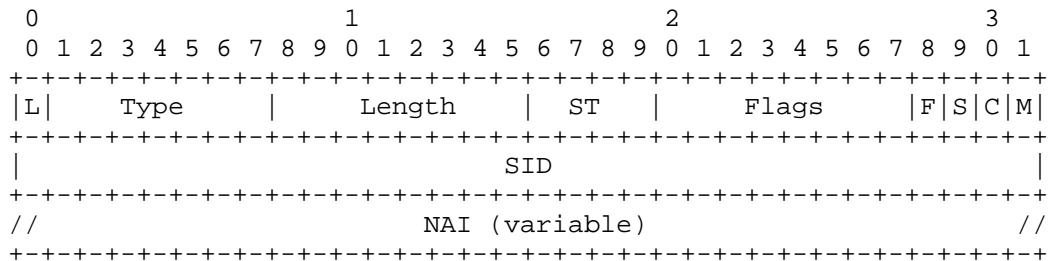


Figure 2: SR-ERO Subobject format

The fields in the SR-ERO Subobject are as follows:

The 'L' Flag indicates whether the subobject represents a loose-hop in the LSP [RFC3209]. If this flag is unset, a PCC MUST not overwrite the SID value present in the SR-ERO subobject. Otherwise, a PCC MAY expand or replace one or more SID value(s) in the received SR-ERO based on its local policy.

Type is the type of the SR-ERO subobject. This document defines the SR-ERO subobject type, and requests a new codepoint from IANA.

Length contains the total length of the subobject in octets, including the L, Type and Length fields. Length MUST be at least 8, and MUST be a multiple of 4. As mentioned earlier, an SR-ERO subobject MUST have at least SID or NAI. The length should take into consideration SID or NAI only if they are not null. The flags described below used to indicate whether SID or NAI field is null.

SID Type (ST) indicates the type of information associated with the SID contained in the object body. The SID-Type values are described later in this document.

Flags is used to carry any additional information pertaining to SID. Currently, the following flag bits are defined:

- \* M: When this bit is set, the SID value represents an MPLS label stack entry as specified in [RFC5462] where only the label value is specified by the PCE. Other fields (TC, S, and TTL) fields MUST be considered invalid, and PCC MUST set these fields according to its local policy and MPLS forwarding rules.
- \* C: When this bit as well as the M bit are set, then the SID value represents an MPLS label stack entry as specified in [RFC5462], where all the entry's fields (Label, TC, S, and TTL) are specified by the PCE. However, a PCC MAY choose to override TC, S, and TTL values according its local policy and MPLS forwarding rules.
- \* S: When this bit is set, the SID value in the subobject body is null. In this case, the PCC is responsible for choosing the SID value, e.g., by looking up its TED using the NAI which, in this case, MUST be present in the subobject.
- \* F: When this bit is set, the NAI value in the subobject body is null.

Editorial Note: we need to decide how to treat an SR-ERO subobject in which both NAI and SID are null.

SID is the Segment Identifier.

NAI contains the NAI associated with the SID. Depending on the value of ST, the NAI can have different format as described in the following section.

### 5.3.2. NAI Associated with SID

This document defines the following NAIs:

'IPv4 Node ID' is specified as an IPv4 address. In this case, ST value is 1, and the Length is 8 or 12 depending on either SID or NAI or both are included in the subobject.

'IPv6 Node ID' is specified as an IPv6 address. In this case, ST and Length are 2, and Length is 8, 20, or 24 depending on either SID or NAI or both are included in the subobject.

'IPv4 Adjacency' is specified as a pair of IPv4 addresses. In this case, ST value is 3. The Length is 8, 12, or 16 depending on either SID or NAI or both are included in the subobject, and the format of the NAI is shown in the following figure:

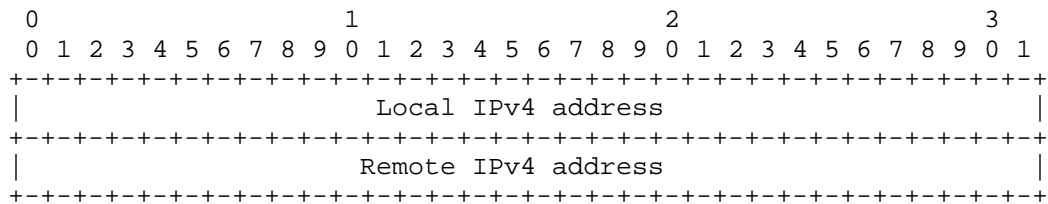


Figure 3: NAI for IPv4 Adjacency

'IPv6 Adjacency' is specified as a pair of IPv6 addresses. In this case, ST value is 4. The Length is 8, 36 or 40 depending on whether SID or NAI or both included in the subobject, and the format of the NAI is shown in the following figure:

