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Compressed SRv6 Segment List Encoding

Abstract

Segment Routing over IPv6 (SRv6) is the instantiation of Segment Routing (SR) on the IPv6 dataplane. This document specifies new flavors for the SR segment endpoint behaviors defined in RFC 8986, which enable the compression of an SRv6 segment list. Such compression significantly reduces the size of the SRv6 encapsulation needed to steer packets over long segment lists.

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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1. Introduction

The Segment Routing (SR) architecture [RFC8402] describes two data plane instantiations of SR: SR over MPLS (SR-MPLS) and SR over IPv6 (SRv6).

SRv6 Network Programming [RFC8986] defines a framework to build a network program with topological and service segments (also referred

to by their Segment Identifier (SID)) carried in a Segment Routing Header (SRH) [RFC8754].

Some SRv6 applications such as strict path traffic engineering may require long segment lists. Compressing the encoding of these long segment lists in the packet header can significantly reduce the header size. This document specifies new flavors to the SR segment endpoint behaviors defined in [RFC8986] that enable a compressed encoding of the SRv6 segment list.

The flavors defined in this document leverage the SRv6 data plane defined in [RFC8754] and [RFC8986], and are compatible with the SRv6 control plane extensions for IS-IS [RFC9352], OSPF [RFC9513], and BGP [RFC9252].

2. Terminology

This document leverages the terms defined in [RFC8402], [RFC8754], and [RFC8986]. The reader is assumed to be familiar with this terminology.

This document introduces the following new terms:

* Locator-Block: The most significant bits of a SID locator that represent the SRv6 SID block. The Locator-Block is referred to as "B" in Section 3.1 of [RFC8986].

* Locator-Node: The least significant bits of a SID locator that identify the SR segment endpoint node instantiating the SID. The Locator-Node is referred to as "N" in Section 3.1 of [RFC8986].

* Compressed-SID (C-SID): A compressed encoding of a SID. The C-SID includes the Locator-Node and Function bits of the SID being compressed.

* C-SID container: A 128-bit container holding a list of one or more C-SIDs.

* C-SID sequence: A group of one or more consecutive segment list entries carrying the common Locator-Block and at least one C-SID container.

* Uncompressed SID sequence: A group of one or more consecutive uncompressed SIDs in a segment list.

* Compressed segment list encoding: A segment list encoding that reduces the packet header length thanks to one or more C-SID sequences. A compressed segment list encoding also contains zero, one, or more uncompressed SID sequences.

*Global Identifiers Block (GIB): The pool of C-SID values available for global allocation.

*Local Identifiers Block (LIB): The pool of C-SID values available for local allocation.

In this document, the length of each constituent part of a SID is referred to as follows.

*LBL is the Locator-Block length of the SID.

*LNL is the Locator-Node length of the SID.

*FL is the Function length of the SID.

*AL is the Argument length of the SID.

In addition, LNFL is the sum of the Locator-Node length and the Function length of the SID. It is also referred to as the C-SID length.

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.

3. Basic Concepts

In an SR domain, all SRv6 SIDs instantiated from the same Locator-Block share the same most significant bits. In addition, when the combined length of the SRv6 SID Locator, Function, and Argument is smaller than 128 bits, the least significant bits of the SID are padded with zeros. The compressed segment list encoding seeks to decrease the packet header length by avoiding the repetition of the same Locator-Block and reducing the use of padding bits.

The compressed segment list encoding is fully compatible with and builds upon the mechanisms specified in [RFC8754] and [RFC8986]. The compressed encoding is achieved by combining a compressed segment list encoding logic on the SR source node (Section 6) with new flavors of the base SRv6 segment endpoint behaviors that decode this compressed encoding (Section 4).

A segment list can be encoded in the packet header using any combination of compressed and uncompressed sequences. The C-SID sequences leverage the flavors defined in this document, while the uncompressed sequences use behaviors and flavors defined in other

documents, such as [RFC8986]. An SR source node constructs and compresses the SID-list depending on the SIDs instantiated on each SR segment endpoint node that the packet should traverse, as well as its own compression capabilities.

The compressed segment list encoding works with any Locator-Block allocation. For example, each routing domain within the SR domain can be allocated a /48 Locator-Block from a global IPv6 block available to the operator, or from a prefix allocated to SRv6 SIDs as discussed in Section 5 of [I-D.ietf-6man-sids].

4. SR Segment Endpoint Flavors

This section defines two SR segment endpoint flavors, NEXT-C-SID and REPLACE-C-SID, for the End, End.X, End.T, End.B6.Encaps, End.B6.Encaps.Red, and End.BM behaviors of [RFC8986]. This section also defines a REPLACE-C-SID flavor for the End.DX6, End.DX4, End.DT6, End.DT4, End.DT46, End.DX2, End.DX2V, End.DT2U, and End.DT2M behaviors of [RFC8986]. A counterpart NEXT-C-SID flavor is not defined for these SIDs because they can be included within a C-SID sequence that uses the NEXT-C-SID flavor without any modification of the procedure defined in [RFC8986]. Future documents may extend the applicability of the NEXT-C-SID and REPLACE-C-SID flavors to other SR segment endpoint behaviors (see Section 11).

The use of these flavors, either individually or in combination, enables the compressed segment list encoding.

The NEXT-C-SID flavor and the REPLACE-C-SID flavor both leverage the SID Argument to determine the next segment to be processed, but employ different segment list compression schemes. With the NEXT-C-SID flavor, each C-SID container is a fully formed SRv6 SID with the common Locator-Block for all the C-SIDs in the C-SID container, a Locator-Node and Function that are those of the first C-SID, and an Argument carrying the subsequent C-SIDs. With the REPLACE-C-SID flavor, only the first element in a C-SID sequence is a fully formed SRv6 SID. It has the common Locator-Block for all the C-SIDs in the C-SID sequence, and a Locator-Node and Function that are those of the first C-SID. The remaining elements in the C-SID sequence are C-SID containers carrying the subsequent C-SIDs without the Locator-Block.

SRv6 is intended for use in a variety of networks that require different prefix lengths and SID numbering spaces. Each of the two flavors introduced in this document comes with its own recommendations for Locator-Block and C-SID length, as specified in Section 4.1 and Section 4.2. These flavors are best suited for different environments, depending on the requirements of the network. For instance, larger C-SID lengths may be more suitable for networks requiring ample SID numbering space, while smaller C-SID lengths are

better for compression efficiency. The two compression flavors allow the compressed segment list encoding to adapt to a range of requirements, with support for multiple compression levels. Network operators can choose the flavor that best suits their use case, deployment design, and network scale.

The SIDs of both flavors can co-exist in the same SR domain, on the same SR segment endpoint node, and even in the same segment list. However, it is RECOMMENDED, for ease of operation, that a single compressed encoding flavor be used in a given routing domain. In a multi-domain deployment, different flavors may be used in different routing domains of the SR domain.

In the remainder of this document, the term "a SID of this document" refers to any End, End.X, End.T, End.B6.Encaps, End.B6.Encaps.Red, or End.BM SID with the NEXT-C-SID or the REPLACE-C-SID flavor, and with any combination of Penultimate Segment Pop (PSP), Ultimate Segment Pop (USP), and Ultimate Segment Decapsulation (USD) flavor, or any End.DX6, End.DX4, End.DT6, End.DT4, End.DT46, End.DX2, End.DX2V, End.DT2U, or End.DT2M with the REPLACE-C-SID flavor. All the SIDs introduced in this document are listed in Table 1.

In the remainder of this document, the terms "NEXT-C-SID flavor SID" and "REPLACE-C-SID flavor SID" refer to any SID of this document with the NEXT-C-SID flavor and with the REPLACE-C-SID flavor, respectively.

4.1. NEXT-C-SID Flavor

A C-SID sequence using the NEXT-C-SID flavor comprises one or more C-SID containers. Each C-SID container is a fully formed 128-bit SID structured as shown in Figure 1. It carries a Locator-Block followed by a series of C-SIDs. The Locator-Node and Function of the C-SID container are those of the first C-SID, and its Argument is the contiguous series of subsequent C-SIDs. The second C-SID is encoded in the most significant bits of the C-SID container Argument, the third C-SID is encoded in the bits of the Argument that immediately follow the second C-SID, and so on. When all C-SIDs have the same length, a C-SID container can carry up to K C-SIDs, where K is computed as floor((128-LBL)/LNFL) (floor(x) is the greatest integer less than or equal to x [GKP94]). Each C-SID container for NEXT-C-SID is independent, such that contiguous C-SID containers in a C-SID sequence can be considered as separate C-SID sequences.

When a C-SID sequence comprises at least two C-SIDs, the last C-SID in the sequence is not required to have the NEXT-C-SID flavor. It can be bound to any behavior and flavor(s), including the REPLACE-C-SID flavor, as long as the updated destination address resulting from the processing of the previous C-SID in the sequence is a valid form for

that last SID. Line S12 of the first pseudocode in Section 6.2 provides sufficient conditions to ensure this property.

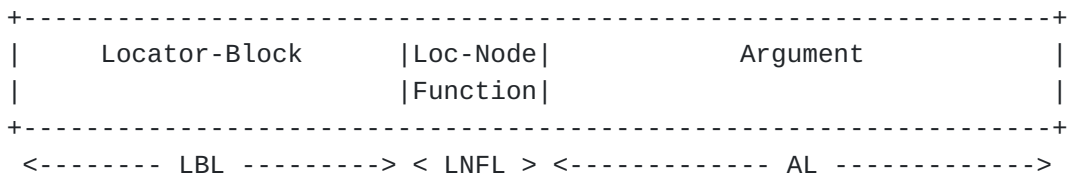


Figure 1: Structure of a NEXT-C-SID flavor SID (scaled for a 48-bit Locator-Block, 16-bit combined Locator-Node and Function, and 64-bit Argument)

An implementation MUST support a 32-bit Locator-Block length (LBL) and a 16-bit C-SID length (LNFL) for NEXT-C-SID flavor SIDs, and may support any other Locator-Block and C-SID length. A deployment SHOULD use a consistent Locator-Block length and C-SID length for all SIDs of the SR domain.

The Argument length (AL) for NEXT-C-SID flavor SIDs is equal to 128-LBL-LNFL.

When processing an IPv6 packet that matches a FIB entry locally instantiated as a SID with the NEXT-C-SID flavor, the SR segment endpoint node applies the procedure specified in the following subsection that corresponds to the SID behavior. If the SID also has the PSP, USP, or USD flavor, the procedure is modified as described in Section 4.1.7.

An SR segment endpoint node instantiating a SID with the NEXT-C-SID flavor MUST accept any Argument value for that SID.

At high level, for any SID with the NEXT-C-SID flavor, the SR segment endpoint node determines the next SID of the SID list as follows. If the Argument value of the active SID is non-zero, the SR segment endpoint node constructs the next SID from the active SID by copying the entire SID Argument value to the bits that immediately follow the Locator-Block, thus overwriting the active SID Locator-Node and Function with those of the next C-SID, and filling the least significant LNFL bits of the Argument with zeros. Otherwise (if the Argument value is 0), the SR segment endpoint node copies the next 128-bit Segment List entry from the SRH to the Destination Address field of the IPv6 header.

4.1.1. End with NEXT-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End SID with the NEXT-C-SID flavor, the procedure

described in Section 4.1 of [RFC8986] is executed with the following modifications.

The below pseudocode is inserted between lines S01 and S02 of the SRH processing in Section 4.1 of [RFC8986]. In addition, this pseudocode is executed before processing any extension header that is not an SRH, a Hop-by-Hop header or a Destination Option header, or before processing the upper-layer header, whichever comes first.

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.   Submit the packet to the egress IPv6 FIB lookup for
         transmission to the next destination.
N09. }
```

Notes:

- *DA.Argument identifies the value contained in the bits [(LBL+LNFL)..127] in the Destination Address of the IPv6 header.

- *The value in the Segments Left field of the SRH is not modified when DA.Argument in the received packet has a non-zero value.

A rendering of the complete pseudocode is provided in Appendix A.1.

4.1.2. End.X with NEXT-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.X SID with the NEXT-C-SID flavor, the procedure described in Section 4.2 of [RFC8986] is executed with the following modifications.

The pseudocode in Section 4.1.1 of this document is modified by replacing line N08 as shown below.

