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The IPv6 Compact Routing Header (CRH)

Abstract

This document defines two new Routing header types. Collectively, they are called the Compact Routing Headers (CRH). Individually, they are called CRH-16 and CRH-32.

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1. Introduction

   IPv6 [RFC8200] source nodes use Routing headers to specify the path
   that a packet takes to its destination. The IETF has defined several
   Routing header types [IANA-RH]. This document defines two new
   Routing header types. Collectively, they are called the Compact
   Routing Headers (CRH). Individually, they are called CRH-16 and
   CRH-32.

   The CRH allows IPv6 source nodes to specify the path that a packet
   takes to its destination. The CRH:

     *Can be encoded in relatively few bytes.

     *Is designed to operate within a limited domain. (See Section 9).

   The following are reasons for encoding the CRH in as few bytes as
   possible:

     *Many ASIC-based forwarders copy headers from buffer memory to on-
      chip memory. As header sizes increase, so does the cost of this
      copy.

     *Because Path MTU Discovery (PMTUD) [RFC8201] is not entirely
      reliable, many IPv6 hosts refrain from sending packets larger
      than the IPv6 minimum link MTU (i.e., 1280 bytes). When packets

are small, the overhead imposed by large Routing Headers is
excessive.

2. 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. The Compressed Routing Headers (CRH)

Both CRH versions (i.e., CRH-16 and CRH-32) contain the following
fields:

  *Next Header - Defined in [RFC8200].

  *Hdr Ext Len - Defined in [RFC8200].

  *Routing Type - Defined in [RFC8200]. (CRH-16 value is 5. CRH-32
   value is 6).

  *Segments Left - Defined in [RFC8200].

  *Type-specific Data - Described in [RFC8200].

In the CRH, the Type-specific data field contains a list of Segment
Identifiers (SIDs). Each SID represents both of the following:

  *A segment of the path that the packet takes to its destination.

  *An entry in the CRH Forwarding Information Base (CRH-FIB)
   (Section 4).

SIDs are listed in reverse order. So, the first SID in the list
represents the final segment in the path. Because segments are
listed in reverse order, the Segments Left field can be used as an
index into the SID list. In this document, the "current SID" is the
SID list entry referenced by the Segments Left field.

The first segment in the path can be omitted from the list. See
Appendix A for examples.

In the CRH-16 (Figure 1), each SID is encoded in 16-bits. In the
CRH-32 (Figure 2), each SID is encoded in 32-bits.

In all cases, the CRH MUST end on a 64-bit boundary. So, the Type-
specific data field MUST be padded with zeros if the CRH would
otherwise not end on a 64-bit boundary.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Next Header  |  Hdr Ext Len  |  Routing Type |  Segments Left |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            SID[0]             |            SID[1]              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-|
|                          .........
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
```

Figure 1: CRH-16

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Next Header  |  Hdr Ext Len  |  Routing Type |  Segments Left |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
+                             SID[0]                            +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
+                             SID[1]                            +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                                                             //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
+                             SID[n]                            +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
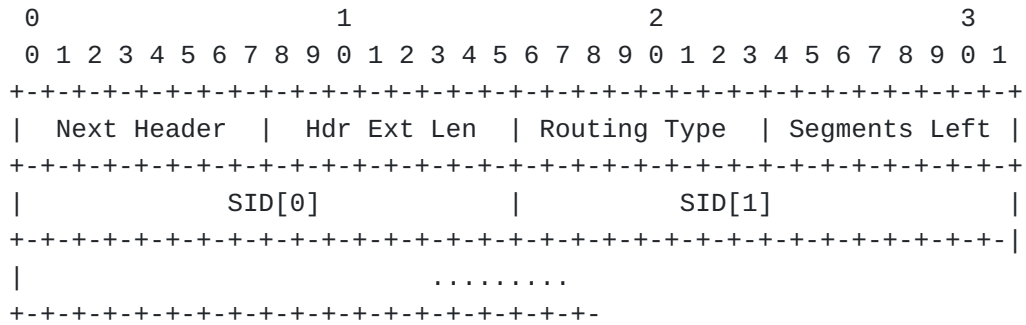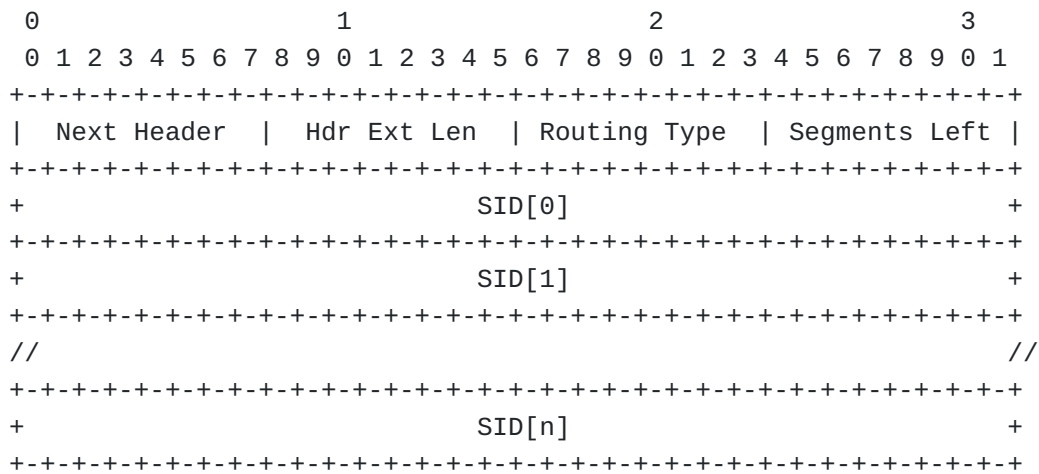
Figure 2: CRH-32

4. The CRH Forwarding Information Base (CRH-FIB)

Each SID identifies a CRH-FIB entry.

Each CRH-FIB entry contains:

   *An IPv6 address.

   *A topological function.

   *Arguments for the topological function. (Optional).

The first ten bits of the IPv6 address MUST NOT be fe00. That prefix
is reserved for link-local [RFC6890] addresses.

The topological function specifies how the processing node forwards the packet to the next segment endpoint. The following are examples:

  *Forward the packet through the least-cost path to the next
   segment endpoint.

  *Forward the packet through a specified interface.

  *Encapsulate the packet in another IPv6 header of any type (e.g.,
   MPLS, IPv6) and forward either through the least cost path or a
   specified interface.

Some topological functions require parameters. For example, a topological function might require a parameter that identifies the interface through which the packet should be forwarded.

The CRH-FIB can be populated:

  *By an operator, using a Command Line Interface (CLI).

  *By a controller, using the Path Computation Element (PCE)
   Communication Protocol (PCEP) [RFC5440] or the Network
   Configuration Protocol (NETCONF) [RFC6241].

  *By a distributed routing protocol [ISO10589-Second-Edition],
   [RFC5340], [RFC4271].

5. Processing Rules

The following rules describe CRH processing:

  *If Segments Left equals 0, skip over the CRH and process the next
   header in the packet.

  *If Hdr Ext Len indicates that the CRH is larger than the
   implementation can process, discard the packet and send an ICMPv6
   [RFC4443] Parameter Problem, Code 0, message to the Source
   Address, pointing to the Hdr Ext Len field.

  *Compute L, the minimum CRH length (Section 5.1).

  *If L is greater than Hdr Ext Len, discard the packet and send an
   ICMPv6 Parameter Problem, Code 0, message to the Source Address,
   pointing to the Segments Left field.

  *Decrement Segments Left.

  *Search for the current SID in the CRH-FIB. In this document, the
   "current SID" is the SID list entry referenced by the Segments
   Left field.

*If the search does not return a CRH-FIB entry, discard the packet
    and send an ICMPv6 Parameter Problem, Code 0, message to the
    Source Address, pointing to the current SID.

   *If Segments Left is greater than 0 and the CRH-FIB entry contains
    a multicast address, discard the packet and send an ICMPv6
    Parameter Problem, Code 0, message to the Source Address,
    pointing to the current SID.

   *Copy the IPv6 address from the CRH-FIB entry to the Destination
    Address field in the IPv6 header.

   *Decrement the IPv6 Hop Limit.

   *Submit the packet, its topological function and its parameters to
    the IPv6 module. See NOTE.

NOTE: By default, the IPv6 module determines the next-hop and
forwards the packet. However, the topological function may elicit
another behavior. For example, the IPv6 module may forward the
packet through a specified interface.

5.1. Computing Minimum CRH Length

The algorithm described in this section accepts the following CRH
fields as its input parameters:

   *Routing Type (i.e., CRH-16 or CRH-32).

   *Segments Left.

It yields L, the minimum CRH length. The minimum CRH length is
measured in 8-octet units, not including the first 8 octets.