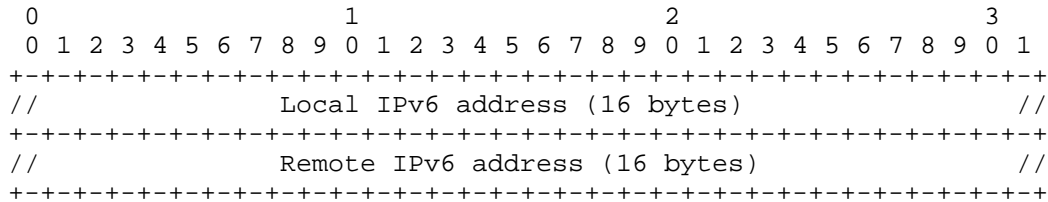


Figure 4: NAI for IPv6 adjacency

'Unnumbered Adjacency with IPv4 NodeIDs' is specified as a pair of Node ID / Interface ID tuples. In this case, ST value is 5. The Length is 8, 20, or 24 depending on whether SID or NAI or both included in the subobject, and the format of the NAI is shown in the following figure:

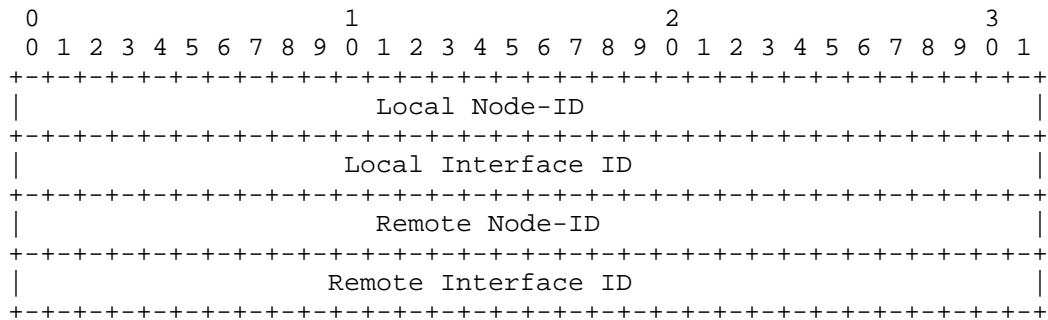


Figure 5: NAI for Unnumbered adjacency with IPv4 Node IDs

Editorial Note: We are yet to decide if another SID subobject is required for unnumbered adjacency with 128 bit node ID.

### 5.3.3. ERO Processing

A PCEP speaker that does not recognize the SR-ERO subobject in PCRep, PCInitiate, PCUpd or PCRpt messages MUST reject the entire PCEP message and MUST send a PCE error message with Error-Type=3 ("Unknown Object") and Error-Value=2 ("Unrecognized object Type") or Error-Type=4 ("Not supported object") and Error-Value=2 ("Not supported object Type"), defined in [RFC5440].

When the SID represents an MPLS label (i.e. the M bit is set), its value (20 most significant bits) MUST be larger than 15, unless it is special purpose label, such as an Entropy Label Indicator (ELI) or an Entropy Label (EL). If a PCEP speaker receives a label ERO subobject with an invalid value, it MUST send the PCE error message with Error-Type = 10 ("Reception of an invalid object") and Error Value = TBD ("Bad label value"). If both M and C bits of an ERO subobject are set, and if a PCEP speaker finds erroneous setting in one or more of TC, S, and TTL fields, it MUST send a PCE error with Error-Type = 10 ("Reception of an invalid object") and Error-Value = TBD ("Bad label format").

If a PCC receives a stack of SR-ERO subobjects, and the number of stack exceeds the maximum number of SIDs that the PCC can impose on the packet, it MAY send a PCE error with Error-Type = 10 ("Reception of an invalid object") and Error-Value = TBD ("Unsupported number of Segment ERO subobjects").

When a PCEP speaker detects that all subobjects of ERO are not identical, and if it cannot handle such ERO, it MUST send PCE error with Error-Type = 10 ("Reception of an invalid object") and Error-Value = TBD ("Non-identical ERO subobjects").

