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1. Introduction

As defined in [\[RFC8402\]](#), Segment Routing (SR) architecture allows the source node to steer a packet through a path indicated by an ordered list of instructions, called segments. A segment can represent any instruction, topological or service-based, and it can have a semantic local to an SR node or global within an SR domain.

[\[RFC5440\]](#) describes Path Computation Element communication Protocol (PCEP) for communication between a Path Computation Client (PCC) and a PCE or between a pair of PCEs. A PCE or a PCC operating as a PCE (in a hierarchical PCE environment) computes paths for MPLS Traffic Engineering LSPs (MPLS-TE LSPs) based on various constraints and optimization criteria.

[\[RFC8231\]](#) 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 [\[RFC8281\]](#). As per [\[RFC8664\]](#), 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 computed, the stateful PCE can initiate an SR-TE path on a PCC using

PCEP extensions specified in [[RFC8281](#)] and the SR-specific PCEP extensions specified in [[RFC8664](#)].

[[RFC8664](#)] specifies PCEP extensions for supporting a SR-TE LSP for the MPLS data-plane. This document extends [[RFC8664](#)] to support SR for the IPv6 data-plane. Additionally, using procedures described in this document, a PCC can request an SRv6 path from either a stateful or stateless PCE. This specification relies on the PATH-SETUP-TYPE TLV and procedures specified in [[RFC8408](#)].

This specification provides a mechanism for a network controller (acting as a PCE) to instantiate candidate paths for an SR Policy onto a head-end node (acting as a PCC) using PCEP. For more information on the SR Policy Architecture, see [[RFC9256](#)] which applies to both SR-MPLS and SRv6.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [[RFC2119](#)] [[RFC8174](#)] when, and only when, they appear in all capitals, as shown here.

2. Terminology

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

This document uses the following terms defined in [[RFC8051](#)]: Stateful PCE, Delegation.

Further, the following terms are used in the document,

MSD: Maximum SID Depth.

PST: Path Setup Type.

SR: Segment Routing.

SID: Segment Identifier.

SRv6: Segment Routing over IPv6 data-plane.

SRH: IPv6 Segment Routing Header [[RFC8754](#)].

SRv6 Path: IPv6 Segment List (List of IPv6 SIDs representing a path in IPv6 SR domain in the context of this document)

Further, note that the term LSP used in the PCEP specifications, would be equivalent to an SRv6 Path (represented as a list of SRv6 segments) in the context of supporting SRv6 in PCEP.

3. Overview of PCEP Operation in SRv6 Networks

Basic operations for PCEP speakers are built on [[RFC8664](#)].

In PCEP messages, route information is carried in the Explicit Route Object (ERO), which consists of a sequence of subobjects. [[RFC8664](#)] defined a new Explicit Route Object (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 for SR-MPLS. SR-capable PCEP speakers can generate and/or process such an 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 [[RFC8281](#)], as well as in the PCEP LSP Update Request (PCUpd) and PCEP LSP State Report (PCRpt) messages defined in [[RFC8231](#)]. [[RFC8664](#)] also defines a new Reported Route Object (RRO) called SR-RRO to represent the SID list that was applied by the PCC, that is, the actual path taken by the LSP in SR-MPLS network.

The SRv6 Paths computed by a PCE can be represented as an ordered list of SRv6 segments. This document defines new subobjects "SRv6-ERO" and "SRv6-RRO" in the ERO and the RRO respectively to carry the SRv6 SID. SRv6-capable PCEP speakers **MUST** be able to generate and/or process these subobjects.

When a PCEP session between a PCC and a PCE is established, both PCEP speakers exchange their capabilities to indicate their ability to support SRv6 specific functionality as described in [Section 4.1.1](#).

In summary, this document,

- *Defines a new PCEP capability for SRv6.
- *Defines a new subobject SRv6-ERO in ERO.
- *Defines a new subobject SRv6-RRO in RRO.
- *Defines a new path setup type (PST) [[RFC8408](#)] carried in the PATH-SETUP-TYPE TLV and the PATH-SETUP-TYPE-CAPABILITY TLV.

3.1. Operation Overview

In SR networks, an SR source node [[RFC8754](#)] steers a packet into an SR Policy resulting in a segment list.

When SR leverages the IPv6 data-plane (i.e. SRv6), the PCEP procedures and mechanisms are extended in this document.

This document describes the extension to support SRv6 in PCEP. A PCC or PCE indicates its ability to support SRv6 during the PCEP session Initialization Phase via a new SRv6-PCE-CAPABILITY sub-TLV (see details in [Section 4.1.1](#)).

3.2. SRv6-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 [[RFC8281](#)], and PCRpt and PCUpd messages specified in [[RFC8231](#)]. However, PCEP messages pertaining to SRv6 **MUST** include PATH-SETUP-TYPE TLV in the RP (Request Parameters) or SRP (Stateful PCE Request Parameters) object to clearly identify that SRv6 is intended.

4. Object Formats

4.1. The OPEN Object

4.1.1. The SRv6 PCE Capability sub-TLV

This document defines a new Path Setup Type (PST) [[RFC8408](#)] for SRv6, as follows.

*PST = 3 : Path is setup using SRv6.

A PCEP speaker indicates its support of the function described in this document by sending a PATH-SETUP-TYPE-CAPABILITY TLV in the OPEN object with this new PST "3" included in the PST list.

This document also defines the SRv6-PCE-CAPABILITY sub-TLV. PCEP speakers use this sub-TLV to exchange information about their SRv6 capability. If a PCEP speaker includes PST=3 in the PST List of the PATH-SETUP-TYPE-CAPABILITY TLV then it **MUST** also include the SRv6-PCE-CAPABILITY sub-TLV inside the PATH-SETUP-TYPE-CAPABILITY TLV. For further error handling, please see [Section 5](#).

The format of the SRv6-PCE-CAPABILITY sub-TLV is shown in the following figure.

