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Label Switched Path Ping for Segment Routing Path Segment Identifier with MPLS Data Plane
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Abstract

Segment Routing (SR) leverages source routing to steer packets through an ordered list of instructions, called segments. SR can be instantiated over the MPLS data plane. Path Segment Identifiers (PSIDs) are used to identify and correlate bidirectional or end-to-end paths in Segment Routing networks. This document defines procedures (i.e. six new Target forwarding Equivalence Class (FEC) Stack sub-TLVs) for the use of LSP Ping to support connectivity verification and fault isolation for SR paths that include Path Segment Identifiers. The mechanisms described enable the validation and tracing of SR paths with Path SIDs in MPLS networks, complementing existing SR-MPLS OAM capabilities.

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1. Introduction

A Path Segment is a local segment [RFC9545] that uniquely identifies an SR path on the egress node. A Path Segment Identifier (PSID) is a single label that is assigned from the Segment Routing Local Block (SRLB) [RFC8402] of the egress node of an SR path.

As specified in [RFC9545], PSID is a single label inserted by the ingress node of the SR path, and then processed by the egress node of the SR path. The PSID is placed within the MPLS label stack as a label immediately following the last label of the SR path. The egress node pops the PSID.

Procedure for LSP Ping [RFC8029] as defined in Section 7.4 of [RFC8287] is also applicable to PSID, and this document appends existing step 4a with a new step 4b specific to PSID. Concretely, LSP Ping can be used to check the correct operation of a PSID and verify the PSID against the control plane. Checking correct operation means that an initiator can use LSP Ping to check whether a PSID reached the intended node and got processed by that node correctly. Moreover, verifying a PSID against the control plane means that the initiator can use LSP Ping to verify the SR Path context (segment-list, candidate path, or SR policy) associated with the PSID as signaled or provisioned at the egress node. To that end, this document specifies six new Target Forwarding Equivalence Class (FEC) Stack sub-TLVs for such PSID checks.

LSP Traceroute [RFC8287] is left out of this document because transit nodes are not involved in PSID processing.

2. Conventions

2.1. 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.

2.2. Terminology

This document uses the terminology defined in [RFC3031], [RFC8402], [RFC8029], and [RFC9545], readers are expected to be familiar with those terms.

Segment-List-ID

The Segment-List-ID field is a 4-octet identifier that uniquely identifies a segment list within the context of the candidate path of an SR Policy. Although not defined in [RFC9256], the Segment-List-ID is the same identifier as the one that can be signalled through control plane procotols including BGP (Section 2.1 of [I-D.ietf-idr-sr-policy-seglist-id], PCEP (Section 5.2 of [I-D.ietf-pce-multipath]), and BGP-LS (Section 5.7.4 of [I-D.ietf-idr-bgp-ls-sr-policy]).

3. Path Segment ID Sub-TLVs

Analogous to what's defined in Section 5 of [RFC8287] and Section 4 of [RFC9703], six new sub-TLVs are defined for the Target FEC Stack TLV (Type 1), the Reverse-Path Target FEC Stack TLV (Type 16), and the Reply Path TLV (Type 21). Note that the structures of the six new sub-TLVs follow the TLV's structure defined in Section 3 of [RFC8029].

Sub-Type	Sub-TLV Name
TBD1	SR Policy Associated PSID - IPv4
TBD2	SR Candidate Path Associated PSID - IPv4
TBD3	SR Segment List Associated PSID - IPv4
TBD4	SR Policy Associated PSID - IPv6
TBD5	SR Candidate Path Associated PSID - IPv6
TBD6	SR Segment List Associated PSID - IPv6

Table 1: Sub-TLVs for PSID Checks

As specified in Section 2 of [RFC9545], a PSID is used to identify a segment list, some or all segment lists in a Candidate path or an SR policy, so six different Target FEC Stack sub-TLVs need to be defined for PSID. The ordered list of selection rules for the six Target FEC Stack sub-TLVs are defined as follows:

* When a PSID is used to identify all segment lists in an SR Policy, the Target FEC Stack sub-TLV of the type "SR Policy Associated PSID" (for IPv4 or IPv6) MUST be used for PSID checks.

* When a PSID is used to identify all segment lists in an SR Candidate Path, the Target FEC Stack sub-TLV of the type "SR Candidate Path Associated PSID" (for IPv4 or IPv6) MUST be used for PSID checks.

* When a PSID is used to identify a Segment List, the Target FEC Stack sub-TLV of the type "SR Segment List Associated PSID" (for IPv4 or IPv6) MUST be used for PSID checks.