If a PCEP speaker receives an SR-ERO subobject in which both SID and NAI are absent, it MUST consider the entire ERO object invalid and send a PCE error with Error-Type = 10 ("Reception of an invalid object") and Error-Value = TBD ("Both SID and NAI are absent in ERO subobject").

#### 5.4. RRO Object

A PCC can record SR-TE LSP and report the LSP to a PCE via RRO. An RRO object contains one or more subobjects called "SR-RRO subobjects" whose format is shown below:

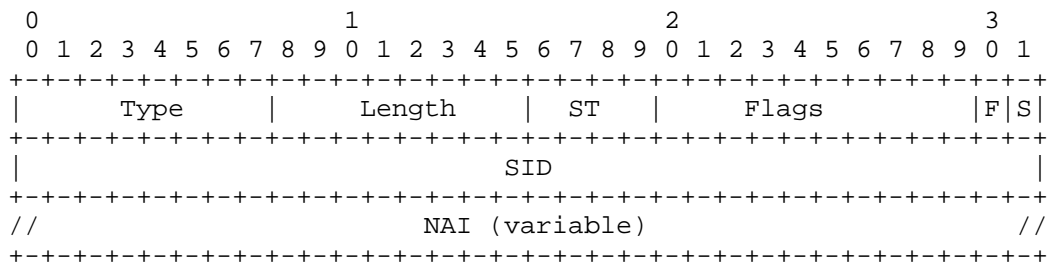


Figure 6: SR-RRO Subobject format

The format of SR-RRO subobject is the same as that of SR-ERO subobject without L, C, and M flags. The F and S flags are used with the same meaning.

A PCC MUST assume that SR-RRO subobjects are organized such that the first subobject relative to the beginning of RRO contains the information about the topmost label, and the last subobject contains information about the bottommost label of the SR-TE LSP.

##### 5.4.1. RRO Processing

Processing rules of SR-RRO subobject are identical to those of SR-ERO subobject.

If a PCEP speaker receives an SR-RRO subobject in which both SID and NAI are absent, it MUST consider the entire RRO object invalid and send a PCE error with Error-Type = 10 ("Reception of an invalid object") and Error-Value = TBD ("Both SID and NAI are absent in RRO subobject").

## 6. Backward Compatibility

A PCEP speaker that does not support the SR PCEP capability cannot recognize the SR-ERO or SR-RRO subobjects. As such, it MUST send a PCEP error with Error-Type = 4 (Not supported object) and Error-Value = 2 (Not supported object Type) as per [RFC5440].

## 7. Management Considerations

### 7.1. Policy

PCEP implementation:

- o Can enable SR PCEP capability either by default or via explicit configuration.
- o May generate PCEP error due to unsupported number of SR-ERO or SR-RRO subobjects either by default or via explicit configuration.

### 7.2. The PCEP Data Model

A PCEP MIB module is defined in [I-D.ietf-pce-pcep-mib] needs be extended to cover additional functionality provided by [RFC5440] and [I-D.ietf-pce-pce-initiated-lsp]. Such extension will cover the new functionality specified in this document.

## 8. Security Considerations

The security considerations described in [RFC5440] and [I-D.ietf-pce-pce-initiated-lsp] are applicable to this specification. No additional security measure is required.

## 9. IANA Considerations

### 9.1. PCEP Objects

IANA is requested to allocate a new ERO subobject and a new RRO subobject types (recommended values = 5 and 6 respectively).

### 9.2. PCEP-Error Object

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

Error-Type	Meaning
10	Reception of an invalid object.

Error-value=2: Bad label value.  
Error-value=3: Unsupported number of Segment ERO subobjects.  
Error-value=4: Bad label format.  
Error-value=5: Non-identical ERO subobjects.  
Error-value=6: Both SID and NAI are absent in ERO subobject.  
Error-value=7: Both SID and NAI are absent in RRO subobject.

### 9.3. PCEP TLV Type Indicators

This document defines the following new PCEP TLVs:

Value	Meaning	Reference
26	SR-PCE-CAPABILITY	This document

### 9.4. New Path Setup Type

This document defines a new setup type for the PATH-SETUP-TYPE TLV as follows:

Value	Description	Reference
1	Traffic engineering path is setup using Segment Routing technique.	This document

## 10. Contributors

The following people contributed to this document:

- Lakshmi Sharma (Cisco Systems)

## 11. Acknowledgements

We like to thank Ina Minei, George Swallow, and Marek Zavodsky for the valuable comments.

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