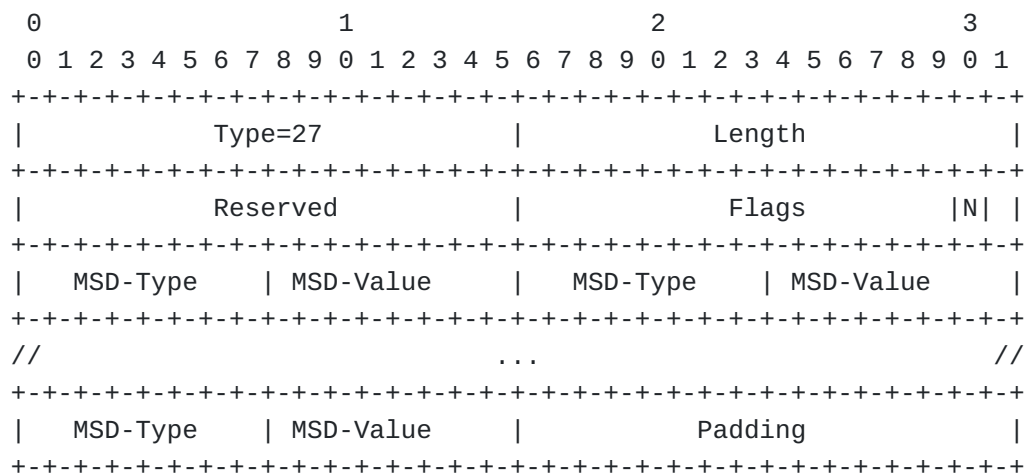


Figure 1: SRv6-PCE-CAPABILITY sub-TLV format

The code point for the TLV type is 27 and the format is compliant with the PCEP TLV format defined in [\[RFC5440\]](#). That is, the sub-TLV is composed of 2 octets for the type, 2 octets specifying the length, and a Value field. The Type field when set to 27 identifies the SRv6-PCE-CAPABILITY sub-TLV and the presence of the sub-TLV indicates the support for the SRv6 paths in PCEP. The Length field defines the length of the value portion in octets. The sub-TLV is padded to 4-octet alignment, and padding is not included in the Length field. The (MSD-Type,MSD-Value) pairs are **OPTIONAL**. The number of (MSD-Type,MSD-Value) pairs can be determined from the Length field of the TLV.

The value comprises of -

Reserved: 2 octet, this field **MUST** be set to 0 on transmission, and ignored on receipt.

Flags: 2 octet, one bit is currently assigned in this document. [Section 9.6](#)

-N bit (bit position 14): A PCC sets this flag bit to 1 to indicate that it is capable of resolving a Node or Adjacency Identifier (NAI) to an SRv6-SID.

-Unassigned bits **MUST** be set to 0 on transmission and ignored on receipt

A pair of (MSD-Type, MSD-Value): Where MSD-Type (1 octet) is as per the IGP MSD Type registry created by [\[RFC8491\]](#) and populated with SRv6 MSD types as per [\[RFC9352\]](#); MSD-Value (1 octet) is as per [\[RFC8491\]](#).

The SRv6 MSD information advertised via SRv6-PCE-Capability sub-TLV conveys the SRv6 capabilities of the PCEP speaker alone. However,

when it comes to the computation of an SR Policy for the SRv6 data-plane, the SRv6 MSD capabilities of all the intermediate SRv6 Endpoint node as well as the tail-end node also need to be considered to ensure those midpoints are able to correctly process their segments and for the tail-end to dispose of the SRv6 encapsulation. The SRv6 MSD capabilities of other nodes might be learned as part of the topology information via BGP-LS[RFC9514] or via PCEP if the PCE also happens to have PCEP sessions to those nodes.

It is recommended that the SRv6 MSD information be not included in the SRv6-PCE-Capability sub-TLV in deployments where the PCE is able to obtain this via IGP/BGP-LS as part of the topology information.

4.2. The RP/SRP Object

This document defines a new Path Setup Type (PST=3) for SRv6. In order to indicate that the path is for SRv6, any RP or SRP object **MUST** include the PATH-SETUP-TYPE TLV as specified in [RFC8408], where PST is set to 3.

4.3. ERO

In order to support SRv6, a new "SRv6-ERO" subobject is defined for inclusion in the ERO.

4.3.1. SRv6-ERO Subobject

An SRv6-ERO subobject is formatted as shown in the following figure.

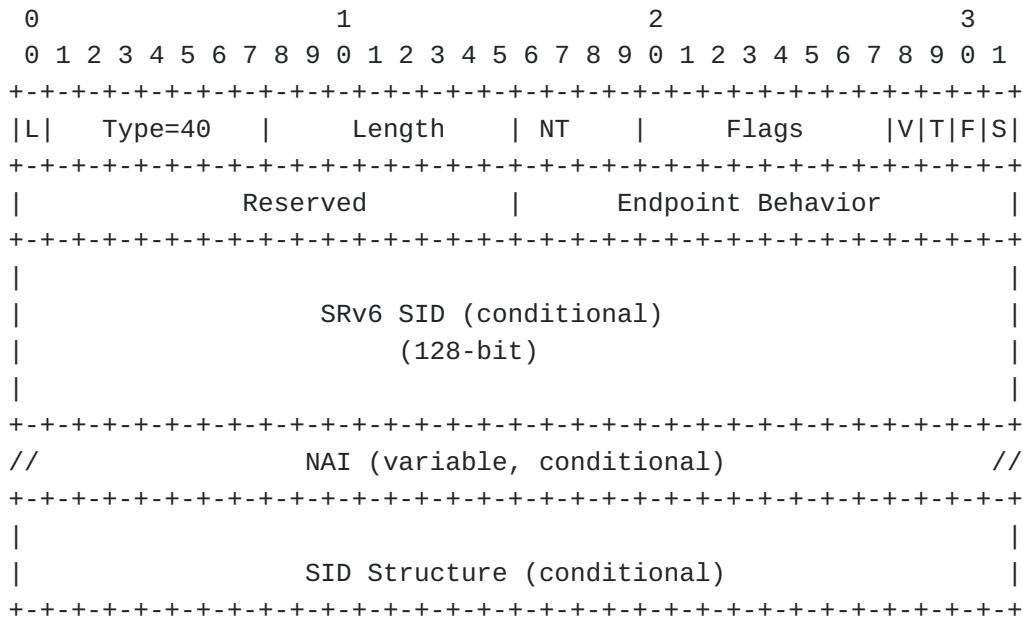


Figure 2: SRv6-ERO Subobject Format

The fields in the SRv6-ERO subobject are as follows:

The 'L' Flag: Indicates whether the subobject represents a loose-hop (see [[RFC3209](#)]). If this flag is set to zero, a PCC **MUST NOT** overwrite the SID value present in the SRv6-ERO subobject. Otherwise, a PCC **MAY** expand or replace one or more SID values in the received SRv6-ERO based on its local policy.

Type: indicates the content of the subobject, i.e. when the field is set to 40, the subobject is an SRv6-ERO subobject representing an SRv6 SID.

Length: Contains the total length of the subobject in octets. The Length **MUST** be at least 24, and **MUST** be a multiple of 4. An SRv6-ERO subobject **MUST** contain at least one of an SRv6-SID or an NAI. The S and F bit in the Flags field indicates whether the SRv6-SID or NAI fields are absent.

NAI Type (NT): Indicates the type and format of the NAI contained in the object body, if any is present. If the F bit is set to one (see below) then the NT field has no meaning and **MUST** be ignored by the receiver. This document creates a new PCEP SRv6-ERO NAI Types registry in [Section 9.2](#) and allocates the following values.

If NT value is 0, the NAI **MUST NOT** be included.

When NT value is 2, the NAI is as per the 'IPv6 Node ID' format defined in [[RFC8664](#)], which specifies an IPv6 address. This is used to identify the owner of the SRv6 Identifier. This is optional, as the LOC (the locator portion) of the SRv6 SID serves a similar purpose (when present).

When NT value is 4, the NAI is as per the 'IPv6 Adjacency' format defined in [[RFC8664](#)], which specify a pair of IPv6 addresses. This is used to identify the IPv6 Adjacency and used with the SRv6 Adj-SID.

When NT value is 6, the NAI is as per the 'link-local IPv6 addresses' format defined in [[RFC8664](#)], which specify a pair of (global IPv6 address, interface ID) tuples. It is used to identify the IPv6 Adjacency and used with the SRv6 Adj-SID.

Flags: Used to carry additional information pertaining to the SRv6-SID. This document defines the following flag bits. The other bits **MUST** be set to zero by the sender and **MUST** be ignored by the receiver. This document creates a new registry SRv6-ERO Flag Field registry in [Section 9.3](#) and allocates the following values.

*S: When this bit is set to 1, the SRv6-SID value in the subobject body is absent. In this case, the PCC is responsible for choosing

the SRv6-SID value, e.g., by looking up in the SR-DB using the NAI which, in this case, **MUST** be present in the subobject. If the S bit is set to 1 then F bit **MUST** be set to zero.

*F: When this bit is set to 1, the NAI value in the subobject body is absent. The F bit **MUST** be set to 1 if NT=0, and otherwise **MUST** be set to zero. The S and F bits **MUST NOT** both be set to 1.

*T: When this bit is set to 1, the SID Structure value in the subobject body is present. The T bit **MUST** be set to 0 when S bit is set to 1. If the T bit is set when the S bit is set, the T bit **MUST** be ignored. Thus, the T bit indicates the presence of an optional 8-byte SID Structure when SRv6 SID is included. The SID Structure is defined in [Section 4.3.1.1](#).

*V: The "SID verification" bit usage is as per Section 5.1 of [\[RFC9256\]](#). If a PCC "Verification fails" for a SID, it **MUST** report this error by including the LSP-ERROR-CODE TLV with LSP error-value "SID Verification fails" in the LSP object in the PCRpt message to the PCE.

Reserved: **MUST** be set to zero while sending and ignored on receipt.

Endpoint Behavior: A 16-bit field representing the behavior associated with the SRv6 SIDs. This information is optional, but it is recommended to signal it always if possible. It could be used for maintainability and diagnostic purpose. If behavior is not known, value '0xFFFF' defined in the registry "SRv6 Endpoint Behaviors" is used [\[RFC8986\]](#).

SRv6 SID: SRv6 Identifier is an 128-bit value representing the SRv6 segment.

NAI: The NAI associated with the SRv6-SID. The NAI's format depends on the value in the NT field, and is described in [\[RFC8664\]](#).

At least one SRv6-SID or the NAI **MUST** be included in the SRv6-ERO subobject, and both **MAY** be included.

4.3.1.1. SID Structure

The SID Structure is an optional part of the SR-ERO subobject, as described in [Section 4.3.1](#).

[\[RFC8986\]](#) defines an SRv6 SID as consisting of LOC:FUNCT:ARG, where a locator (LOC) is encoded in the L most significant bits of the SID, followed by F bits of function (FUNCT) and A bits of arguments (ARG). A locator may be represented as B:N where B is the SRv6 SID locator block (IPv6 prefix allocated for SRv6 SIDs by the operator)

and N is the identifier of the parent node instantiating the SID called locator node.

It is formatted as shown in the following figure.