* When a PSID is used to identify some segment lists in a Candidate path or an SR policy, the Target FEC Stack sub-TLV of the type "SR Segment List Associated PSID" (for IPv4 or IPv6) MUST be used for PSID checks. In this case, multiple LSP Ping messages MUST be sent, and one Target FEC Stack sub-TLV of the type "SR Segment List Associated PSID" (for IPv4 or IPv6) MUST be carried in each LSP Ping message.

These six new Target FEC Stack sub-TLVs are not expected to be present in the same message. If more than one of these sub-TLVs are present in a message, only the first sub-TLV will be processed per the validation rules in Section 4.

3.1. SR Policy Associated PSID - IPv4 Sub-TLV

The SR Policy Associated PSID - IPv4 sub-TLV is defined as follows:

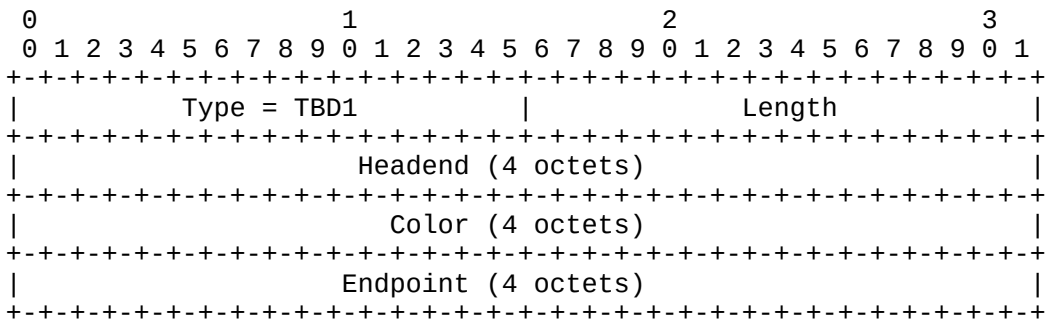

Figure 1: SR Policy Associated PSID - IPv4 sub-TLV Format

Type (length: 2 octets)

The Type field identifies the sub-TLV as an SR Policy Associated PSID - IPv4 Sub-TLV. The value is set to (TBD1) and is to be assigned by IANA.

Length (length: 2 octets)

The Length field indicates the length of the sub-TLV in octets, excluding the first 4 octets (Type and Length fields). The value MUST be set to 12.

Headend (length: 4 octets)

The Headend field encodes the headend IPv4 address of the SR Policy. This field is defined in Section 2.1 of [RFC9256].

Color (length: 4 octets)

The Color field identifies the color (i.e., policy identifier) of the SR Policy and is encoded as defined in Section 2.1 of [RFC9256].

Endpoint (length: 4 octets)

The Endpoint field encodes the endpoint IPv4 address of the SR Policy. This field is defined in Section 2.1 of [RFC9256].

3.2. SR Candidate Path Associated PSID - IPv4 Sub-TLV

The SR Candidate Path Associated PSID - IPv4 sub-TLV is defined as follows:

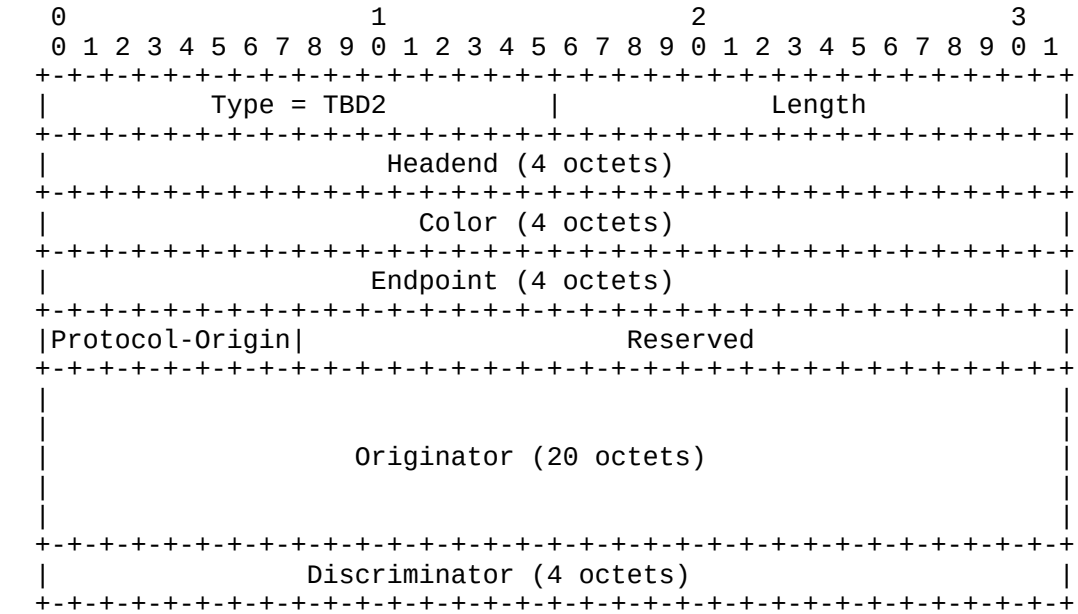

Figure 2: SR Candidate Path Associated PSID - IPv4 sub-TLV Format

Type (length: 2 octets)

The Type field identifies the sub-TLV as an SR Candidate Path Associated PSID - IPv4 sub-TLV. The value is set to (TBD2) and is to be assigned by IANA.

Length (length: 2 octets)

The Length field indicates the length of the sub-TLV in octets, excluding the first 4 octets (Type and Length fields). The value MUST be set to 40.

Headend (length: 4 octets)

The Headend field encodes the headend IPv4 address of the SR Candidate Path. This field is defined in Section 2.1 of [RFC9256].

Color (length: 4 octets)

The Color field identifies the policy color and is defined in Section 2.1 of [RFC9256].

Endpoint (length: 4 octets)

The Endpoint field encodes the endpoint IPv4 address of the SR Candidate Path. This field is defined in Section 2.1 of [RFC9256].

Protocol-Origin (length: 1 octet)

The Protocol-Origin field indicates the protocol that originated the SR Candidate Path. It is defined in Section 2.3 of [RFC9256] and takes values from the IANA registry [PROTOCOL-ORIGIN]. If an unsupported value is used, validation at the responder MUST fail.

Reserved (length: 3 octets)

The Reserved field is reserved for future use. It MUST be set to zero when sent and MUST be ignored upon receipt.

Originator (length: 20 octets)

The Originator field identifies the originator of the SR Candidate Path and is encoded as defined in Section 2.4 of [RFC9256].

Discriminator (length: 4 octets)

The Discriminator field uniquely identifies the SR Candidate Path within the context of the Headend, Color, and Endpoint. This field is defined in Section 2.5 of [RFC9256].

3.3. SR Segment List Associated PSID - IPv4 Sub-TLV

The SR Segment List Associated PSID - IPv4 sub-TLV is used to identify a specific segment list within the context of a candidate path of an SR Policy. The format of this sub-TLV is shown in Figure 3.

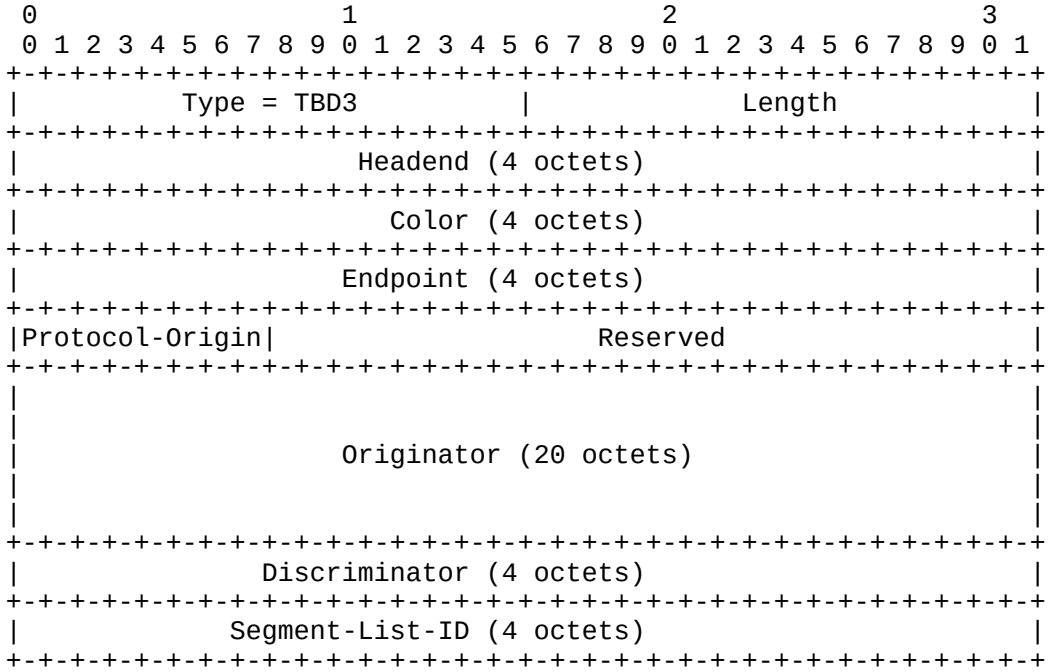

Figure 3: SR Segment List Associated PSID - IPv4 sub-TLV Format

Type (length: 2 octets)

The Type field identifies the sub-TLV as an SR Segment List Associated PSID - IPv4 sub-TLV. The value is set to (TBD3) and is to be assigned by IANA.