```
N08.   Submit the packet to the IPv6 module for transmission to the
         new destination via a member of J.
```

Note: the variable J is defined in Section 4.2 of [RFC8986].

The resulting pseudocode is inserted between lines S01 and S02 of the SRH processing in Section 4.1 of [RFC8986] after applying the modification described in Section 4.2 of [RFC8986]. In addition, this pseudocode is executed before processing any extension header that is not an SRH, a Hop-by-Hop header or a Destination Option header, or before processing the upper-layer header, whichever comes first.

A rendering of the complete pseudocode is provided in Appendix A.2.

4.1.3. End.T with NEXT-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.T SID with the NEXT-C-SID flavor, the procedure described in Section 4.3 of [RFC8986] is executed with the following modifications.

The pseudocode in Section 4.1.1 of this document is modified by replacing line N08 as shown below.

```
N08.1.   Set the packet's associated FIB table to T.
N08.2.   Submit the packet to the egress IPv6 FIB lookup for
           transmission to the new destination.
```

Note: the variable T is defined in Section 4.3 of [RFC8986].

The resulting pseudocode is inserted between lines S01 and S02 of the SRH processing in Section 4.1 of [RFC8986] after applying the modification described in Section 4.3 of [RFC8986]. In addition, this pseudocode is executed before processing any extension header that is not an SRH, a Hop-by-Hop header or a Destination Option header, or before processing the upper-layer header, whichever comes first.

A rendering of the complete pseudocode is provided in Appendix A.3.

4.1.4. End.B6.Encaps with NEXT-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.B6.Encaps SID with the NEXT-C-SID flavor, the procedure described in Section 4.13 of [RFC8986] is executed with the following modifications.

The pseudocode in Section 4.1.1 of this document is modified by replacing line N08 as shown below.

```
N08.1.   Push a new IPv6 header with its own SRH containing B.
N08.2.   Set the outer IPv6 SA to A.
N08.3.   Set the outer IPv6 DA to the first SID of B.
N08.4.   Set the outer Payload Length, Traffic Class, Flow Label,
           Hop Limit, and Next Header fields.
N08.5.   Submit the packet to the egress IPv6 FIB lookup for
           transmission to the next destination.
```

Note: the variables A and B, as well as the values of the Payload Length, Traffic Class, Flow Label, Hop Limit, and Next Header are defined in Section 4.13 of [RFC8986].

The resulting pseudocode is inserted between lines S01 and S02 of the SRH processing in Section 4.13 of [RFC8986]. In addition, this pseudocode is executed before processing any extension header that is not an SRH, a Hop-by-Hop header or a Destination Option header, or before processing the upper-layer header, whichever comes first.

A rendering of the complete pseudocode is provided in Appendix A.4.

Similar to the base End.B6.Encaps SID defined in Section 4.13 of [RFC8986], the NEXT-C-SID flavor variant updates the Destination Address field of the inner IPv6 header to the next SID in the original segment list before encapsulating the packet with the segment list of SR Policy B. At the endpoint of SR Policy B, the encapsulation is removed and the inner packet is forwarded towards the exposed destination address, which already contains the next SID in the original segment list.

4.1.5. End.B6.Encaps.Red with NEXT-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.B6.Encaps.Red SID with the NEXT-C-SID flavor, the procedure described in Section 4.14 of [RFC8986] is executed with the same modifications as in Section 4.1.4 of this document.

4.1.6. End.BM with NEXT-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.BM SID with the NEXT-C-SID flavor, the procedure described in Section 4.15 of [RFC8986] is executed with the following modifications.

The pseudocode in Section 4.1.1 of this document is modified by replacing line N08 as shown below.

```
N08.1.   Push the MPLS label stack for B.
N08.2.   Submit the packet to the MPLS engine for transmission.
```

Note: the variable B is defined in Section 4.15 of [RFC8986].

The resulting pseudocode is inserted between lines S01 and S02 of the SRH processing in Section 4.15 of [RFC8986]. In addition, this pseudocode is executed before processing any extension header that is not an SRH, a Hop-by-Hop header or a Destination Option header, or before processing the upper-layer header, whichever comes first.

A rendering of the complete pseudocode is provided in Appendix A.5.

4.1.7. Combination with PSP, USP and USD flavors

PSP: The PSP flavor defined in Section 4.16.1 of [RFC8986] is unchanged when combined with the NEXT-C-SID flavor.

USP: The USP flavor defined in Section 4.16.2 of [RFC8986] is unchanged when combined with the NEXT-C-SID flavor.

USD: The USP flavor defined in Section 4.16.3 of [RFC8986] is unchanged when combined with the NEXT-C-SID flavor.

4.2. REPLACE-C-SID Flavor

A C-SID sequence using the REPLACE-C-SID flavor starts with a C-SID container in fully formed 128-bit SID format. The Locator-Block of this SID is the common Locator-Block for all the C-SIDs in the C-SID sequence, its Locator-Node and Function are those of the first C-SID, and its Argument carries the index of the current C-SID in the current C-SID container. The Argument value is initially 0. When more segments are present in the segment list, the C-SID sequence continues with one or more C-SID containers in packed format carrying the subsequent C-SIDs in the sequence. Each container in packed format is a 128-bit Segment List entry split into K "positions" of LNFL bits, where K is computed as floor(128/LNFL). If LNFL does not divide into 128 perfectly, a zero pad is added in the least significant bits of the C-SID container to fill the bits left over. The second C-SID in the C-SID sequence is encoded in the least significant bit position of the first C-SID container in packed format (position K-1), the third C-SID is encoded in position K-2, and so on.

The last C-SID in the C-SID sequence is not required to have the REPLACE-C-SID flavor. It can be bound to any behavior and flavor(s), including the NEXT-C-SID flavor, as long as it meets the conditions defined in Section 6.

The structure of a SID with the REPLACE-C-SID flavor is shown in Figure 2. The same structure is also that of the C-SID container for REPLACE-C-SID in fully formed 128-bit SID format.

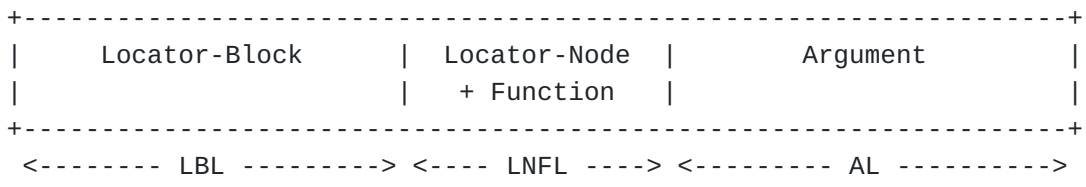


Figure 2: Structure of a REPLACE-C-SID flavor SID (scaled for a 48-bit Locator-Block, 32-bit combined Locator-Node and Function, and 48-bit Argument)

The structure of a C-SID container for REPLACE-C-SID in packed format is shown in Figure 3.

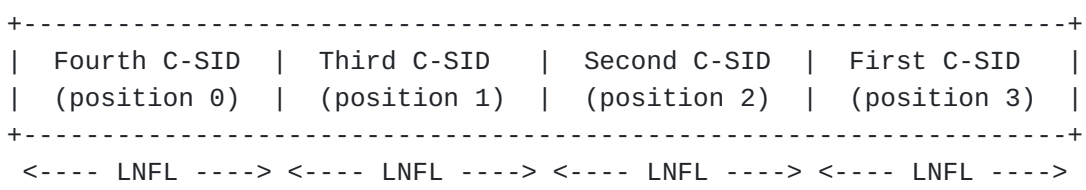


Figure 3: Structure of a C-SID container for REPLACE-C-SID using a 32-bit C-SID length (K = 4)

The REPLACE-C-SID flavor SIDs support any Locator-Block length (LBL), depending on the needs of the operator, as long as it does not exceed 128-LNFL-ceiling(log_2(128/LNFL)) (ceiling(x) is the least integer greater than or equal to x [GKP94]), so that enough bits remain available for the C-SID and Argument. A Locator-Block length of 48, 56, 64, 72, or 80 bits is RECOMMENDED for address planning reasons.

This document defines the REPLACE-C-SID flavor for 16-bit and 32-bit C-SID lengths (LNFL). An implementation MUST support a 32-bit C-SID length for REPLACE-C-SID flavor SIDs.

A deployment SHOULD use a consistent Locator-Block length and C-SID length for all SIDs of the SR domain.

The Argument length (AL) for REPLACE-C-SID flavor SIDs is equal to 128-LBL-LNFL. The index value is encoded in the least significant X bits of the Argument, where X is computed as ceiling(log_2(128/LNFL)).

When processing an IPv6 packet that matches a FIB entry locally instantiated as a SID with the REPLACE-C-SID flavor, the SR segment endpoint node applies the procedure specified in the following subsection that corresponds to the SID behavior. If the SID also has the PSP, USP, or USD flavor, the procedure is modified as described in Section 4.2.8.

At high level, at the start of a C-SID sequence using the REPLACE-C-SID flavor, the first C-SID container in fully formed 128-bit SID format is copied to the Destination Address of the IPv6 header. Then, for any SID with the REPLACE-C-SID flavor, the SR segment endpoint node determines the next SID of the SID list as follows. When an SRH is present, the SR segment endpoint node decrements the index value in the Argument of the active SID if the index value is not 0 or, if it is 0, decrements the Segments Left value in the SRH and sets the index value in the Argument of the active SID to K-1. The updated index value indicates the position of the next C-SID within the C-SID container in packed format at the "Segment List" index "Segments Left" in the SRH. The SR segment endpoint node then constructs the next SID by copying this next C-SID to the bits that immediately follow the Locator-Block in the Destination Address field of the IPv6 header, thus overwriting the active SID Locator-Node and Function with those of the next C-SID. If no SRH is present, the SR segment endpoint node ignores the index value in the SID Argument (except End.DT2M, see Section 4.2.7) and processes the upper-layer header as per [RFC8986]. The C-SID sequence ends with a last C-SID in the last C-SID container that does not have the REPLACE-C-SID flavor, or with the special C-SID value 0, or when reaching the end of the segment list, whichever comes first.

4.2.1. End with REPLACE-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End SID with the REPLACE-C-SID flavor, the SRH processing described in Section 4.1 of [RFC8986] is executed with the following modifications.

Line S02 of SRH processing in Section 4.1 of [RFC8986] is replaced as follows.

```
S02.   If (Segments Left == 0 and (DA.Arg.Index == 0 or
           Segment List[0][DA.Arg.Index-1] == 0)) {
```

Lines S09 to S15 are replaced by the following pseudo code.

```
R01. If (DA.Arg.Index != 0) {
R02.   If ((Last Entry > max_LE) or (Segments Left > Last Entry)) {
R03.     Send an ICMP Parameter Problem to the Source Address,
           Code 0 (Erroneous header field encountered),
           Pointer set to the Segments Left field,
           interrupt packet processing and discard the packet.
R04.   }
R05.   Decrement DA.Arg.Index by 1.
R06.   If (Segment List[Segments Left][DA.Arg.Index] == 0) {
R07.     Decrement Segments Left by 1.
R08.     Decrement IPv6 Hop Limit by 1.
R09.     Update IPv6 DA with Segment List[Segments Left]
R10.     Submit the packet to the egress IPv6 FIB lookup for
          transmission to the new destination.
R11.   }
R12. } Else {
R13.   If((Last Entry > max_LE) or (Segments Left > Last Entry+1)){
R14.     Send an ICMP Parameter Problem to the Source Address,
           Code 0 (Erroneous header field encountered),
           Pointer set to the Segments Left field,
           interrupt packet processing and discard the packet.
R15.   }
R16.   Decrement Segments Left by 1.
R17.   Set DA.Arg.Index to (floor(128/LNFL) - 1).
R18. }
R19. Decrement IPv6 Hop Limit by 1.
R20. Write Segment List[Segments Left][DA.Arg.Index] into the bits
       [LBL..LBL+LNFL-1] of the Destination Address of the IPv6
       header.
R21. Submit the packet to the egress IPv6 FIB lookup for
       transmission to the new destination.
```

Notes:

*DA.Arg.Index identifies the value contained in the bits [(128-ceiling(log_2(128/LNFL)))..127] in the Destination Address of the IPv6 header.

*Segment List[Segments Left][DA.Arg.Index] identifies the value contained in the bits [DA.Arg.Index*LNFL.. (DA.Arg.Index+1)*LNFL-1] in the SRH Segment List entry at index Segments Left.

The upper-layer header processing described in Section 4.1.1 of [RFC8986] is unchanged.

A rendering of the complete pseudocode is provided in Appendix A.6.

4.2.2. End.X with REPLACE-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.X SID with the REPLACE-C-SID flavor, the procedure described in Section 4.2 of [RFC8986] is executed with the following modifications.

The pseudocode in Section 4.2.1 of this document is modified by replacing lines R10 and R21 as shown below.