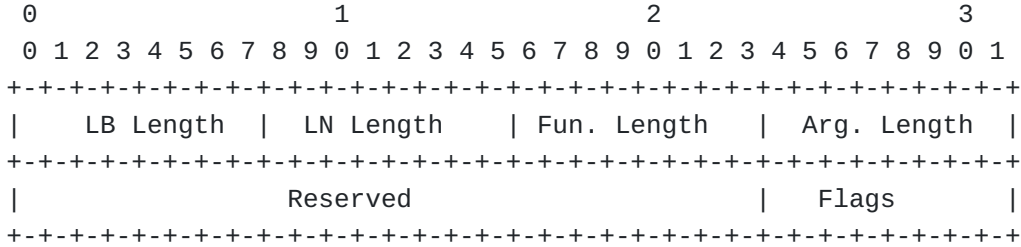


Figure 3: SID Structure Format

where:

LB Length: 1 octet. SRv6 SID Locator Block length in bits.

LN Length: 1 octet. SRv6 SID Locator Node length in bits.

Fun. Length: 1 octet. SRv6 SID Function length in bits.

Arg. Length: 1 octet. SRv6 SID Arguments length in bits.

The sum of all four sizes in the SID Structure must be lower or equal to 128 bits. If the sum of all four sizes advertised in the SID Structure is larger than 128 bits, the corresponding SRv6 SID **MUST** be considered invalid and a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-Value = 37 ("Invalid SRv6 SID Structure") is returned.

Reserved: **MUST** be set to zero while sending and ignored on receipt.

Flags: Currently no flags are defined. Unassigned bits must be set to zero while sending and ignored on receipt.

The SRv6 SID Structure provides the detailed encoding information of an SRv6 SID, which is useful in the use cases that require to know the SRv6 SID structure. When a PCEP speaker receives the SRv6 SID and its structure information, the SRv6 SID can be parsed based on the SRv6 SID Structure and/or possible local policies. The SRv6 SID Structure could be used by the PCE for ease of operations and monitoring. For example, this information could be used for validation of SRv6 SIDs being instantiated in the network and checked for conformance to the SRv6 SID allocation scheme chosen by the operator as described in Section 3.2 of [\[RFC8986\]](#). In the

future, PCE might also be utilized to verify and automate the security of the SRv6 domain by provisioning filtering rules at the domain boundaries as described in Section 5 of [[RFC8754](#)]. The details of these potential applications are outside the scope of this document.

4.3.1.2. Order of the Optional fields

The optional elements in the SRv6-ERO subobject i.e. SRv6 SID, NAI and the SID Structure **MUST** be encoded in the order as depicted in [Figure 2](#). The presence or absence of each of them is indicated by the respective flags i.e. S flag, F flag and T flag.

In order to ensure future compatibility, any optional elements added to the SRv6-ERO subobject in the future must specify their order and request the Internet Assigned Numbers Authority (IANA) to allocate a flag to indicate their presence from the subregistry created in [Section 9.3](#).

4.4. RRO

In order to support SRv6, a new "SRv6-RRO" subobject is defined for inclusion in the RRO.

4.4.1. SRv6-RRO Subobject

A PCC reports an SRv6 path to a PCE by sending a PCRpt message, per [[RFC8231](#)]. The RRO on this message represents the SID list that was applied by the PCC, that is, the actual path taken. The procedures of [[RFC8664](#)] with respect to the RRO apply equally to this specification without change.

An RRO contains one or more subobjects called "SRv6-RRO subobjects" whose format is shown below.

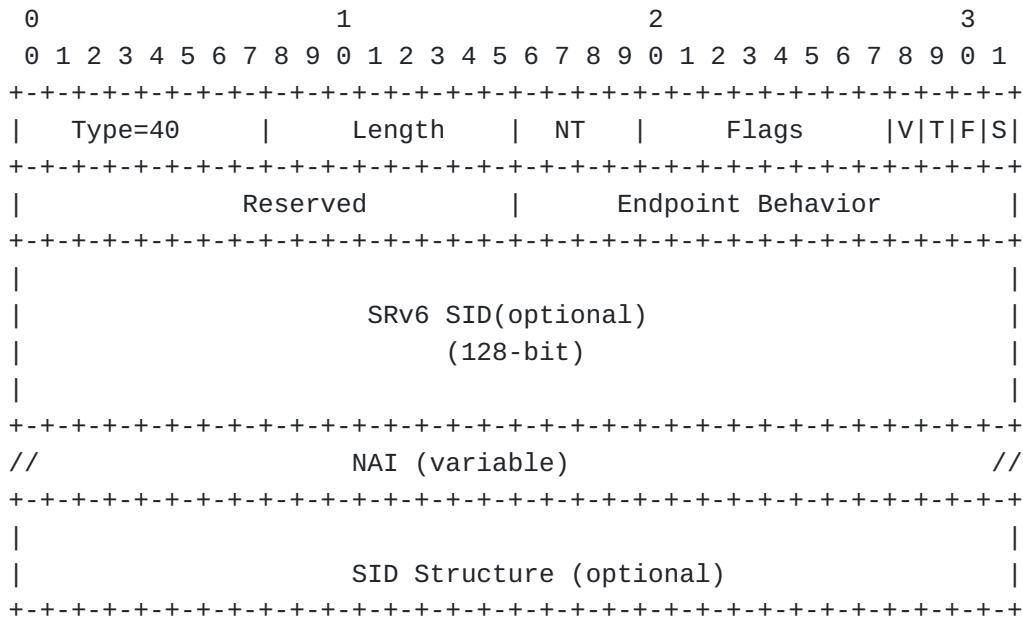


Figure 4: SRv6-RR0 Subobject Format

The format of the SRv6-RR0 subobject is the same as that of the SRv6-ERO subobject, but without the L flag.

The V flag has no meaning in the SRv6-RR0 and is ignored on receipt at the PCE.

Ordering of SRv6-RR0 subobjects by PCC in PCRpt message remains as per [\[RFC8664\]](#).

The ordering of optional elements in the SRv6-RR0 subobject is the same as described in [Section 4.3.1.2](#).