Length (length: 2 octets)

The Length field indicates the length of the sub-TLV in octets, excluding the first 4 octets (Type and Length fields). The value MUST be set to 44.

Headend (length: 4 octets)

The Headend field encodes the headend IPv4 address of the SR Policy. This field is defined in Section 2.1 of [RFC9256].

Color (length: 4 octets)

The Color field identifies the color of the SR Policy and is encoded as specified in Section 2.1 of [RFC9256].

Endpoint (length: 4 octets)

The Endpoint field specifies the endpoint IPv4 address of the SR Policy, as defined in Section 2.1 of [RFC9256].

Protocol-Origin (length: 1 octet)

The Protocol-Origin field indicates the protocol that originated the SR Candidate Path. It is defined in Section 2.3 of [RFC9256] and takes values from the IANA registry [PROTOCOL-ORIGIN]. If an unsupported value is used, validation at the responder MUST fail.

Reserved (length: 3 octets)

The Reserved field is reserved for future use. It MUST be set to zero when transmitted and MUST be ignored upon receipt.

Originator (length: 20 octets)

The Originator field identifies the originator of the SR Candidate Path and is defined in Section 2.4 of [RFC9256].

Discriminator (length: 4 octets)

The Discriminator field uniquely identifies the SR Candidate Path within the context of the Headend, Color, and Endpoint. This field is defined in Section 2.5 of [RFC9256].

Segment-List-ID (length: 4 octets)

The Segment-List-ID field is a 4-octet identifier that uniquely identifies a segment list within the context of the candidate path of an SR Policy. This field is defined in terminology of Section 2.2.

3.4. SR Policy Associated PSID - IPv6 Sub-TLV

The SR Policy Associated PSID - IPv6 sub-TLV is defined as follows:

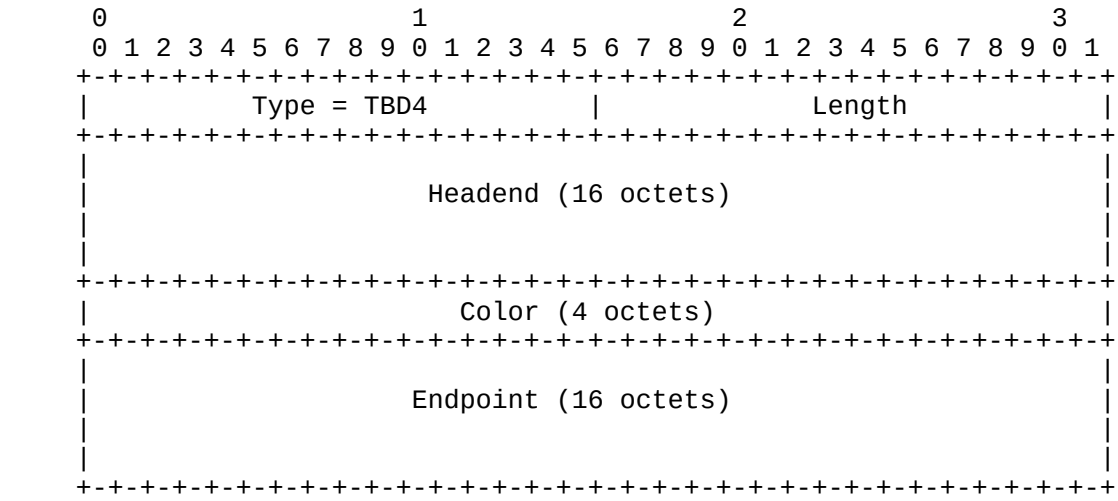

Figure 4: SR Policy Associated PSID - IPv6 sub-TLV Format

Type (length: 2 octets)

The Type field identifies the sub-TLV as an SR Policy Associated PSID - IPv6 Sub-TLV. The value is set to (TBD4) and is to be assigned by IANA.

Length (length: 2 octets)

The Length field indicates the length of the sub-TLV in octets, excluding the first 4 octets (Type and Length fields). The value MUST be set to 36.