```
R10. Submit the packet to the IPv6 module for transmission to the
       new destination via a member of J.

R21. Submit the packet to the IPv6 module for transmission to the
       new destination via a member of J.
```

Note: the variable J is defined in Section 4.2 of [RFC8986].

The SRH processing in Section 4.2 of [RFC8986] is replaced with the resulting pseudocode. The upper-layer header processing is unchanged.

A rendering of the complete pseudocode is provided in Appendix A.7.

4.2.3. End.T with REPLACE-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.T SID with the REPLACE-C-SID flavor, the procedure described in Section 4.3 of [RFC8986] is executed with the following modifications.

The pseudocode in Section 4.2.1 of this document is modified by replacing lines R10 and R21 as shown below.

```
R10.1. Set the packet's associated FIB table to T.
R10.2. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the new destination.

R21.1. Set the packet's associated FIB table to T.
R21.2. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the new destination.
```

Note: the variable T is defined in Section 4.3 of [RFC8986].

The SRH processing in Section 4.3 of [RFC8986] is replaced with the resulting pseudocode. The upper-layer header processing is unchanged.

A rendering of the complete pseudocode is provided in Appendix A.8.

4.2.4. End.B6.Encaps with REPLACE-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.B6.Encaps SID with the REPLACE-C-SID flavor, the procedure described in Section 4.13 of [RFC8986] is executed with the following modifications.

The pseudocode in Section 4.2.1 of this document is modified by replacing lines R10 and R21 as shown below.

```
R10.1. Push a new IPv6 header with its own SRH containing B.
R10.2. Set the outer IPv6 SA to A.
R10.3. Set the outer IPv6 DA to the first SID of B.
R10.4. Set the outer Payload Length, Traffic Class, Flow Label,
         Hop Limit, and Next Header fields.
R10.5. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the next destination.

R21.1. Push a new IPv6 header with its own SRH containing B.
R21.2. Set the outer IPv6 SA to A.
R21.3. Set the outer IPv6 DA to the first SID of B.
R21.4. Set the outer Payload Length, Traffic Class, Flow Label,
         Hop Limit, and Next Header fields.
R21.5. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the next destination.
```

Note: the variables A and B, as well as the values of the Payload Length, Traffic Class, Flow Label, Hop Limit, and Next Header are defined in Section 4.13 of [RFC8986].

The SRH processing in Section 4.13 of [RFC8986] is replaced with the resulting pseudocode. The upper-layer header processing is unchanged.

A rendering of the complete pseudocode is provided in Appendix A.9.

4.2.5. End.B6.Encaps.Red with REPLACE-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.B6.Encaps.Red SID with the REPLACE-C-SID flavor, the procedure described in Section 4.14 of [RFC8986] is executed with the same modifications as in Section 4.2.4 of this document.

4.2.6. End.BM with REPLACE-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.BM SID with the REPLACE-C-SID flavor, the procedure described in Section 4.15 of [RFC8986] is executed with the following modifications.

The pseudocode in Section 4.2.1 of this document is modified by replacing lines R10 and R21 as shown below.

```
R10.1. Push the MPLS label stack for B.
R10.2. Submit the packet to the MPLS engine for transmission.

R21.1. Push the MPLS label stack for B.
R21.2. Submit the packet to the MPLS engine for transmission.
```

Note: the variable B is defined in Section 4.15 of [RFC8986].

The SRH processing in Section 4.15 of [RFC8986] is replaced with the resulting pseudocode. The upper-layer header processing is unchanged.

A rendering of the complete pseudocode is provided in Appendix A.10.

4.2.7. End.DX and End.DT with REPLACE-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.DX6, End.DX4, End.DT6, End.DT4, End.DT46, End.DX2, End.DX2V, or End.DT2U SID with the REPLACE-C-SID flavor, the corresponding procedure described in Sections 4.4 through 4.11 of [RFC8986] is executed.

These SIDs differ from those defined in [RFC8986] by the presence of an Argument as part of the SID structure. The Argument value is ignored by the SR segment endpoint node.

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.DT2M SID with the REPLACE-C-SID flavor, the procedure described in Section 4.12 of [RFC8986] is executed with the following modification.

The value of Arg.FE2 is 16-bit long. The SR segment endpoint node obtains the value Arg.FE2 from the 16 most significant bits of DA.Argument if DA.Arg.Index is zero, or from the 16 least significant bits of the next position in the current C-SID container (Segment List[Segments Left][DA.Arg.Index-1]) otherwise (DA.Arg.Index is non-zero).

4.2.8. Combination with PSP, USP, and USD flavors

PSP: When combined with the REPLACE-C-SID flavor, the additional PSP flavor instructions defined in Section 4.16.1.2 of [RFC8986] are inserted after lines R09 and R20 of the pseudocode in Section 4.2.1, and the first line of the inserted instructions after R20 is modified as follows.

```
R20.1.   If (Segments Left == 0 and (DA.Arg.Index == 0 or
             Segment List[0][DA.Arg.Index-1] == 0)) {
```

Note: Segment List[Segments Left][DA.Arg.Index-1] identifies the value contained in the bits [(DA.Arg.Index-1)*LNFL..DA.Arg.Index*LNFL-1] in the SRH Segment List entry at index Segments Left.

USP: When combined with the REPLACE-C-SID flavor, the line S03 of the pseudocode in Section 4.2.1 are substituted by the USP flavor instructions S03.1 to S03.4 defined in Section 4.16.2 of [RFC8986]. Note that S03 is shown in the complete pseudocode in Appendix A.6.

USD: The USD flavor defined in Section 4.16.3 of [RFC8986] is unchanged when combined with the REPLACE-C-SID flavor.

5. C-SID Allocation

The C-SID value of 0 is reserved. It is used to indicate the end of a C-SID container.

In order to efficiently manage the C-SID numbering space, a deployment may divide it into two non-overlapping sub-spaces: a Global Identifiers Block (GIB) and a Local Identifiers Block (LIB).

The C-SID values that are allocated from the GIB have a global semantic within the Locator-Block, while those that are allocated from the LIB have a local semantic on an SR segment endpoint node and within the scope of the Locator-Block.

The concept of LIB is applicable to SRv6 and specifically to its NEXT-C-SID and REPLACE-C-SID flavors. The shorter the C-SID, the more benefit the LIB brings.

The opportunity to use these sub-spaces, their size, and their C-SID allocation policy depends on the C-SID length relative to the size of the network (e.g., number of nodes, links, service routes). Some guidelines for a typical deployment scenario are provided in the below subsections.

5.1. Global C-SID

A global C-SID is a C-SID allocated from the GIB.

A global C-SID identifies a segment defined at the Locator-Block level. The tuple (Locator-Block, C-SID) identifies the same segment across all nodes of the SR domain. A typical example is a prefix segment bound to the End behavior.

A node can have multiple global C-SIDs under the same Locator-Block (e.g., one per IGP flexible algorithm ([RFC9350])). Multiple nodes may share the same global C-SID (e.g., anycast).

5.2. Local C-SID

A local C-SID is a C-SID allocated from the LIB.

A local C-SID identifies a segment defined at the node level and within the scope of a particular Locator-Block. The tuple (Locator-Block, C-SID) identifies a different segment on each node of the SR domain. A typical example is a non-routed Adjacency segment bound to the End.X behavior.

Let N1 and N2 be two different physical nodes of the SR domain and I a local C-SID value, N1 may allocate value I to SID S1 and N2 may allocate the same value I to SID S2.

5.3. GIB/LIB Usage

GIB and LIB usage is a local implementation and/or configuration decision, however, some guidelines for determining usage for specific SID behaviors and recommendations are provided.

The GIB number space is shared among all SR segment endpoint nodes using SRv6 locators under a Locator-Block space. The more SIDs assigned from this space, per node, the faster it is exhausted. Therefore its use is prioritized for global segments, such as SIDs that identify a node.

The LIB number space is unique per node. Each node is able to fully utilize the entire LIB number space without consideration of assignments at other nodes. Therefore its use is prioritized for local segments, such as SIDs that identify services (of which there may be many) at nodes, cross-connects, or adjacencies.

While a longer C-SID length permits more flexibility in which SID behaviors may be assigned from the GIB, it also reduces the compression efficiency.

Given the previous Locator-Block and C-SID length recommendations, the following GIB/LIB usage is recommended:

*NEXT-C-SID:

-GIB: End

-LIB: End.X, End.T, End.DT4/6/46/2U/2M, End.DX4/6/2/2V (including large-scale pseudowire), End.B6.Encaps, End.B6.Encaps.Red, End.BM

*REPLACE-C-SID:

  -GIB: End, End.X, End.T, End.DT4/6/46/2U/2M, End.DX4/6/2/2V, End.B6.Encaps, End.B6.Encaps.Red, End.BM

  -LIB: End.DX2/2V for large-scale pseudowire

Any other allocation is possible but may lead to a suboptimal use of the C-SID numbering space.

5.4. Recommended Installation of C-SIDs in FIB

Section 4.3 of [RFC8754] defines how an SR segment endpoint node identifies a locally instantiated SRv6 SID. To ensure that any valid argument value is accepted, an SR segment endpoint node instantiating a NEXT-C-SID or REPLACE-C-SID flavor SID SHOULD install a corresponding FIB entry that matches only the Locator and Function parts of the SID (i.e., with a prefix length of LBL + LNL + FL).

In addition, an SR segment endpoint node instantiating NEXT-C-SID flavor SIDs from both GIB and LIB may install combined "Global + Local" FIB entries to match a sequence of global and local C-SIDs in a single longest prefix match (LPM) lookup.

For example, let us consider an SR segment endpoint node 10 instantiating the following two NEXT-C-SID flavor SIDs according to the C-SID length, Locator-Block length, and GIB/LIB recommendations in this section.

*2001:db8:b1:10:: bound to the End behavior with the NEXT-C-SID flavor is instantiated from GIB with

  -Locator-Block length (LBL) = 48 (Locator-Block value 0x20010db800b1),

  -Locator-Node length (LNL) = 16 (Locator-Node value 0x0010),

  -Function length (FL) = 0, and

  -Argument length (AL) = 64.

*2001:db8:b1:f123:: bound to the End.X behavior for its local IGP adjacency 123 with the NEXT-C-SID flavor is instantiated from LIB with

  -Locator-Block length (LBL) = 48 (Locator-Block value 0x20010db800b1),

  -Locator-Node length (LNL) = 0,

-Function length (FL) = 16 (Function value 0xf123), and

-Argument length (AL) = 64.

For SID 2001:db8:b1:10::, Node 10 would install the FIB entry 2001:db8:b1:10::/64 bound the End SID with the NEXT-C-SID flavor.

For SID 2001:db8:b1:f123::, Node 10 would install the FIB entry 2001:db8:b1:f123::/64 bound the End.X SID for adjacency 123 with the NEXT-C-SID flavor.

In addition, Node 10 may also install the combined FIB entry 2001:db8:b1:10:f123::/80 bound the End.X SID for adjacency 123 with the NEXT-C-SID flavor.

As another example, let us consider an SR segment endpoint node 20 instantiating the following two REPLACE-C-SID flavor SIDs according to the C-SID length, Locator-Block length, and GIB/LIB recommendations in this section.

* 2001:db8:b2:20:1:: from GIB with Locator-Block length (LBL) = 48, Locator-Node length (LNL) = 16, Function length (FL) = 16, Argument length (AL) = 48, and bound to the End behavior with the REPLACE-C-SID flavor.

* 2001:db8:b2:20:123:: from GIB with Locator-Block length (LBL) = 48, Locator-Node length (LNL) = 16, Function length (FL) = 16, Argument length (AL) = 48, and bound to the End.X behavior for its local IGP adjacency 123 with the REPLACE-C-SID flavor.

For SID 2001:db8:b2:20:1::, Node 20 would install the FIB entry 2001:db8:b2:20:1::/80 bound the End SID with the REPLACE-C-SID flavor.

For SID 2001:db8:b2:20:123::, Node 20 would install the FIB entry 2001:db8:b2:20:123::/80 bound the End.X SID for adjacency 123 with the REPLACE-C-SID flavor.

6. SR Source Node

An SR source node may learn from a control plane protocol (see Section 8) or local configuration the SIDs that it can use in a segment list, along with their respective SR segment endpoint behavior, flavors, structure, and any other relevant attribute (e.g., the set of L3 adjacencies associated with an End.X SID).

6.1. Segment Validation for Compression

As part of the compression process or as a preliminary step, the SR source node MUST validate the SID structure, if known, of each SID of

this document in the segment list. The SR source node does so regardless of whether the segment list is explicitly configured, locally computed, or advertised by a controller (e.g., via BGP [I-D.ietf-idr-segment-routing-te-policy] or PCEP [I-D.ietf-pce-segment-routing-ipv6]).

A SID structure is valid for compression if it meets all the following conditions.

- *The Locator-Block length is not 0.
- *The sum of the Locator-Node length and Function length is not 0.
- *The Argument length is equal to 128-LBL-LNL-FL.

When compressing a segment list, the SR source node MUST treat an invalid SID structure as unknown, and treats the SID as incompressible.

Section 8 discusses how the SIDs of this document and their structure can be advertised to the SR source node through various control plane protocols.

6.2. Segment List Compression

An SR source node MAY compress a segment list when it includes NEXT-C-SID and/or REPLACE-C-SID flavor SIDs in order to reduce the packet header length.

It is out of the scope of this document to describe the mechanism through which an uncompressed segment list is derived. As a general guidance for implementation or future specification, such a mechanism should aim to select the combination of SIDs that would result in the shortest compressed segment list. For example, by selecting a C-SID flavor SID over an equivalent non-C-SID flavor SID or by consistently selecting SIDs of the same C-SID flavor within each routing domain.

The segment list that the SR source node pushes onto the packet MUST comply with the rules in Section 6.3 and Section 6.4 and result in the same forwarding path as the original segment list.

If an SR source node chooses to compress the segment list, one method is described below for illustrative purposes. Any other method producing a compressed segment list of equal or shorter length than the uncompressed segment list is compliant.

This method walks the uncompressed segment list and compresses each series of consecutive NEXT-C-SID flavor SIDs and each series of consecutive REPLACE-C-SID flavor SIDs.

*When the compression method encounters a series of one or more consecutive compressible NEXT-C-SID flavor SIDs, it compresses the series as follows. A SID with the NEXT-C-SID flavor is compressible if its structure is known to the SR source node and its Argument value is 0.