5. Procedures

5.1. Exchanging the SRv6 Capability

A PCC indicates that it is capable of supporting the head-end functions for SRv6 by including the SRv6-PCE-CAPABILITY sub-TLV in the Open message that it sends to a PCE. A PCE indicates that it is capable of computing SRv6 paths by including the SRv6-PCE-CAPABILITY sub-TLV in the Open message that it sends to a PCC.

If a PCEP speaker receives a PATH-SETUP-TYPE-CAPABILITY TLV with a PST list containing PST=3, but the SRv6-PCE-CAPABILITY sub-TLV is absent, then the PCEP speaker **MUST** send a PCErr message with Error-Type = 10 (Reception of an invalid object) and Error-Value = 34 (Missing PCE-SRv6-CAPABILITY sub-TLV) and **MUST** then close the PCEP session. If a PCEP speaker receives a PATH-SETUP-TYPE-CAPABILITY TLV with an SRv6-PCE-CAPABILITY sub-TLV, but the PST list does not

contain PST=3, then the PCEP speaker **MUST** ignore the SRv6-PCE-CAPABILITY sub-TLV.

In case the MSD-Type in SRv6-PCE-CAPABILITY sub-TLV received by the PCE does not correspond to one of the SRv6 MSD types, the PCE **MUST** respond with a PCErr message (Error-Type = 1 "PCEP session establishment failure" and Error-Value = 1 "reception of an invalid Open message or a non Open message.").

Note that the MSD-Type, MSD-Value exchanged via the SRv6-PCE-CAPABILITY sub-TLV indicates the SRv6 SID imposition limit for the sender PCC node only. However, if a PCE learns these via alternate mechanisms, e.g. routing protocols [[RFC9352](#)], then it ignores the values in the SRv6-PCE-CAPABILITY sub-TLV. Furthermore, whenever a PCE learns any other SRv6 MSD types that may be defined in the future via alternate mechanisms, it **MUST** use those values regardless of the values exchanged in the SRv6-PCE-CAPABILITY sub-TLV.

During path computation, PCE must consider the MSD information of all the nodes along the path instead of only the MSD information of the ingress PCC since a packet may be dropped on any node in a forwarding path because of MSD exceeding. The MSD capabilities of all SR nodes along the path can be learned as part of the topology information via IGP/BGP-LS or via PCEP if the PCE also happens to have PCEP sessions to those nodes.

A PCE **MUST NOT** send SRv6 paths exceeding the SRv6 MSD capabilities of the PCC. If a PCC needs to modify the SRv6 MSD value signaled via the Open message, it **MUST** close the PCEP session and re-establish it with the new value. If the PCC receives an SRv6 path that exceed its SRv6 MSD capabilities, the PCC **MUST** send a PCErr message with Error-Type = 10 (Reception of an invalid object) and Error-Value = 39 (Unsupported number of SRv6-ERO subobjects).

The N flag and (MSD-Type,MSD-Value) pair inside the SRv6-PCE-CAPABILITY sub-TLV are meaningful only in the Open message sent to a PCE. As such, the flags **MUST** be set to zero and a (MSD-Type,MSD-Value) pair **MUST NOT** be present in the SRv6-PCE-CAPABILITY sub-TLV in an Open message sent to a PCC. Similarly, a PCC **MUST** ignore flags and any (MSD-Type,MSD-Value) pair in a received Open message. If a PCE receives multiple SRv6-PCE-CAPABILITY sub-TLVs in an Open message, it processes only the first sub-TLV received.

5.2. ERO Processing

The processing of ERO remains unchanged in accordance with both [[RFC5440](#)] and [[RFC8664](#)].

5.2.1. SRv6 ERO Validation

If a PCC does not support the SRv6 PCE Capability and thus cannot recognize the SRv6-ERO or SRv6-RR0 subobjects, it should respond according to the rules for a malformed object as described in [\[RFC5440\]](#).

On receiving an SRv6-ERO, a PCC **MUST** validate that the Length field, the S bit, the F bit, the T bit, and the NT field are consistent, as follows.

*If NT=0, the F bit **MUST** be 1, the S bit **MUST** be zero and the Length **MUST** be 24.

*If NT=2, the F bit **MUST** be zero. If the S bit is 1, the Length **MUST** be 24, otherwise the Length **MUST** be 40.

*If NT=4, the F bit **MUST** be zero. If the S bit is 1, the Length **MUST** be 40, otherwise the Length **MUST** be 56.

*If NT=6, the F bit **MUST** be zero. If the S bit is 1, the Length **MUST** be 48, otherwise the Length **MUST** be 64.

*If T bit is 1, then S bit **MUST** be zero.

If a PCC finds that the NT field, Length field, S bit, F bit, and T bit are not consistent, it **MUST** consider the entire ERO invalid and **MUST** send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-Value = 11 ("Malformed object").

If a PCC does not recognize or support the value in the NT field, it **MUST** consider the entire ERO invalid and send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-value = 40 ("Unsupported NAI Type in the SRv6-ERO/SRv6-RR0 subobject").

If a PCC receives an SRv6-ERO subobject in which the S and F bits are both set to 1 (that is, both the SID and NAI are absent), it **MUST** consider the entire ERO invalid and send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-value = 41 ("Both SID and NAI are absent in the SRv6-ERO subobject").

If a PCC receives an SRv6-ERO subobject in which the S bit is set to 1 and the F bit is set to zero (that is, the SID is absent and the NAI is present), but the PCC does not support NAI resolution, it **MUST** consider the entire ERO invalid and send a PCErr message with Error-Type = 4 ("Not supported object") and Error-value = 4 ("Unsupported parameter").

If a PCC detects that the subobjects of an ERO are a mixture of SRv6- ERO subobjects and subobjects of other types, then it **MUST**

send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-value = 42 ("ERO mixes SRv6-ERO subobjects with other subobject types").