Headend (length: 16 octets)

The Headend field encodes the headend IPv6 address of the SR Policy. This field is defined in Section 2.1 of [RFC9256].

Color (length: 4 octets)

The Color field identifies the color (i.e., policy identifier) of the SR Policy and is encoded as defined in Section 2.1 of [RFC9256].

Endpoint (length: 16 octets)

The Endpoint field encodes the endpoint IPv6 address of the SR Policy. This field is defined in Section 2.1 of [RFC9256].

3.5. SR Candidate Path Associated PSID - IPv6 Sub-TLV

The SR Candidate Path Associated PSID - IPv6 sub-TLV is defined as follows:

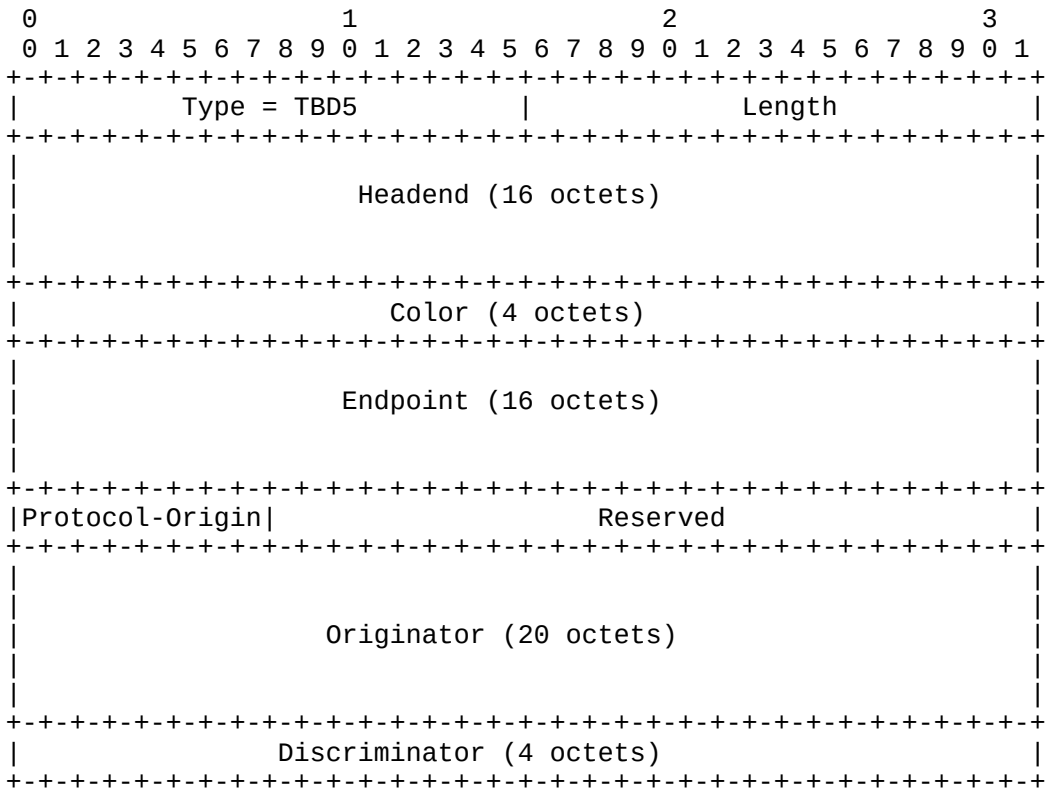

Figure 5: SR Candidate Path Associated PSID - IPv6 sub-TLV Format

Type (length: 2 octets)

The Type field identifies the sub-TLV as an SR Candidate Path Associated PSID - IPv6 sub-TLV. The value is set to (TBD5) and is to be assigned by IANA.

Length (length: 2 octets)

The Length field indicates the length of the sub-TLV in octets, excluding the first 4 octets (Type and Length fields). The value MUST be set to 64.

Headend (length: 16 octets)

The Headend field encodes the headend IPv6 address of the SR Candidate Path. This field is defined in Section 2.1 of [RFC9256].

Color (length: 4 octets)

The Color field identifies the policy color and is defined in Section 2.1 of [RFC9256].

Endpoint (length: 16 octets)

The Endpoint field encodes the endpoint IPv6 address of the SR Candidate Path. This field is defined in Section 2.1 of [RFC9256].

Protocol-Origin (length: 1 octet)

The Protocol-Origin field indicates the protocol that originated the SR Candidate Path. It is defined in Section 2.3 of [RFC9256] and takes values from the IANA registry [PROTOCOL-ORIGIN]. If an unsupported value is used, validation at the responder MUST fail.