```
S01. Initialize a C-SID container equal to the first SID in the
       series, and initialize the remaining capacity of the C-SID
       container to the AL of that SID
S02. For each subsequent SID in the series {
S03.   If the current SID Locator-Block matches that of the C-SID
         container and the current SID LNFL is lower than or equal to
         the remaining capacity of the C-SID container {
S04.     Copy the current SID Locator-Node and Function to the most
           significant remaining Argument bits of the C-SID container
           and decrement the remaining capacity by LNFL
S05.   } Else {
S06.     Push the C-SID container onto the compressed segment list
S07.     Initialize a new C-SID container equal to the current SID in
           the series, and initialize the remaining capacity of the
           C-SID container to the AL of that SID
S08.   } // End If
S09. } // End For
S10. If at least one SID remains in the uncompressed segment list
       (following the series of compressible NEXT-C-SID flavor SIDs){
S11.   Set S to the next SID in the uncompressed segment list
S12.   If S is advertised with a SID structure, and the Locator-Block
         of S matches that of the C-SID container, and the sum of the
         Locator-Node, Function, and Argument length of S is lower
         than or equal to the remaining capacity of the C-SID
         container {
S13.     Copy the Locator-Node, Function, and Argument of S to the
           most significant remaining Argument bits of the C-SID
           container
S14.   } // End If
S15. } // End If
S16. Push the C-SID container onto the compressed segment list
```

*When the compression method encounters a series of REPLACE-C-SID flavor SIDs of the same C-SID length in the uncompressed segment list, it compresses the series as per the following high-level pseudo code. A compression checking function ComCheck(F, S) is defined to check if two SIDs F and S share the same SID structure and Locator-Block value, and if S has either no Argument or an

```
      Argument with value 0. If the check passes, then ComCheck(F,S)
      returns true.

S01. Initialize the first C-SID container in full SID format equal to
       the first SID in the series
S02. Initialize the second C-SID container in packed format if there
       are more than one SIDs, and initialize the remaining capacity
       of the C-SID container to 128 bits
S03. For each subsequent SID in the uncompressed segment list {
S04.   Set S to the current SID in the uncompressed segment list
S05.   If ComCheck(First SID, S) {
S06.     If the LNFL of S is lower than or equal to
           the remaining capacity of the C-SID container {
S07.       Copy the Locator-Node and Function of S to the least
             significant remaining bits of the C-SID container
             and decrement the remaining capacity by LNFL  // Note
S08.     } Else {
S09.       Push the C-SID container onto the compressed segment list
S10.       Initialize a new C-SID container in packed format with all
             bits set to 0
S11        Copy the Locator-Node and Function of S to the least
             significant remaining bits of the C-SID container
             and decrement the remaining capacity by LNFL  // Note
S12.     }
S13.     If S is not a REPLACE-C-SID flavor SID, then break
S14.   } Else {
S15.     Break
S16.   } // End If
S17. } // End For
S18. Push the C-SID container (if it is not empty) onto the
       compressed segment list
```

Note: When the last C-SID is an End.DT2M SID with the REPLACE-C-SID flavor, if there is 0 or at least two C-SID positions left in the current C-SID container, the C-SID is encoded as described above and the value of the Arg.FE2 argument is placed in the 16 least significant bits of the next C-SID position. Otherwise (if there is only one C-SID position left in the current C-SID container), the current C-SID container is pushed onto the segment list (the value of the C-SID position 0 remains zero) and the End.DT2M SID with the REPLACE-C-SID flavor is encoded in full SID format with the value of the Arg.FE2 argument in the 16 most significant bits of the SID Argument.

*In all remaining cases (i.e., when the compression method encounters a SID in the uncompressed segment list that is not handled by any of the previous subroutines), it pushes this SID as is onto the compressed segment list.

Regardless of how a compressed segment list is produced, the SR source node writes it in the IPv6 packet as described in Section 4.1 of [RFC8754]. The text is reproduced below for reference.

> A source node steers a packet into an SR Policy. If the SR Policy results in a Segment List containing a single segment, and there is no need to add information to the SRH flag or add TLV; the DA is set to the single Segment List entry, and the SRH MAY be omitted.
>
> When needed, the SRH is created as follows:
>
> The Next Header and Hdr Ext Len fields are set as specified in [RFC8200].
>
> The Routing Type field is set to 4.
>
> The DA of the packet is set with the value of the first segment.
>
> The first element of the SRH Segment List is the ultimate segment. The second element is the penultimate segment, and so on.
>
> The Segments Left field is set to n-1, where n is the number of elements in the SR Policy.
>
> The Last Entry field is set to n-1, where n is the number of elements in the SR Policy.
>
> TLVs (including HMAC) may be set according to their specification.
>
> The packet is forwarded toward the packet's Destination Address (the first segment).
>
> When a source does not require the entire SID list to be preserved in the SRH, a reduced SRH may be used.
>
> A reduced SRH does not contain the first segment of the related SR Policy (the first segment is the one already in the DA of the IPv6 header), and the Last Entry field is set to n-2, where n is the number of elements in the SR Policy.

6.3. Rules for segment lists containing NEXT-C-SID flavor SIDs

1. If a Destination Option header would follow an SRH with a segment list of more than one segment compressed as a single NEXT-C-SID container, the SR source node MUST NOT omit the SRH.

2. When the last Segment List entry (index 0) in the SRH is a C-SID container representing more than one segment, the PSP operation is performed at the segment preceding the first segment of this C-SID container in the segment list. If the PSP behavior should

instead be performed at the penultimate segment along the path, the SR source node MUST NOT compress the ultimate segment of the segment list into a C-SID container.

3. If a Destination Option header would follow an SRH with a last Segment List entry being a NEXT-C-SID container representing more than one segment, the SR source node MUST ensure that the PSP operation is not performed before the penultimate SR segment endpoint node along the path.

6.4. Rules for segment lists containing REPLACE-C-SID flavor SIDs

1. All SIDs compressed in a REPLACE-C-SID sequence MUST share the same Locator-Block and the same compression scheme.

2. All SIDs except the last one in a C-SID sequence for REPLACE-C-SID MUST have the REPLACE-C-SID flavor. If the last C-SID container is fully filled (i.e., the last C-SID is at position 0 in the C-SID container) and the last SID in the C-SID sequence is not the last segment in the segment list, the last SID in the C-SID sequence MUST NOT have the REPLACE-C-SID flavor.

3. When a REPLACE-C-SID flavor C-SID is present as the last SID in a container that is not the last Segment List entry (index 0) in the SRH, the next element in the segment list MUST be a REPLACE-C-SID container in packed format carrying at least one C-SID.

The SR source node determines the compression scheme of REPLACE-C-SID flavor SIDs as follows.

When receiving a SID advertisement for a REPLACE-C-SID flavor SID with LNL=16, FL=0, AL=128-LBL-NL-FL, and the value of the Argument is all 0, the SR source node marks both the SID and its locator as using 16-bit compression. All other SIDs allocated from this locator with LNL=16, FL=16, AL=128-LBL-NL-FL, and the value of the Argument is all 0 are also marked as using 16-bit compression. When receiving a SID advertisement for a REPLACE-C-SID flavor SID with LNFL=32, AL=128-LBL-NL-FL, and the value of the Argument is all 0, the SR source node marks both the SID and its locator as using 32-bit compression.

6.5. Upper-Layer Checksums

The Destination Address used in the IPv6 pseudo-header (Section 8.1 of [RFC8200]) is that of the ultimate destination.

At the originating node, that address will be the Destination Address as it is expected to be received by the ultimate destination. When the last element in the compressed segment list is a C-SID container, this address can be obtained from the last element in the uncompressed segment list or by repeatedly applying the segment

behavior as described in Section 9.2. This applies regardless of whether an SRH in present in the IPv6 packet or omitted.

At the recipient(s), that address will be in the Destination Address field of the IPv6 header.

7. Inter-Domain Compression

Some SRv6 traffic may need to cross multiple routing domains, such as different Autonomous Systems (ASes) or different routing areas within an SR domain. Different routing domains may use different addressing schema and Locator-Blocks.

A property of a C-SID sequence is that all C-SIDs in the sequence share the same Locator-Block. Therefore, a segment list that spans across multiple routing domains using different Locator-Blocks may need a separate C-SID sequence for each domain.

This section defines an OPTIONAL solution to improve the efficiency of C-SID compression in multi-domain environments by enabling a C-SID sequence to combine C-SIDs having different Locator-Blocks.

The solution leverages two new SR segment endpoint behaviors, "Endpoint with SRv6 Prefix Swap" ("End.PS" for short) and "Endpoint with L3 cross-connect and SRv6 Prefix Swap" ("End.XPS" for short), that enable modifying the Locator-Block for the next C-SID in the C-SID sequence at the routing domain boundary.

7.1. End.PS: Prefix Swap

The End.PS behavior is a variant of the End behavior that modifies the Locator-Block of the active C-SID sequence. This document defines the End.PS behavior with the NEXT-C-SID flavor and the End.PS behavior with the REPLACE-C-SID flavor.

An End.PS SID is used to transition to a new Locator-Block when the routing domain boundary is on the SR segment endpoint node.

Each instance of an End.PS SID is associated with a target Locator-Block B2/m, where B2 is an IPv6 address prefix and m is the associated prefix length. The target Locator-Block is a local property of the End.PS SID on the SR segment endpoint node.

Note: a local SID property is an attribute associated with the SID when it is instantiated on the SR segment endpoint node. When the SR segment endpoint node identifies the destination address of a received packet as a locally instantiated SID, it also retrieves any local property associated with this SID. Other examples of local SID properties include the set of L3 adjacencies of an End.X SID (Section

4.2 of [RFC8986]) and the lookup table of an End.DT6 SID (Section 4.6 of [RFC8986]).

The means by which an SR source node learns the target Locator-Block associated with an End.PS SID are outside the scope of this document. As examples, it could be learnt via configuration or signaled by a controller.

7.1.1. End.PS with NEXT-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.PS SID with the NEXT-C-SID flavor and associated with the target Locator-Block B2/m, the SR segment endpoint node applies the procedure specified in Section 4.1.1 with the lines N05 to N06 replaced as follows.