In case a PCEP speaker receives an SRv6-ERO subobject, when the PST is not set to 3 or SRv6-PCE-CAPABILITY sub-TLV was not exchanged, it **MUST** send a PCErr message with Error-Type = 19 ("Invalid Operation") and Error-Value = 19 ("Attempted SRv6 when the capability was not advertised").

If a PCC receives an SRv6 path that exceeds the SRv6 MSD capabilities, it **MUST** send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-Value = 43 ("Unsupported number of SRv6-ERO subobjects") as per [\[RFC8664\]](#).

5.2.2. Interpreting the SRv6-ERO

The SRv6-ERO contains a sequence of subobjects. According to [\[RFC9256\]](#), each SRv6-ERO subobject in the sequence identifies a segment that the traffic will be directed to, in the order given. That is, the first subobject identifies the first segment the traffic will be directed to, the second SRv6-ERO subobject represents the second segment, and so on.

5.3. RRO Processing

The syntax checking rules that apply to the SRv6-RRO subobject are identical to those of the SRv6-ERO subobject, except as noted below.

If a PCEP speaker receives an SRv6-RRO subobject in which both SRv6 SID and NAI are absent, it **MUST** consider the entire RRO invalid and send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-Value = 35 ("Both SID and NAI are absent in SRv6-RRO subobject").

If a PCE detects that the subobjects of an RRO are a mixture of SRv6-RRO subobjects and subobjects of other types, then it **MUST** send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-Value = 36 ("RRO mixes SRv6-RRO subobjects with other subobject types").

The mechanism by which the PCC learns the path is outside the scope of this document.

6. Security Considerations

The security considerations described in [\[RFC5440\]](#), section 2.5 of [\[RFC6952\]](#), [\[RFC8231\]](#), [\[RFC8281\]](#), [\[RFC8253\]](#) and [\[RFC8664\]](#) are applicable to this specification.

Note that this specification enables a network controller to instantiate an SRv6 path in the network. This creates an additional vulnerability if the security mechanisms of [\[RFC5440\]](#), [\[RFC8231\]](#), and [\[RFC8281\]](#) are not used. If there is no integrity protection on the session, then an attacker could create an SRv6 path that may not be subjected to the further verification checks. Further, the MSD field in the Open message could disclose node forwarding capabilities if suitable security mechanisms are not in place. Hence, securing the PCEP session using Transport Layer Security (TLS) [\[RFC8253\]](#) is **RECOMMENDED**.

7. Manageability Considerations

All manageability requirements and considerations listed in [\[RFC5440\]](#), [\[RFC8231\]](#), [\[RFC8281\]](#), and [\[RFC8664\]](#) apply to PCEP protocol extensions defined in this document. In addition, requirements and considerations listed in this section apply.

7.1. Control of Function and Policy

A PCEP implementation **SHOULD** allow the operator to configure the SRv6 capability. Further a policy to accept NAI only for the SRv6 **SHOULD** be allowed to be set.

7.2. Information and Data Models

The PCEP YANG module is out of the scope of this document and defined in other documents, for example, [\[I-D.ietf-pce-pcep-yang\]](#). An augmented YANG module for SRv6 is also specified in another document [\[I-D.ietf-pce-pcep-srv6-yang\]](#) that allows for SRv6 capability and MSD configurations as well as to monitor the SRv6 paths set in the network.

7.3. Liveness Detection and Monitoring

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

7.4. Verify Correct Operations

Verification of the mechanisms defined in this document can be built on those already listed in [\[RFC5440\]](#), [\[RFC8231\]](#), and [\[RFC8664\]](#).

7.5. Requirements On Other Protocols

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

7.6. Impact On Network Operations

Mechanisms defined in [\[RFC5440\]](#), [\[RFC8231\]](#), and [\[RFC8664\]](#) also apply to PCEP extensions defined in this document.

8. Implementation Status

[Note to the RFC Editor - remove this section before publication, as well as remove the reference to [\[RFC7942\]](#)].

This section records the status of known implementations of the protocol defined by this specification at the time of posting of this Internet-Draft, and is based on a proposal described in [\[RFC7942\]](#). The description of implementations in this section is intended to assist the IETF in its decision processes in progressing drafts to RFCs. Please note that the listing of any individual implementation here does not imply endorsement by the IETF. Furthermore, no effort has been spent to verify the information presented here that was supplied by IETF contributors. This is not intended as, and must not be construed to be, a catalog of available implementations or their features. Readers are advised to note that other implementations may exist.

According to [\[RFC7942\]](#), "this will allow reviewers and working groups to assign due consideration to documents that have the benefit of running code, which may serve as evidence of valuable experimentation and feedback that have made the implemented protocols more mature. It is up to the individual working groups to use this information as they see fit".

8.1. Cisco's Commercial Delivery

*Organization: Cisco Systems, Inc.

*Implementation: IOS-XR PCE and PCC.

*Description: Implementation with experimental codepoints.

*Maturity Level: Production

*Coverage: Partial

*Contact: ssidor@cisco.com

8.2. Huawei's Commercial Delivery

*Organization: Huawei Technologies Co.,Ltd.

*Implementation: Huawei Routers and NCE Controller

*Description: Huawei has Implemented this draft to support PCE-Initiated SRv6 Policy.

*Maturity Level: Production

*Coverage: Partial

*Contact: yuwei.yuwei@huawei.com

9. IANA Considerations

9.1. PCEP ERO and RRO subobjects

This document defines a new subobject type for the PCEP explicit route object (ERO), and a new subobject type for the PCEP reported route object (RRO). The code points for subobject types of these objects is maintained in the RSVP parameters registry, under the EXPLICIT_ROUTE and REPORTED_ROUTE objects. IANA is requested to confirm the following allocations in the RSVP Parameters registry for each of the new subobject types defined in this document.