Reserved (length: 3 octets)

The Reserved field is reserved for future use. It MUST be set to zero when sent and MUST be ignored upon receipt.

Originator (length: 20 octets)

The Originator field identifies the originator of the SR Candidate Path and is encoded as defined in Section 2.4 of [RFC9256].

Discriminator (length: 4 octets)

The Discriminator field uniquely identifies the SR Candidate Path within the context of the Headend, Color, and Endpoint. This field is defined in Section 2.5 of [RFC9256].

3.6. SR Segment List Associated PSID - IPv6 Sub-TLV

The SR Segment List Associated PSID - IPv6 sub-TLV is used to identify a specific segment list within the context of a candidate path of an SR Policy. The format of this sub-TLV is shown in Figure 6.

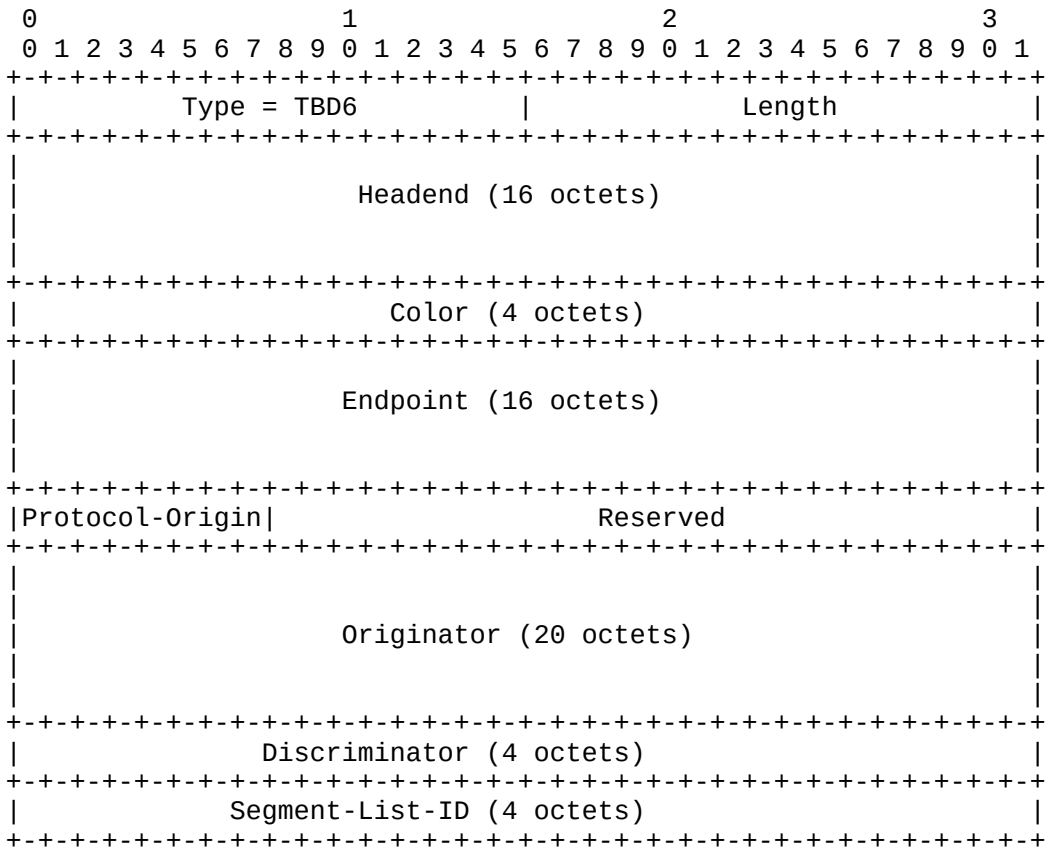

Figure 6: SR Segment List Associated PSID - IPv6 sub-TLV Format

Type (length: 2 octets)

The Type field identifies the sub-TLV as an SR Segment List Associated PSID - IPv6 sub-TLV. The value is set to (TBD6) and is to be assigned by IANA.

Length (length: 2 octets)

The Length field indicates the length of the sub-TLV in octets, excluding the first 4 octets (Type and Length fields). The value MUST be set to 68.

Headend (length: 16 octets)

The Headend field encodes the headend IPv6 address of the SR Policy. This field is defined in Section 2.1 of [RFC9256].

Color (length: 4 octets)

The Color field identifies the color of the SR Policy and is encoded as specified in Section 2.1 of [RFC9256].

Endpoint (length: 16 octets)

The Endpoint field specifies the endpoint IPv6 address of the SR Policy, as defined in Section 2.1 of [RFC9256].