```
N05.1. Initialize an IPv6 address A equal to B2.
N05.2. Copy DA.Argument into the bits [m..(m+AL-1)] of A.
N06.   Copy A to the Destination Address of the IPv6 header.
```

7.1.2. End.PS with REPLACE-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.PS SID with the REPLACE-C-SID flavor and associated with the target Locator-Block B2/m, the SR segment endpoint node applies the procedure specified in Section 4.2.1 with the line R20 replaced as follows.

```
R20.1. Initialize an IPv6 address A equal to B2.
R20.2. Write Segment List[Segments Left][DA.Arg.Index] into the bits
         [m..m+LNFL-1] of the Destination Address of the IPv6 header.
R20.3. Copy A to the Destination Address of the IPv6 header.
```

7.2. End.XPS: L3 Cross-Connect and Prefix Swap

The End.XPS behavior is a variant of the End.X behavior that modifies the Locator-Block of the active C-SID sequence. This document defines the End.XPS behavior with the NEXT-C-SID flavor and the End.XPS behavior with the REPLACE-C-SID flavor.

An End.XPS SID is used to transition to a new Locator-Block when the routing domain boundary is on a link adjacent to the SR segment endpoint node.

Each instance of an End.XPS SID is associated with a target Locator-Block B2/m and a set, J, of one or more L3 adjacencies. The target Locator-Block and set of adjacencies are local properties of the End.XPS SID on the SR segment endpoint node.

The means by which an SR source node learns the target Locator-Block associated with an End.XPS SID are outside the scope of this document. As examples, it could be learnt via configuration or signaled by a controller.

7.2.1. End.XPS with NEXT-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.XPS SID with the NEXT-C-SID flavor and associated with the target Locator-Block B2/m, the SR segment endpoint node applies the procedure specified in Section 4.1.2 with the lines N05 to N06 (of the pseudocode in Section 4.1.1) replaced as follows.

```
N05.1. Initialize an IPv6 address A equal to B2.
N05.2. Copy DA.Argument into the bits [m..(m+AL-1)] of A.
N06.   Copy A to the Destination Address of the IPv6 header.
```

7.2.2. End.XPS with REPLACE-C-SID

When processing an IPv6 packet that matches a FIB entry locally instantiated as an End.XPS SID with the REPLACE-C-SID flavor and associated with the target Locator-Block B2/m, the SR segment endpoint node applies the procedure specified in Section 4.2.2 with the line R20 (of the pseudocode in Section 4.2.1) replaced as follows.