Object	Subobject	Subobject Type
-----	-----	-----
EXPLICIT_ROUTE	SRv6-ERO (PCEP-specific)	40
ROUTE_RECORD	SRv6-RRO (PCEP-specific)	40

9.2. New SRv6-ERO NAI Type Registry

IANA is requested to create a new sub-registry, named "PCEP SRv6-ERO NAI Types", within the "Path Computation Element Protocol (PCEP) Numbers" registry to manage the 4-bit NT field in SRv6-ERO subobject. The allocation policy for this new registry is by IETF Review[[RFC8126](#)].The new registry contains the following values.

Value	Description	Reference
-----	-----	-----
0	NAI is absent.	This document
1	Unassigned	
2	NAI is an IPv6 node ID.	This document
3	Unassigned	
4	NAI is an IPv6 adjacency with global IPv6 addresses.	This document
5	Unassigned	
6	NAI is an IPv6 adjacency with link-local IPv6 addresses.	This document
7-15	Unassigned	

9.3. New SRv6-ERO Flag Registry

IANA is requested to create a new sub-registry, named "SRv6-ERO Flag Field", within the "Path Computation Element Protocol (PCEP) Numbers" registry to manage the 12-bit Flag field of the SRv6-ERO subobject. New values are to be assigned by Standards Action [[RFC8126](#)]. Each bit should be tracked with the following qualities.

*Bit (counting from bit 0 as the most significant bit)

*Description

*Reference

The following values are defined in this document.

Bit	Description	Reference
-----	-----	-----
0-7	Unassigned	
8	SID Verification (V)	This document
9	SID Structure is present (T)	This document
10	NAI is absent (F)	This document
11	SID is absent (S)	This document

9.4. LSP-ERROR-CODE TLV

This document defines a new value in the sub-registry "LSP-ERROR-CODE TLV Error Code Field" in the "Path Computation Element Protocol(PCEP) Numbers" registry.

Value	Meaning	Reference
---	-----	-----
TBD	SID Verification fails	This document

9.5. PATH-SETUP-TYPE-CAPABILITY Sub-TLV Type Indicators

IANA maintains a sub-registry, named "PATH-SETUP-TYPE-CAPABILITY Sub-TLV Type Indicators", within the "Path Computation Element Protocol (PCEP) Numbers" registry to manage the type indicator space for sub-TLVs of the PATH-SETUP-TYPE-CAPABILITY TLV. IANA is requested to confirm the following allocations in the sub-registry.

Value	Meaning	Reference
-----	-----	-----
27	SRv6-PCE-CAPABILITY	This Document

9.6. SRv6 PCE Capability Flags

IANA is requested to create a new sub-registry, named "SRv6 Capability Flag Field", within the "Path Computation Element Protocol (PCEP) Numbers" registry to manage the 16-bit Flag field of the SRv6-PCE-CAPABILITY sub-TLV. New values are to be assigned by Standards Action [[RFC8126](#)]. Each bit should be tracked with the following qualities.

*Bit (counting from bit 0 as the most significant bit)

*Description

*Reference

The following values are defined in this document.

Bit	Description	Reference
-----	-----	-----
0-13	Unassigned	
14	Node or Adjacency Identifier (NAI) is supported (N)	This document
15	Unassigned	

9.7. New Path Setup Type

[[RFC8408](#)] created a sub-registry within the "Path Computation Element Protocol (PCEP) Numbers" registry called "PCEP Path Setup Types". IANA is requested to confirm the following allocations in the sub-registry.

Value	Description	Reference
-----	-----	-----
3	Traffic engineering path is setup using SRv6.	This Document

9.8. ERROR Objects

IANA is requested to confirm the following allocations in the PCEP-ERROR Object Error Types and Values registry for the following new error-values.

Error-Type	Meaning
-----	-----
10	Reception of an invalid object Error-value = 34 (Missing PCE-SRV6-CAPABILITY sub-TLV) Error-value = 35 (Both SID and NAI are absent in SRv6-RR0 subobject) Error-value = 36 (RR0 mixes SRv6-RR0 subobjects with other subobject types) Error-value = 37 (Invalid SRv6 SID Structure)
19	Invalid Operation Error-value = 19 (Attempted SRv6 when the capability was not advertised)

IANA is requested to make new allocations in the PCEP-ERROR Object Error Types and Values registry for the following new error-values.

Error-Type	Meaning
-----	-----
10	Reception of an invalid object Error-value = TBD (Unsupported number of SRv6-ERO subobjects) Error-value = TBD (Unsupported NAI Type in the SRv6-ERO/SRv6-RR0 subobject) Error-value = TBD (Both SID and NAI are absent in the SRv6-ERO subobject) Error-value = TBD (ERO mixes SRv6-ERO subobjects with other subobject types) Error-value = TBD (Unsupported number of SRv6-ERO subobjects)

10. References

10.1. Normative References

- [RFC3209] Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V., and G. Swallow, "RSVP-TE: Extensions to RSVP for LSP Tunnels", RFC 3209, DOI 10.17487/RFC3209, December 2001, <<https://www.rfc-editor.org/rfc/rfc3209>>.
- [RFC5440] Vasseur, JP., Ed. and JL. Le Roux, Ed., "Path Computation Element (PCE) Communication Protocol (PCEP)", RFC 5440, DOI 10.17487/RFC5440, March 2009, <<https://www.rfc-editor.org/rfc/rfc5440>>.
- [RFC8126] Cotton, M., Leiba, B., and T. Narten, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26,

RFC 8126, DOI 10.17487/RFC8126, June 2017, <<https://www.rfc-editor.org/rfc/rfc8126>>.

[RFC8231] Crabbe, E., Minei, I., Medved, J., and R. Varga, "Path Computation Element Communication Protocol (PCEP) Extensions for Stateful PCE", RFC 8231, DOI 10.17487/RFC8231, September 2017, <<https://www.rfc-editor.org/rfc/rfc8231>>.