Protocol-Origin (length: 1 octet)

The Protocol-Origin field indicates the protocol that originated the SR Candidate Path. It is defined in Section 2.3 of [RFC9256] and takes values from the IANA registry [PROTOCOL-ORIGIN]. If an unsupported value is used, validation at the responder MUST fail.

Reserved (length: 3 octets)

The Reserved field is reserved for future use. It MUST be set to zero when transmitted and MUST be ignored upon receipt.

Originator (length: 20 octets)

The Originator field identifies the originator of the SR Candidate Path and is defined in Section 2.4 of [RFC9256].

Discriminator (length: 4 octets)

The Discriminator field uniquely identifies the SR Candidate Path within the context of the Headend, Color, and Endpoint. This field is defined in Section 2.5 of [RFC9256].

Segment-List-ID (length: 4 octets)

The Segment-List-ID field is a 4-octet identifier that uniquely identifies a segment list within the context of the candidate path of an SR Policy. This field is defined in terminology of Section 2.2.

4. PSID FEC Validation

The MPLS LSP Ping procedures may be initiated by the headend of the Segment Routing path or a centralized topology-aware data plane monitoring system as described in [RFC8403]. For the PSID, the responder nodes that receive echo request and send echo reply MUST be the endpoint of the SR path.

When an endpoint receives the LSP echo request packet with top FEC being the PSID, it MUST perform validity checks on the content of the PSID FEC Stack sub-TLV.

If a malformed FEC Stack sub-TLV is received, then a return code of 1, "Malformed echo request received" as defined in [RFC8029] MUST be sent. The section below is appended to step 4a of Section 7.4 of [RFC8287].

4.1. PSID FEC Validation Rules

4b. Segment Routing PSID Validation:

If the Label-stack-depth is 1 and the Target FEC Stack sub-TLV at FEC-stack-depth is TBD1 (SR Policy Associated PSID - IPv4 sub-TLV), {

Set the Best-return-code to 10, "Mapping for this FEC is not the given label at stack-depth <RSC>" if any below conditions fail (the notation <RSC> refers to the Return Subcode):

- Validate that the PSID is signaled or provisioned for the SR Policy {

  o Validate that the signaled or provisioned headend, color, and endpoint, for the PSID, matches with the corresponding fields in the received SR Policy Associated PSID - IPv4 sub-TLV.

  }

}

If all the above validations have passed, set the return code to 3 "Replying router is an egress for the FEC at stack-depth <RSC>".

Set FEC-Status to 1 and return.

}

```
   Else, if the Label-stack-depth is 1 and the Target FEC Stack sub-TLV
   at FEC-stack-depth is TBD2 (SR Candidate Path Associated PSID - IPv4
   sub-TLV), {

      Set the Best-return-code to 10, "Mapping for this FEC is not the
      given label at stack-depth <RSC>" if any below conditions fail:

      -  Validate that the PSID is signaled or provisioned for the SR
         Candidate Path {

         o  Validate that the signaled or provisioned headend, color,
            endpoint, originator, and discriminator, for the PSID,
            matches with the corresponding fields in the received SR
            Candidate Path Associated PSID - IPv4 sub-TLV.

         }

      }

      If all the above validations have passed, set the return code to 3
      "Replying router is an egress for the FEC at stack-depth <RSC>".

      Set FEC-Status to 1 and return.

   }

   Else, if the Label-stack-depth is 1 and the Target FEC Stack sub-TLV
   at FEC-stack-depth is TBD3 (SR Segment List Associated PSID - IPv4
   sub-TLV), {

      Set the Best-return-code to 10, "Mapping for this FEC is not the
      given label at stack-depth <RSC>" if any below conditions fail:

      -  Validate that the PSID is signaled or provisioned for the SR
         Segment List {

         o  Validate that the signaled or provisioned headend, color,
            endpoint, originator, discriminator, and segment-list-id,
            for the PSID, matches with the corresponding fields in the
            received SR Segment List Associated PSID - IPv4 sub-TLV.

         }

      }

      If all the above validations have passed, set the return code to 3
      "Replying router is an egress for the FEC at stack-depth <RSC>".
```

Set FEC-Status to 1 and return.

}

Else, if the Label-stack-depth is 1 and the Target FEC Stack sub-TLV at FEC-stack-depth is TBD4 (SR Policy Associated PSID - IPv6 sub-TLV), {

Set the Best-return-code to 10, "Mapping for this FEC is not the given label at stack-depth <RSC>" if any below conditions fail (the notation <RSC> refers to the Return Subcode):

- Validate that the PSID is signaled or provisioned for the SR Policy {

  o Validate that the signaled or provisioned headend, color, and endpoint, for the PSID, matches with the corresponding fields in the received SR Policy Associated PSID - IPv6 sub-TLV.