```
R20.1. Initialize an IPv6 address A equal to B2.
R20.2. Write Segment List[Segments Left][DA.Arg.Index] into the bits
         [m..m+LNFL-1] of the Destination Address of the IPv6 header.
R20.3. Copy A to the Destination Address of the IPv6 header.
```

8. Control Plane

This document does not require any new extensions to routing protocols.

Section 8 of [RFC8986] provides an overview of the control plane protocols used for signaling of the SRv6 SIDs introduced by that document. The SRv6 SIDs introduced by this document are advertised using the same SRv6 extensions for various routing protocols, such as

- *IS-IS [RFC9352]
- *OSPFv3 [RFC9513]
- *BGP [RFC9252], [RFC9514],
  [I-D.ietf-idr-segment-routing-te-policy],
  [I-D.ietf-idr-bgp-ls-sr-policy]

*PCEP [I-D.ietf-pce-segment-routing-ipv6]

The SR segment endpoint node MUST set the SID Argument bits to 0 when advertising a locally instantiated SID of this document in the routing protocol (e.g., IS-IS [RFC9352], OSPF [RFC9513], or BGP-LS [RFC9514]).

Signaling the SRv6 SID Structure is REQUIRED for all the SIDs introduced in this document. It is used by an SR source node to compress a segment list as described in Section 6. The node initiating the SID advertisement MUST set the length values in the SRv6 SID Structure to match the format of the SID on the SR segment endpoint node. For example, for a SID of this document instantiated from a /48 SRv6 SID block and a /64 Locator, and having a 16-bit Function, the SRv6 SID Structure advertisement carries the following values.

*Locator-Block length: 48

*Locator-Node length: 16

*Function length: 16

*Argument length: 48 (= 128-48-16-16)

A local C-SID MAY be advertised in the control plane individually and/or in combination with a global C-SID instantiated on the same SR segment endpoint node, with the End behavior, and the same Locator-Block and flavor as the local C-SID. A combined global and local C-SID is advertised as follows.

*The SID Locator-Block is that shared by the global and local C-SIDs

*The SID Locator-Node is that of global C-SID

*The SID Function is that of the local C-SID

*The SID Argument length is equal to 128-LBL-LNL-FL and the SID Argument value is 0

*All other attributes of the SID (e.g., endpoint behavior or algorithm) are those of the local C-SID

The local C-SID combined advertisement is needed in particular for control plane protocols mandating that the SID is a subnet of a locator advertised in the same protocol (e.g., Section 8 of [RFC9352] and Section 9 of [RFC9513] for advertising Adjacency SIDs in IS-IS and OSPFv3, respectively).

For a segment list computed by a controller and signaled to an SR source node (e.g., via BGP [I-D.ietf-idr-segment-routing-te-policy] or PCEP [I-D.ietf-pce-segment-routing-ipv6]), the controller provides the ordered segment list comprising the uncompressed SIDs, with their respective behavior and structure, to the SR source node. The SR source node may then compress the segment list as described in Section 6.

When a node that does not support this specification receives an advertisement of a SID of this document, it handles it as described in the corresponding control plane specification (e.g., Sections 7.2, 8.1, and 8.2 of [RFC9352], Sections 8, 9.1, and 9.2 of [RFC9513], and Section 3.1 of [RFC9252]).

9. Operational Considerations

9.1. Pinging a SID

An SR source node may ping an SRv6 SID by sending an ICMPv6 echo request packet destined to the SRv6 SID, with or without a segment list. This operation is illustrated in Appendix A.1.2 of [RFC9259].

When pinging a SID of this document without a segment list, the SR source node places the SID in the destination address of the ICMPv6 echo request and MUST set the Argument of the SID to 0. The Argument value 0 allows the SID SR segment endpoint node (Section 4) to identify itself as the ultimate destination of the packet and process the ICMPv6 payload. If the SR source node sets a non-zero Argument value, the SR segment endpoint node would instead attempt to determine the next destination of the packet.

When pinging a SID of this document via a segment list, the SR source node MUST construct the IPv6 packet as described in Section 6 and compute the ICMPv6 checksum as described in Section 6.5.

9.2. ICMP Error Processing

When an IPv6 node encounters an error while processing a packet, it may report that error by sending an IPv6 error message to the packet source with an enclosed copy of the invoking packet. For the source of an invoking packet to process the ICMP error message, the ultimate destination address of the IPv6 header may be required.

Section 5.4 of [RFC8754] defines the logic that an SR source node follows to determine the ultimate destination of an invoking packet containing an SRH.

For an SR source node that supports the compressed segment list encoding defined in this document, the logic to determine the ultimate destination is generalized as follows.

* If the destination address of the invoking IPv6 packet matches a known SRv6 SID, modify the invoking IPv6 packet by applying the SID behavior associated with the matched SRv6 SID;

* Repeat until the application of the SID behavior would result in the processing of the upper-layer header.

The destination address of the resulting IPv6 packet may be used as the ultimate destination of the invoking IPv6 packet.

Since the SR source node that needs to determine the ultimate destination is the same node that originally built the segment list in the invoking packet, it is able to perform this operation for all the SIDs in the packet.

10. Implementation Status

This section is to be removed before publishing as an RFC.

RFC-Editor: Please clean up the references cited by this section before publication.

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".

This section is provided in compliance with the SPRING working group policies ([SPRING-WG-POLICIES]).

10.1. Cisco Systems

Cisco Systems reported the following implementations of the SR segment endpoint node NEXT-C-SID flavor (Section 4.1) and the SR source node efficient SID-list encoding (Section 6) for NEXT-C-SID flavor SIDs. These are used as part of its SRv6 TI-LFA, micro-loop avoidance, and traffic engineering functionalities.

- Cisco NCS 540 Series routers running IOS XR 7.3.x or above [IMPL-CISCO-NCS540]

- Cisco NCS 560 Series routers running IOS XR 7.6.x or above [IMPL-CISCO-NCS560]

- Cisco NCS 5500 Series routers running IOS XR 7.3.x or above [IMPL-CISCO-NCS5500]

- Cisco NCS 5700 Series routers running IOS XR 7.5.x or above [IMPL-CISCO-NCS5700]

- Cisco 8000 Series routers running IOS XR 7.5.x or above [IMPL-CISCO-8000]

- Cisco ASR 9000 Series routers running IOS XR 7.5.x or above [IMPL-CISCO-ASR9000]

At the time of this report, all the implementations listed above are in production and follow the specification in the latest version of this document, including all the "MUST" and "SHOULD" clauses for the NEXT-C-SID flavor.

This report was last updated on January 11, 2023.

10.2. Huawei Technologies

Huawei Technologies reported the following implementations of the SR segment endpoint node REPLACE-C-SID flavor (Section 4.2). These are used as part of its SRv6 TI-LFA, micro-loop avoidance, and traffic engineering functionalities.

- Huawei ATN8XX,ATN910C,ATN980B routers running VRPV800R021C00 or above.

- Huawei CX600-M2 routers running VRPV800R021C00 or above.

- Huawei NE40E,ME60-X1X2,ME60-X3X8X16 routers running VRPV800R021C00 or above.

- Huawei NE5000E,NE9000 routers running VRPV800R021C00 or above.

*Huawei NCE-IP Controller running V1R21C00 or above.

At the time of this report, all the implementations listed above are in production and follow the specification in the latest version of this document, including all the "MUST" and "SHOULD" clauses for the REPLACE-C-SID flavor.

This report was last updated on January 11, 2023.

10.3. Nokia

Nokia reported the following implementations ([IMPL-NOKIA-20.10]) of the SR segment endpoint node NEXT-C-SID flavor (Section 4.1). These are used as part of its shortest path forwarding (in algorithm 0 and Flex-Algo), remote and TI-LFA repair tunnel, and Traffic Engineering functionalities.

*Nokia 7950 XRS 20/20e routers running SROS Release 22.10 or above

*Nokia 7750 SR-12e routers running SROS Release 22.10 or above

*Nokia 7750 SR-7/12 routers running SROS Release 22.10 or above

*Nokia 7750 SR-7s/14s routers running SROS Release 22.10 or above

*Nokia 7750 SR-1/1s/2s routers running SROS Release 22.10 or above

At the time of this report, all the implementations listed above are in production and follow the specification in the latest version of this document, including all the "MUST" and "SHOULD" clauses for the NEXT-C-SID flavor.

This report was last updated on February 3, 2023.

10.4. Arrcus

Arrcus reported the following implementations of the SR segment endpoint node NEXT-C-SID flavor (Section 4.1). These are used as part of its SRv6 shortest path forwarding (in algorithm 0 and Flex-Algo), TI-LFA, micro-loop avoidance and Traffic Engineering functionalities.

*Arrcus running on Ufi Space routers S9510-28DC, S9710-76D, S9600-30DX and S9700-23D with ArcOS v5.2.1 or above

*Arrcus running n Ufi Space routers S9600-72XC and S9700-53DX with ArcOS v5.1.1D or above

*Arrcus running on Quanta router IXA and IXAE with ArcOS v5.1.1D or above

At the time of this report, all the implementations listed above are in production and follow the specification in the latest version of this document, including all the "MUST" and "SHOULD" clauses for the NEXT-C-SID flavor.

This report was last updated on March 11, 2023.

10.5. Juniper Networks

Juniper Networks reported the following implementations of the SR segment endpoint node NEXT-C-SID flavor (Section 4.1). These are used as part of its SRv6 shortest path forwarding (in algorithm 0 and Flex-Algo), TI-LFA, micro-loop avoidance, and Traffic Engineering functionalities.

Juniper release 23.3 onwards supports this functionality.

At the time of this report, all the implementations listed above are in development and follow the specification in the latest version of this document, including all the "MUST" and "SHOULD" clauses for the NEXT-C-SID flavor.

This report was last updated on May 30, 2023.

10.6. Marvell

Marvell reported support in the Marvell Prestera Packet Processor for the SR segment endpoint node NEXT-C-SID flavor (Section 4.1) and REPLACE-C-SID flavor (Section 4.2).

This report was last updated on February 15, 2023.

10.7. Broadcom

Broadcom reported the following implementations of the SR segment endpoint node NEXT-C-SID flavor (Section 4.1) and REPLACE-C-SID flavor (Section 4.2). These are used as part of its SRv6 TI-LFA, micro-loop avoidance, and traffic engineering functionalities. All implementation of the following list is in general availability for customers using BCM SDK 6.5.26 or above.

*88850 (Jericho2c+) series

*88690 (Jericho2) series

*88800 (Jericho2c) series

*88480 (Qunran2a) series

*88280 (Qunran2u) series

*88295 (Qunran2n) series

*88830 (Jericho2x) series

At the time of this report, all the implementations listed above are in production and follow the specification in the latest version of this document, including all the "MUST" and "SHOULD" clauses for the NEXT-C-SID and REPLACE-C-SID flavors.

For 78900 (Tomahawk) series-related support, please contact the Broadcom team.

This report was last updated on February 21, 2023.

10.8. ZTE Corporation

ZTE Corporation reported the following implementations of the SR segment endpoint node REPLACE-C-SID flavor (Section 4.2). These are used as part of its SRv6 TI-LFA, micro-loop avoidance, and traffic engineering functionalities.

*ZTE M6000-18S(BRAS), M6000-8S Plus(BRAS) routers running V5.00.10.09 or above.

*ZTE M6000-18S(SR), M6000-8S Plus(SR) routers running V5.00.10.80 or above.

*ZTE T8000-18 routers running V5.00.10.07 or above.

This report was last updated on March 29, 2023.

10.9. New H3C Technologies

New H3C Technologies reported the following implementations of the SR segment endpoint node REPLACE-C-SID flavor (Section 4.2). These are used as part of its SRv6 TI-LFA, micro-loop avoidance, and traffic engineering functionalities.

*H3C CR16000-F, SR8800-X routers running Version 7.1.075 or above.

*H3C CR18000, CR19000 routers running Version 7.1.071 or above.

This report was last updated on March 29, 2023.

10.10. Ruijie Network

Ruijie Network reported the following implementations of the SR segment endpoint node REPLACE-C-SID flavor (Section 4.2). These are

used as part of its SRv6 TI-LFA, micro-loop avoidance, and traffic engineering functionalities.

*RUIJIE RG-N8018-R, RG-N8010-R routers running N8000-R_RGOS 12.8(3)B0801 or above.

This report was last updated on March 29, 2023.

10.11. Ciena

Ciena reported the following implementations of the SR segment endpoint node NEXT-C-SID flavor (Section 4.1). These are used as part of its shortest path forwarding (in algorithm 0 and Flex-Algo), remote and TI-LFA repair tunnel, and Traffic Engineering functionalities.

The following platforms support implementation of the above.

*Ciena 5162, 5164, 5166, 5168 routers running SAOS 10.10 or above

*Ciena 8110, 8112, 8190 routers running SAOS 10.10 or above

At the time of this report, all the implementations listed above are in production and follow the specification in the latest version of this document, including all the "MUST" and "SHOULD" clauses for the NEXT-C-SID flavor.

This report was last updated on February 6, 2024.

10.12. Centec

Centec reported the following implementations of the SR segment endpoint node REPLACE-C-SID flavor (Section 4.2). These are used as part of its SRv6 TI-LFA, micro-loop avoidance, and traffic engineering functionalities. All implementation of the following list is in general availability for customers using Centec SDK 5.6.8 or above.

*CTC7132 (TsingMa) Series

*CTC8180 (TsingMa.MX) Series

This report was last updated on February 14, 2024.

10.13. Open Source

The authors found the following open source implementations of the SR segment endpoint node NEXT-C-SID flavor (Section 4.1).

*The Linux kernel, version 6.1 [IMPL-OSS-LINUX]

*The Software for Open Networking in the Cloud (SONiC), version 202212 [IMPL-OSS-SONIC], and Switch Abstraction Interface (SAI), version 1.9.0 [IMPL-OSS-SAI]

*The Vector Packet Processor (VPP), version 20.05 [IMPL-OSS-VPP]

*A generic P4 implementation [IMPL-OSS-P4]

The authors found the following open source implementations of the SR segment endpoint node REPLACE-C-SID flavor (Section 4.2).

*ONOS and P4 Programmable Switch based [IMPL-OSS-ONOS]

*Open SRv6 Project [IMPL-OSS-OPEN-SRV6]

This section was last updated on January 11, 2023.

10.14. Interoperability Reports

10.14.1. Bell Canada / Ciena 2023

Bell Canada is currently evaluating interoperability between Ciena and Cisco implementations of the NEXT-C-SID flavor defined in this document. Further information will be added to this section when the evaluation is complete.

10.14.2. EANTC 2023

In April 2023, the European Advanced Networking Test Center (EANTC) successfully validated multiple implementations of SRv6 NEXT-C-SID flavor (a.k.a., SRv6 uSID) [EANTC-23].

The participating vendors included Arista, Arrcus, Cisco, Huawei, Juniper, Keysight, Nokia, and Spirent.

10.14.3. China Mobile 2020

In November 2020, China Mobile successfully validated multiple interoperable implementations of the NEXT-C-SID and REPLACE-C-SID flavors defined in this document.

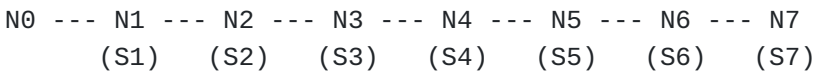
This testing covered two different implementations of the SRv6 endpoint flavors defined in this document:

*Hardware implementation in Cisco ASR 9000 running IOS XR

*Software implementation in Cisco IOS XRv9000 virtual appliance

*Hardware implementation in Huawei NE40E and NE5000E running VRP

The interoperability testing consisted of a packet flow sent by an SR source node N0 via an SR traffic engineering policy with a segment list <S1, S2, S3, S4, S5, S6, S7>, where S1..S7 are SIDs instantiated on SR segment endpoint nodes N1..N7, respectively.



- *N0 is a generic packet generator.
- *N1, N2, and N3 are Huawei routers.
- *N4, N5, and N6 are Cisco routers.
- *N7 is a generic traffic generator acting as a packet receiver.

The SR source node N0 steers the packets onto the SR policy by setting the IPv6 destination address and creating an SRH (as described in Section 4.1 of [RFC8754]) using a compressed segment list encoding. The length of the compressed segment list encoding varies for each scenario.

All SR segment endpoint nodes execute a variant of the End behavior: regular End behavior (as defined in Section 4.1 of [RFC8986]), End behavior with NEXT-C-SID flavor, and End behavior with REPLACE-C-SID flavor. The variant being used at each SR segment endpoint node varies for each scenario.

The interoperability was validated for the following scenarios:

Scenario 1:

- *S1 and S2 are associated with the End behavior with the REPLACE-C-SID flavor
- *S3 is associated with the regular End behavior (no flavor)
- *S4, S5, and S6 are associated with the End behavior with the NEXT-C-SID flavor
- *The SR source node imposes a compressed segment list encoding of 3 SIDs.

Scenario 2:

- *S1, S2..., S6 are associated with the End behavior with the NEXT-C-SID flavor
- *The SR source node imposes a compressed segment list encoding of 2 SIDs.

Scenario 3:

- *S1, S2..., S6 are associated with the End behavior with the REPLACE-C-SID flavor

- *The SR source node imposes a compressed segment list encoding of 3 SIDs.

11. Applicability to other SR Segment Endpoint Behaviors

Future documents may extend the applicability of the NEXT-C-SID and REPLACE-C-SID flavors to other SR segment endpoint behaviors.

For an SR segment endpoint behavior that can be used before the last position of a segment list, a C-SID flavor is defined by reproducing the same logic as described in Section 4.1 and Section 4.2 of this document to determine the next segment in the segment list.

12. Security Considerations

Section 8 of [RFC8402] discusses the security considerations for Segment Routing.

Section 5 of [RFC8754] describes the intra-SR-domain deployment model and how to secure it. Section 7 of [RFC8754] describes the threats applicable to SRv6 and how to mitigate them.

Section 9 of [RFC8986] discusses the security considerations applicable to the SRv6 network programming framework, as well as the SR source node and SR segment endpoint node behaviors that it defines.

This document introduces two new flavors for some of the SR segment endpoint behaviors defined in [RFC8986] and a method by which an SR source node may leverage the SIDs of these flavors to produce a compressed segment list.

An SR source node constructs an IPv6 packet with a compressed segment list as defined in Sections 3.1 and 4.1 of [RFC8754] and Section 5 of [RFC8986]. The paths that an SR source node may enforce using a compressed segment list are the same, from a topology and service perspective, as those that an SR source node could enforce using the SIDs of [RFC8986].

An SR segment endpoint node processes an IPv6 packet matching a locally instantiated SID as defined in [RFC8986], with the pseudocode modifications in Section 4 of this document. These modifications change how the SR segment endpoint node determines the next SID in the packet, but not the semantic of either the active or the next SID. For example, an adjacency segment instantiated with the End.X

behavior remains an adjacency segment regardless of whether it uses the unflavored End.X behavior defined in Section 4.2 of [RFC8986] or a C-SID flavor of that behavior. This document does not introduce any new SID semantic.

Any other transit node processes the packet as described in Section 4.2 of [RFC8754].

This document defines a new method of encoding the SIDs inside a segment list at the SR source node and decoding them at the SR segment endpoint node, but it does not change how the segment list itself is encoded in the IPv6 packet nor the semantic of any segment that it comprises. Therefore, this document is subject to the same security considerations that are discussed in [RFC8402], [RFC8754], and [RFC8986].

13. IANA Considerations

13.1. SRv6 Endpoint Behaviors

This I-D. requests the IANA to update the reference of the following registrations from the "SRv6 Endpoint Behaviors" registry under the top-level "Segment Routing" registry-group (https://www.iana.org/assignments/segment-routing/) with the RFC number of this document once it is published, and transfer change control to the IETF.

Value	Description	Reference
43	End with NEXT-CSID	This I-D.
44	End with NEXT-CSID & PSP	This I-D.
45	End with NEXT-CSID & USP	This I-D.
46	End with NEXT-CSID, PSP & USP	This I-D.
47	End with NEXT-CSID & USD	This I-D.
48	End with NEXT-CSID, PSP & USD	This I-D.
49	End with NEXT-CSID, USP & USD	This I-D.
50	End with NEXT-CSID, PSP, USP & USD	This I-D.
52	End.X with NEXT-CSID	This I-D.
53	End.X with NEXT-CSID & PSP	This I-D.
54	End.X with NEXT-CSID & USP	This I-D.
55	End.X with NEXT-CSID, PSP & USP	This I-D.
56	End.X with NEXT-CSID & USD	This I-D.
57	End.X with NEXT-CSID, PSP & USD	This I-D.
58	End.X with NEXT-CSID, USP & USD	This I-D.
59	End.X with NEXT-CSID, PSP, USP & USD	This I-D.
85	End.T with NEXT-CSID	This I-D.
86	End.T with NEXT-CSID & PSP	This I-D.
87	End.T with NEXT-CSID & USP	This I-D.
88	End.T with NEXT-CSID, PSP & USP	This I-D.

Value	Description	Reference
89	End.T with NEXT-CSID & USD	This I-D.
90	End.T with NEXT-CSID, PSP & USD	This I-D.
91	End.T with NEXT-CSID, USP & USD	This I-D.
92	End.T with NEXT-CSID, PSP, USP & USD	This I-D.
93	End.B6.Encaps with NEXT-CSID	This I-D.
94	End.B6.Encaps.Red with NEXT-CSID	This I-D.
95	End.BM with NEXT-CSID	This I-D.
96	End.PS with NEXT-CSID	This I-D.
97	End.XPS with NEXT-CSID	This I-D.
101	End with REPLACE-CSID	This I-D.
102	End with REPLACE-CSID & PSP	This I-D.
103	End with REPLACE-CSID & USP	This I-D.
104	End with REPLACE-CSID, PSP & USP	This I-D.
105	End.X with REPLACE-CSID	This I-D.
106	End.X with REPLACE-CSID & PSP	This I-D.
107	End.X with REPLACE-CSID & USP	This I-D.
108	End.X with REPLACE-CSID, PSP & USP	This I-D.
109	End.T with REPLACE-CSID	This I-D.
110	End.T with REPLACE-CSID & PSP	This I-D.
111	End.T with REPLACE-CSID & USP	This I-D.
112	End.T with REPLACE-CSID, PSP & USP	This I-D.
114	End.B6.Encaps with REPLACE-CSID	This I-D.
115	End.BM with REPLACE-CSID	This I-D.
116	End.DX6 with REPLACE-CSID	This I-D.
117	End.DX4 with REPLACE-CSID	This I-D.
118	End.DT6 with REPLACE-CSID	This I-D.
119	End.DT4 with REPLACE-CSID	This I-D.
120	End.DT46 with REPLACE-CSID	This I-D.
121	End.DX2 with REPLACE-CSID	This I-D.
122	End.DX2V with REPLACE-CSID	This I-D.
123	End.DT2U with REPLACE-CSID	This I-D.
124	End.DT2M with REPLACE-CSID	This I-D.
127	End.B6.Encaps.Red with REPLACE-CSID	This I-D.
128	End with REPLACE-CSID & USD	This I-D.
129	End with REPLACE-CSID, PSP & USD	This I-D.
130	End with REPLACE-CSID, USP & USD	This I-D.
131	End with REPLACE-CSID, PSP, USP & USD	This I-D.
132	End.X with REPLACE-CSID & USD	This I-D.
133	End.X with REPLACE-CSID, PSP & USD	This I-D.
134	End.X with REPLACE-CSID, USP & USD	This I-D.
135	End.X with REPLACE-CSID, PSP, USP & USD	This I-D.
136	End.T with REPLACE-CSID & USD	This I-D.
137	End.T with REPLACE-CSID, PSP & USD	This I-D.
138	End.T with REPLACE-CSID, USP & USD	This I-D.
139	End.T with REPLACE-CSID, PSP, USP & USD	This I-D.

Value	Description	Reference
140	End.PS with REPLACE-CSID	This I-D.
141	End.XPS with REPLACE-CSID	This I-D.

Table 1: Registration List

14. Acknowledgements

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15. References

15.1. Normative References

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Appendix A. Complete pseudocodes

The content of this section is purely informative rendering of the pseudocodes of [RFC8986] with the modifications in this document. This rendering may not be used as a reference.

A.1. End with NEXT-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address
           with Code 0 (Hop limit exceeded in transit),
           interrupt packet processing, and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.   Submit the packet to the egress IPv6 FIB lookup for
         transmission to the next destination.
N09. }
S02. If (Segments Left == 0) {
S03.   Stop processing the SRH, and proceed to process the next
         header in the packet, whose type is identified by
         the Next Header field in the routing header.
S04. }
S05. If (IPv6 Hop Limit <= 1) {
S06.   Send an ICMP Time Exceeded message to the Source Address
         with Code 0 (Hop limit exceeded in transit),
         interrupt packet processing, and discard the packet.
S07. }
S08. max_LE = (Hdr Ext Len / 2) - 1
S09. If ((Last Entry > max_LE) or (Segments Left > Last Entry+1)) {
S10.   Send an ICMP Parameter Problem to the Source Address
         with Code 0 (Erroneous header field encountered)
         and Pointer set to the Segments Left field,
         interrupt packet processing, and discard the packet.
S11. }
S12. Decrement IPv6 Hop Limit by 1.
S13. Decrement Segments Left by 1.
S14. Update IPv6 DA with Segment List[Segments Left].
S15. Submit the packet to the egress IPv6 FIB lookup for
       transmission to the new destination.
```