[RFC8281] Crabbe, E., Minei, I., Sivabalan, S., and R. Varga, "Path Computation Element Communication Protocol (PCEP) Extensions for PCE-Initiated LSP Setup in a Stateful PCE Model", RFC 8281, DOI 10.17487/RFC8281, December 2017, <<https://www.rfc-editor.org/rfc/rfc8281>>.

[RFC8408] Sivabalan, S., Tantsura, J., Minei, I., Varga, R., and J. Hardwick, "Conveying Path Setup Type in PCE Communication Protocol (PCEP) Messages", RFC 8408, DOI 10.17487/RFC8408, July 2018, <<https://www.rfc-editor.org/rfc/rfc8408>>.

[RFC8491] Tantsura, J., Chunduri, U., Aldrin, S., and L. Ginsberg, "Signaling Maximum SID Depth (MSD) Using IS-IS", RFC 8491, DOI 10.17487/RFC8491, November 2018, <<https://www.rfc-editor.org/rfc/rfc8491>>.

[RFC8253] Lopez, D., Gonzalez de Dios, O., Wu, Q., and D. Dhody, "PCEPS: Usage of TLS to Provide a Secure Transport for the Path Computation Element Communication Protocol (PCEP)", RFC 8253, DOI 10.17487/RFC8253, October 2017, <<https://www.rfc-editor.org/rfc/rfc8253>>.

[RFC8664] Sivabalan, S., Filsfils, C., Tantsura, J., Henderickx, W., and J. Hardwick, "Path Computation Element Communication Protocol (PCEP) Extensions for Segment Routing", RFC 8664, DOI 10.17487/RFC8664, December 2019, <<https://www.rfc-editor.org/rfc/rfc8664>>.

[RFC8986] Filsfils, C., Ed., Camarillo, P., Ed., Leddy, J., Voyer, D., Matsushima, S., and Z. Li, "Segment Routing over IPv6 (SRv6) Network Programming", RFC 8986, DOI 10.17487/RFC8986, February 2021, <<https://www.rfc-editor.org/rfc/rfc8986>>.

[RFC9514] Dawra, G., Filsfils, C., Talaulikar, K., Ed., Chen, M., Bernier, D., and B. Decraene, "Border Gateway Protocol - Link State (BGP-LS) Extensions for Segment Routing over IPv6 (SRv6)", RFC 9514, DOI 10.17487/RFC9514, December 2023, <<https://www.rfc-editor.org/rfc/rfc9514>>.

[RFC2119]

Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/rfc/rfc2119>>.

[RFC8174]

Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/rfc/rfc8174>>.

10.2. Informative References

[RFC4657]

Ash, J., Ed. and J.L. Le Roux, Ed., "Path Computation Element (PCE) Communication Protocol Generic Requirements", RFC 4657, DOI 10.17487/RFC4657, September 2006, <<https://www.rfc-editor.org/rfc/rfc4657>>.

[RFC6952]

Jethanandani, M., Patel, K., and L. Zheng, "Analysis of BGP, LDP, PCEP, and MSDP Issues According to the Keying and Authentication for Routing Protocols (KARP) Design Guide", RFC 6952, DOI 10.17487/RFC6952, May 2013, <<https://www.rfc-editor.org/rfc/rfc6952>>.

[RFC7942]

Sheffer, Y. and A. Farrel, "Improving Awareness of Running Code: The Implementation Status Section", BCP 205, RFC 7942, DOI 10.17487/RFC7942, July 2016, <<https://www.rfc-editor.org/rfc/rfc7942>>.

[RFC8051]

Zhang, X., Ed. and I. Minei, Ed., "Applicability of a Stateful Path Computation Element (PCE)", RFC 8051, DOI 10.17487/RFC8051, January 2017, <<https://www.rfc-editor.org/rfc/rfc8051>>.

[RFC8402]

Filsfils, C., Ed., Previdi, S., Ed., Ginsberg, L., Decraene, B., Litkowski, S., and R. Shakir, "Segment Routing Architecture", RFC 8402, DOI 10.17487/RFC8402, July 2018, <<https://www.rfc-editor.org/rfc/rfc8402>>.

[RFC8754]

Filsfils, C., Ed., Dukes, D., Ed., Previdi, S., Leddy, J., Matsushima, S., and D. Voyer, "IPv6 Segment Routing Header (SRH)", RFC 8754, DOI 10.17487/RFC8754, March 2020, <<https://www.rfc-editor.org/rfc/rfc8754>>.

[RFC9256]

Filsfils, C., Talaulikar, K., Ed., Voyer, D., Bogdanov, A., and P. Mattes, "Segment Routing Policy Architecture", RFC 9256, DOI 10.17487/RFC9256, July 2022, <<https://www.rfc-editor.org/rfc/rfc9256>>.

[RFC9352]

Psenak, P., Ed., Filsfils, C., Bashandy, A., Decraene, B., and Z. Hu, "IS-IS Extensions to Support Segment

Routing over the IPv6 Data Plane", RFC 9352, DOI 10.17487/RFC9352, February 2023, <<https://www.rfc-editor.org/rfc/rfc9352>>.

[I-D.ietf-pce-pcep-yang] Dhody, D., Beeram, V. P., Hardwick, J., and J. Tantsura, "A YANG Data Model for Path Computation Element Communications Protocol (PCEP)", Work in Progress, Internet-Draft, draft-ietf-pce-pcep-yang-23, 18 March 2024, <<https://datatracker.ietf.org/doc/html/draft-ietf-pce-pcep-yang-23>>.

[I-D.ietf-pce-pcep-srv6-yang] Li, C., Sivabalan, S., Peng, S., Koldychev, M., and L. Ndifor, "A YANG Data Model for Segment Routing (SR) Policy and SR in IPv6 (SRv6) support in Path Computation Element Communications Protocol (PCEP)", Work in Progress, Internet-Draft, draft-ietf-pce-pcep-srv6-yang-05, 18 March 2024, <<https://datatracker.ietf.org/doc/html/draft-ietf-pce-pcep-srv6-yang-05>>.

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