  }

}

If all the above validations have passed, set the return code to 3 "Replying router is an egress for the FEC at stack-depth <RSC>".

Set FEC-Status to 1 and return.

}

Else, if the Label-stack-depth is 1 and the Target FEC Stack sub-TLV at FEC-stack-depth is TBD5 (SR Candidate Path Associated PSID - IPv6 sub-TLV), {

Set the Best-return-code to 10, "Mapping for this FEC is not the given label at stack-depth <RSC>" if any below conditions fail:

- Validate that the PSID is signaled or provisioned for the SR Candidate Path {

  o Validate that the signaled or provisioned headend, color, endpoint, originator, and discriminator, for the PSID, matches with the corresponding fields in the received SR Candidate Path Associated PSID - IPv6 sub-TLV.

  }

```
      }

      If all the above validations have passed, set the return code to 3
      "Replying router is an egress for the FEC at stack-depth <RSC>".

      Set FEC-Status to 1 and return.

   }

   Else, if the Label-stack-depth is 1 and the Target FEC Stack sub-TLV
   at FEC-stack-depth is TBD6 (SR Segment List Associated PSID - IPv6
   sub-TLV), {

      Set the Best-return-code to 10, "Mapping for this FEC is not the
      given label at stack-depth <RSC>" if any below conditions fail:

      -  Validate that the PSID is signaled or provisioned for the SR
         Segment List {

         o  Validate that the signaled or provisioned headend, color,
            endpoint, originator, discriminator, and segment-list-id,
            for the PSID, matches with the corresponding fields in the
            received SR Segment List Associated PSID - IPv6 sub-TLV.

         }

      }

      If all the above validations have passed, set the return code to 3
      "Replying router is an egress for the FEC at stack-depth <RSC>".

      Set FEC-Status to 1 and return.

   }

   When an SR Policy Associated PSID - IPv4 sub-TLV, or an SR Candidate
   Path Associated PSID - IPv4 sub-TLV, or an SR Segment List Associated
   PSID - IPv4 sub-TLV, or an SR Policy Associated PSID - IPv6 sub-TLV,
   or an SR Candidate Path Associated PSID - IPv6 sub-TLV, or an SR
   Segment List Associated PSID - IPv6 sub-TLV is carried in Reverse-
   Path Target FEC Stack TLV (Type 16) or Reply Path TLV (Type 21), it
   MUST be sent by an endpoint in an echo reply.  The headend MUST
   perform validity checks as described above without setting the return
   code.  If any of the validations fail, then the headend MUST drop the
   echo reply and SHOULD log and/or report an error.
```

5. Security Considerations

This document defines additional MPLS LSP Ping sub-TLVs and follows the mechanisms defined in [RFC8029]. All the security considerations defined in Section 5 of [RFC8029] apply to this document. The MPLS LSP Ping sub-TLVs defined in this document do not impose any additional security challenges to be considered.

6. IANA Considerations

IANA is requested to assign six new Target FEC Stack sub-TLVs from the "Sub-TLVs for TLV Types 1, 16, and 21" registry [MPLS-LSP-PING] within the "TLVs" registry of the "Multiprotocol Label Switching (MPLS) Label Switched Paths (LSPs) Ping Parameters" registry group. The Standards Action range that requires an error message to be returned if the sub-TLV is not recognized (range 0-16383) should be used.

Sub-Type	Sub-TLV Name	Reference
TBD1	SR Policy Associated PSID - IPv4	Section 3.1 of THIS_DOCUMENT
TBD2	SR Candidate Path Associated PSID - IPv4	Section 3.2 of THIS_DOCUMENT
TBD3	SR Segment List Associated PSID - IPv4	Section 3.3 of THIS_DOCUMENT
TBD4	SR Policy Associated PSID - IPv6	Section 3.4 of THIS_DOCUMENT
TBD5	SR Candidate Path Associated PSID - IPv6	Section 3.5 of THIS_DOCUMENT
TBD6	SR Segment List Associated PSID - IPv6	Section 3.6 of THIS_DOCUMENT

Table 2: Sub-TLVs for TLV Types 1, 16, and 21 Registry

7. Acknowledgements

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8. References

8.1. Normative References

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[PROTOCOL-ORIGIN] "SR Policy Protocol Origin", <https://www.iana.org/assignments/segment-routing/segment-routing.xhtml#sr-policy-protocol-origin>.

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