Before processing the Upper-Layer header or any IPv6 extension header other than Hop-by-Hop or Destination Option of a packet matching a FIB entry locally instantiated as an End SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.   Submit the packet to the egress IPv6 FIB lookup for
         transmission to the next destination.
N09. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End SID with the NEXT-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
         with Code 4 (SR Upper-layer Header Error)
         and Pointer set to the offset of the Upper-Layer header,
         interrupt packet processing, and discard the packet.
S05. }
```

A.2. End.X with NEXT-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End.X SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address
           with Code 0 (Hop limit exceeded in transit),
           interrupt packet processing, and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.   Submit the packet to the IPv6 module for transmission to the
         new destination via a member of J.
N09. }
S02. If (Segments Left == 0) {
S03.   Stop processing the SRH, and proceed to process the next
         header in the packet, whose type is identified by
         the Next Header field in the routing header.
S04. }
S05. If (IPv6 Hop Limit <= 1) {
S06.   Send an ICMP Time Exceeded message to the Source Address
         with Code 0 (Hop limit exceeded in transit),
         interrupt packet processing, and discard the packet.
S07. }
S08. max_LE = (Hdr Ext Len / 2) - 1
S09. If ((Last Entry > max_LE) or (Segments Left > Last Entry+1)) {
S10.   Send an ICMP Parameter Problem to the Source Address
         with Code 0 (Erroneous header field encountered)
         and Pointer set to the Segments Left field,
         interrupt packet processing, and discard the packet.
S11. }
S12. Decrement IPv6 Hop Limit by 1.
S13. Decrement Segments Left by 1.
S14. Update IPv6 DA with Segment List[Segments Left].
S15. Submit the packet to the IPv6 module for transmission
       to the new destination via a member of J.
```

Before processing the Upper-Layer header or any IPv6 extension header other than Hop-by-Hop or Destination Option of a packet matching a FIB entry locally instantiated as an End.X SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.   Submit the packet to the IPv6 module for transmission to the
         new destination via a member of J.
N09. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End.X SID with the NEXT-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
         with Code 4 (SR Upper-layer Header Error)
         and Pointer set to the offset of the Upper-Layer header,
         interrupt packet processing, and discard the packet.
S05. }
```

A.3. End.T with NEXT-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End.T SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address
           with Code 0 (Hop limit exceeded in transit),
           interrupt packet processing, and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.1. Set the packet's associated FIB table to T.
N08.2. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the new destination.
N09. }
S02. If (Segments Left == 0) {
S03.   Stop processing the SRH, and proceed to process the next
         header in the packet, whose type is identified by
         the Next Header field in the routing header.
S04. }
S05. If (IPv6 Hop Limit <= 1) {
S06.   Send an ICMP Time Exceeded message to the Source Address
         with Code 0 (Hop limit exceeded in transit),
         interrupt packet processing, and discard the packet.
S07. }
S08. max_LE = (Hdr Ext Len / 2) - 1
S09. If ((Last Entry > max_LE) or (Segments Left > Last Entry+1)) {
S10.   Send an ICMP Parameter Problem to the Source Address
         with Code 0 (Erroneous header field encountered)
         and Pointer set to the Segments Left field,
         interrupt packet processing, and discard the packet.
S11. }
S12. Decrement IPv6 Hop Limit by 1.
S13. Decrement Segments Left by 1.
S14. Update IPv6 DA with Segment List[Segments Left].
S15.1. Set the packet's associated FIB table to T.
S15.2. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the new destination.
```

Before processing the Upper-Layer header or any IPv6 extension header other than Hop-by-Hop or Destination Option of a packet matching a FIB entry locally instantiated as an End.T SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.1. Set the packet's associated FIB table to T.
N08.2. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the new destination.
N09. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End.T SID with the NEXT-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
         with Code 4 (SR Upper-layer Header Error)
         and Pointer set to the offset of the Upper-Layer header,
         interrupt packet processing, and discard the packet.
S05. }
```

A.4. End.B6.Encaps with NEXT-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End.B6.Encaps SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.1. Push a new IPv6 header with its own SRH containing B.
N08.2. Set the outer IPv6 SA to A.
N08.3. Set the outer IPv6 DA to the first SID of B.
N08.4. Set the outer Payload Length, Traffic Class, Flow Label,
         Hop Limit, and Next Header fields.
N08.5. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the next destination.
N09. }
S02. If (Segments Left == 0) {
S03.   Stop processing the SRH, and proceed to process the next
         header in the packet, whose type is identified by
         the Next Header field in the routing header.
S04. }
S05. If (IPv6 Hop Limit <= 1) {
S06.   Send an ICMP Time Exceeded message to the Source Address
         with Code 0 (Hop limit exceeded in transit),
         interrupt packet processing, and discard the packet.
S07. }
S08. max_LE = (Hdr Ext Len / 2) - 1
S09. If ((Last Entry > max_LE) or (Segments Left > Last Entry+1)) {
S10.   Send an ICMP Parameter Problem to the Source Address
         with Code 0 (Erroneous header field encountered)
         and Pointer set to the Segments Left field,
         interrupt packet processing, and discard the packet.
S11. }
S12. Decrement IPv6 Hop Limit by 1.
S13. Decrement Segments Left by 1.
S14. Update IPv6 DA with Segment List[Segments Left].
S15. Push a new IPv6 header with its own SRH containing B.
S16. Set the outer IPv6 SA to A.
S17. Set the outer IPv6 DA to the first SID of B.
S18. Set the outer Payload Length, Traffic Class, Flow Label,
       Hop Limit, and Next Header fields.
S19. Submit the packet to the egress IPv6 FIB lookup for
       transmission to the new destination.
```

Before processing the Upper-Layer header or any IPv6 extension header other than Hop-by-Hop or Destination Option of a packet matching a

FIB entry locally instantiated as an End.B6.Encaps SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.1. Push a new IPv6 header with its own SRH containing B.
N08.2. Set the outer IPv6 SA to A.
N08.3. Set the outer IPv6 DA to the first SID of B.
N08.4. Set the outer Payload Length, Traffic Class, Flow Label,
         Hop Limit, and Next Header fields.
N08.5. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the next destination.
N09. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End.B6.Encaps SID with the NEXT-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
         with Code 4 (SR Upper-layer Header Error)
         and Pointer set to the offset of the Upper-Layer header,
         interrupt packet processing, and discard the packet.
S05. }
```

A.5. End.BM with NEXT-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End.BM SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.1. Push the MPLS label stack for B.
N08.2. Submit the packet to the MPLS engine for transmission.
N09. }
S02. If (Segments Left == 0) {
S03.   Stop processing the SRH, and proceed to process the next
         header in the packet, whose type is identified by
         the Next Header field in the routing header.
S04. }
S05. If (IPv6 Hop Limit <= 1) {
S06.   Send an ICMP Time Exceeded message to the Source Address
         with Code 0 (Hop limit exceeded in transit),
         interrupt packet processing, and discard the packet.
S07. }
S08. max_LE = (Hdr Ext Len / 2) - 1
S09. If ((Last Entry > max_LE) or (Segments Left > Last Entry+1)) {
S10.   Send an ICMP Parameter Problem to the Source Address
         with Code 0 (Erroneous header field encountered)
         and Pointer set to the Segments Left field,
         interrupt packet processing, and discard the packet.
S11. }
S12. Decrement IPv6 Hop Limit by 1.
S13. Decrement Segments Left by 1.
S14. Update IPv6 DA with Segment List[Segments Left].
S15. Push the MPLS label stack for B.
S16. Submit the packet to the MPLS engine for transmission.
```

Before processing the Upper-Layer header or any IPv6 extension header other than Hop-by-Hop or Destination Option of a packet matching a FIB entry locally instantiated as an End.BM SID with the NEXT-C-SID flavor:

```
N01. If (DA.Argument != 0) {
N02.   If (IPv6 Hop Limit <= 1) {
N03.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
N04.   }
N05.   Copy DA.Argument into the bits [LBL..(LBL+AL-1)] of the
         Destination Address.
N06.   Set the bits [(LBL+AL)..127] of the Destination Address to
         zero.
N07.   Decrement IPv6 Hop Limit by 1.
N08.1. Push the MPLS label stack for B.
N08.2. Submit the packet to the MPLS engine for transmission.
N09. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End.BM SID with the NEXT-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
         with Code 4 (SR Upper-layer Header Error)
         and Pointer set to the offset of the Upper-Layer header,
         interrupt packet processing, and discard the packet.
S05. }
```

A.6. End with REPLACE-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End SID with the REPLACE-C-SID flavor:

```
S01. When an SRH is processed {
S02.   If (Segments Left == 0 and (DA.Arg.Index == 0 or
           Segment List[0][DA.Arg.Index-1] == 0)) {
S03.     Stop processing the SRH, and proceed to process the next
           header in the packet, whose type is identified by
           the Next Header field in the routing header.
S04.   }
S05.   If (IPv6 Hop Limit <= 1) {
S06.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
S07.   }
S08.   max_LE = (Hdr Ext Len / 2) - 1
R01.   If (DA.Arg.Index != 0) {
R02.     If ((Last Entry > max_LE) or (Segments Left > Last Entry)) {
R03.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R04.     }
R05.     Decrement DA.Arg.Index by 1.
R06.     If (Segment List[Segments Left][DA.Arg.Index] == 0) {
R07.       Decrement Segments Left by 1.
R08.       Decrement IPv6 Hop Limit by 1.
R09.       Update IPv6 DA with Segment List[Segments Left]
R10.       Submit the packet to the egress IPv6 FIB lookup for
            transmission to the new destination.
R11.     }
R12.   } Else {
R13.     If((Last Entry > max_LE) or (Segments Left > Last Entry+1)){
R14.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R15.     }
R16.     Decrement Segments Left by 1.
R17.     Set DA.Arg.Index to (128/LNFL - 1).
R18.   }
R19.   Decrement IPv6 Hop Limit by 1.
R20.   Write Segment List[Segments Left][DA.Arg.Index] into the bits
         [LBL..LBL+LNFL-1] of the Destination Address of the IPv6
         header.
R21.   Submit the packet to the egress IPv6 FIB lookup for
         transmission to the new destination.
S16. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End SID with the REPLACE-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
          with Code 4 (SR Upper-layer Header Error)
          and Pointer set to the offset of the Upper-Layer header,
          interrupt packet processing, and discard the packet.
S05. }
```

A.7. End.X with REPLACE-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End.X SID with the REPLACE-C-SID flavor:

```
S01. When an SRH is processed {
S02.   If (Segments Left == 0 and (DA.Arg.Index == 0 or
           Segment List[0][DA.Arg.Index-1] == 0)) {
S03.     Stop processing the SRH, and proceed to process the next
           header in the packet, whose type is identified by
           the Next Header field in the routing header.
S04.   }
S05.   If (IPv6 Hop Limit <= 1) {
S06.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
S07.   }
S08.   max_LE = (Hdr Ext Len / 2) - 1
R01.   If (DA.Arg.Index != 0) {
R02.     If ((Last Entry > max_LE) or (Segments Left > Last Entry)) {
R03.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R04.     }
R05.     Decrement DA.Arg.Index by 1.
R06.     If (Segment List[Segments Left][DA.Arg.Index] == 0) {
R07.       Decrement Segments Left by 1.
R08.       Decrement IPv6 Hop Limit by 1.
R09.       Update IPv6 DA with Segment List[Segments Left]
R10.       Submit the packet to the IPv6 module for transmission to
             the new destination via a member of J.
R11.     }
R12.   } Else {
R13.     If((Last Entry > max_LE) or (Segments Left > Last Entry+1)){
R14.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R15.     }
R16.     Decrement Segments Left by 1.
R17.     Set DA.Arg.Index to (128/LNFL - 1).
R18.   }
R19.   Decrement IPv6 Hop Limit by 1.
R20.   Write Segment List[Segments Left][DA.Arg.Index] into the bits
         [LBL..LBL+LNFL-1] of the Destination Address of the IPv6
         header.
R21.   Submit the packet to the IPv6 module for transmission to the
         new destination via a member of J.
S16. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End.X SID with the REPLACE-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
          with Code 4 (SR Upper-layer Header Error)
          and Pointer set to the offset of the Upper-Layer header,
          interrupt packet processing, and discard the packet.
S05. }
```

A.8. End.T with REPLACE-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End.T SID with the REPLACE-C-SID flavor:

```
S01. When an SRH is processed {
S02.   If (Segments Left == 0 and (DA.Arg.Index == 0 or
           Segment List[0][DA.Arg.Index-1] == 0)) {
S03.     Stop processing the SRH, and proceed to process the next
           header in the packet, whose type is identified by
           the Next Header field in the routing header.
S04.   }
S05.   If (IPv6 Hop Limit <= 1) {
S06.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
S07.   }
S08.   max_LE = (Hdr Ext Len / 2) - 1
R01.   If (DA.Arg.Index != 0) {
R02.     If ((Last Entry > max_LE) or (Segments Left > Last Entry)) {
R03.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R04.     }
R05.     Decrement DA.Arg.Index by 1.
R06.     If (Segment List[Segments Left][DA.Arg.Index] == 0) {
R07.       Decrement Segments Left by 1.
R08.       Decrement IPv6 Hop Limit by 1.
R09.       Update IPv6 DA with Segment List[Segments Left]
R10.1.     Set the packet's associated FIB table to T.
R10.2.     Submit the packet to the egress IPv6 FIB lookup for
             transmission to the new destination.
R11.     }
R12.   } Else {
R13.     If((Last Entry > max_LE) or (Segments Left > Last Entry+1)){
R14.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R15.     }
R16.     Decrement Segments Left by 1.
R17.     Set DA.Arg.Index to (128/LNFL - 1).
R18.   }
R19.   Decrement IPv6 Hop Limit by 1.
R20.   Write Segment List[Segments Left][DA.Arg.Index] into the bits
         [LBL..LBL+LNFL-1] of the Destination Address of the IPv6
         header.
R21.1. Set the packet's associated FIB table to T.
R21.2. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the new destination.
S16. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End.T SID with the REPLACE-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
          with Code 4 (SR Upper-layer Header Error)
          and Pointer set to the offset of the Upper-Layer header,
          interrupt packet processing, and discard the packet.
S05. }
```

A.9. End.B6.Encaps with REPLACE-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End.B6.Encaps SID with the REPLACE-C-SID flavor:

```
S01. When an SRH is processed {
S02.   If (Segments Left == 0 and (DA.Arg.Index == 0 or
           Segment List[0][DA.Arg.Index-1] == 0)) {
S03.     Stop processing the SRH, and proceed to process the next
           header in the packet, whose type is identified by
           the Next Header field in the routing header.
S04.   }
S05.   If (IPv6 Hop Limit <= 1) {
S06.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
S07.   }
S08.   max_LE = (Hdr Ext Len / 2) - 1
R01.   If (DA.Arg.Index != 0) {
R02.     If ((Last Entry > max_LE) or (Segments Left > Last Entry)) {
R03.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R04.     }
R05.     Decrement DA.Arg.Index by 1.
R06.     If (Segment List[Segments Left][DA.Arg.Index] == 0) {
R07.       Decrement Segments Left by 1.
R08.       Decrement IPv6 Hop Limit by 1.
R09.       Update IPv6 DA with Segment List[Segments Left]
R10.1.     Push a new IPv6 header with its own SRH containing B.
R10.2.     Set the outer IPv6 SA to A.
R10.3.     Set the outer IPv6 DA to the first SID of B.
R10.4.     Set the outer Payload Length, Traffic Class, Flow Label,
             Hop Limit, and Next Header fields.
R10.5.     Submit the packet to the egress IPv6 FIB lookup for
             transmission to the next destination.
R11.     }
R12.   } Else {
R13.     If((Last Entry > max_LE) or (Segments Left > Last Entry+1)){
R14.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R15.     }
R16.     Decrement Segments Left by 1.
R17.     Set DA.Arg.Index to (128/LNFL - 1).
R18.   }
R19.   Decrement IPv6 Hop Limit by 1.
R20.   Write Segment List[Segments Left][DA.Arg.Index] into the bits
         [LBL..LBL+LNFL-1] of the Destination Address of the IPv6
         header.
R21.1. Push a new IPv6 header with its own SRH containing B.
R21.2. Set the outer IPv6 SA to A.
```

```
R21.3. Set the outer IPv6 DA to the first SID of B.
R21.4. Set the outer Payload Length, Traffic Class, Flow Label,
         Hop Limit, and Next Header fields.
R21.5. Submit the packet to the egress IPv6 FIB lookup for
         transmission to the next destination.
S16. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End.B6.Encaps SID with the REPLACE-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
          with Code 4 (SR Upper-layer Header Error)
          and Pointer set to the offset of the Upper-Layer header,
          interrupt packet processing, and discard the packet.
S05. }
```

A.10. End.BM with REPLACE-C-SID

When processing the SRH of a packet matching a FIB entry locally instantiated as an End.BM SID with the REPLACE-C-SID flavor:

```
S01. When an SRH is processed {
S02.   If (Segments Left == 0 and (DA.Arg.Index == 0 or
           Segment List[0][DA.Arg.Index-1] == 0)) {
S03.     Stop processing the SRH, and proceed to process the next
           header in the packet, whose type is identified by
           the Next Header field in the routing header.
S04.   }
S05.   If (IPv6 Hop Limit <= 1) {
S06.     Send an ICMP Time Exceeded message to the Source Address,
           Code 0 (Hop limit exceeded in transit),
           interrupt packet processing and discard the packet.
S07.   }
S08.   max_LE = (Hdr Ext Len / 2) - 1
R01.   If (DA.Arg.Index != 0) {
R02.     If ((Last Entry > max_LE) or (Segments Left > Last Entry)) {
R03.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R04.     }
R05.     Decrement DA.Arg.Index by 1.
R06.     If (Segment List[Segments Left][DA.Arg.Index] == 0) {
R07.       Decrement Segments Left by 1.
R08.       Decrement IPv6 Hop Limit by 1.
R09.       Update IPv6 DA with Segment List[Segments Left]
R10.1.     Push the MPLS label stack for B.
R10.2.     Submit the packet to the MPLS engine for transmission.
R11.     }
R12.   } Else {
R13.     If((Last Entry > max_LE) or (Segments Left > Last Entry+1)){
R14.       Send an ICMP Parameter Problem to the Source Address,
             Code 0 (Erroneous header field encountered),
             Pointer set to the Segments Left field,
             interrupt packet processing and discard the packet.
R15.     }
R16.     Decrement Segments Left by 1.
R17.     Set DA.Arg.Index to (128/LNFL - 1).
R18.   }
R19.   Decrement IPv6 Hop Limit by 1.
R20.   Write Segment List[Segments Left][DA.Arg.Index] into the bits
         [LBL..LBL+LNFL-1] of the Destination Address of the IPv6
         header.
R21.1. Push the MPLS label stack for B.
R21.2. Submit the packet to the MPLS engine for transmission.
S16. }
```

When processing the Upper-Layer header of a packet matching a FIB entry locally instantiated as an End.BM SID with the REPLACE-C-SID flavor:

```
S01. If (Upper-Layer header type is allowed by local configuration) {
S02.   Proceed to process the Upper-Layer header
S03. } Else {
S04.   Send an ICMP Parameter Problem to the Source Address
          with Code 4 (SR Upper-layer Header Error)
          and Pointer set to the offset of the Upper-Layer header,
          interrupt packet processing, and discard the packet.
S05. }
```

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