```
<CODE BEGINS>

switch(Routing Type) {
    case CRH-16:
        if (Segments Left <= 2)
            return(0)
        sidsBeyondFirstWord = Segments Left - 2;
        sidPerWord = 4;
    case CRH-32:
        if (Segments Left <= 1)
            return(0)
        sidsBeyondFirstWord = Segments Left - 1;
        sidsPerWord = 2;
    case default:
        return(0xFF);
    }

words = sidsBeyondFirstWord div sidsPerWord;
if (sidsBeyondFirstWord mod sidsPerWord)
    words++;

return(words)



<CODE ENDS>
```

6. Mutability

In the CRH, the Segments Left field is mutable. All remaining fields
are immutable.

7. Applications And SIDs

A CRH contains one or more SIDs. Each SID is processed by exactly
one node.

Therefore, a SID is not required to have domain-wide significance.
Applications can:

   *Allocate SIDs so that they have domain-wide significance.

   *Allocate SIDs so that they have node-local significance.

8. Management Considerations

PING and TRACEROUTE [RFC2151] both operate correctly in the presence
of the CRH.

9. Security Considerations

Networks that process the CRH MUST NOT accept packets containing the
CRH from outside of there limited domain.. Their border routers
SHOULD discard packets that satisfy the following criteria:

  *The packet contains a CRH

  *The Segments Left field in the CRH has a value greater than 0

  *The Destination Address field in the IPv6 header represents an
   interface that resides inside of the network.

Many border routers cannot filter packets based upon the Segments
Left value. These border routers MAY discard packets that satisfy
the following criteria:

  *The packet contains a CRH

  *The Destination Address field in the IPv6 header represents an
   interface that resides inside of the network.

10. Implementation and Deployment Status

Juniper Networks has produced experimental implementations of the
CRH on:

  *A LINUX-based software platform

  *The MX-series (ASIC-based) router

Liquid Telecom has deployed the CRH, on a limited basis, in their
network. Other experimental deployments are in progress.

11. IANA Considerations

This document makes the following registrations in the "Internet
Protocol Version 6 (IPv6) Parameters" "Routing Types" subregistry
maintained by IANA:

Value	Description	Reference
5	CRH-16	This document
6	CRH-32	This document

12. Acknowledgements

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Appendix A. CRH Processing Examples

This appendix demonstrates CRH processing in the following scenarios:

   *The SID list contains one entry for each segment in the path (Appendix A.1).

   *The SID list omits the first entry in the path (Appendix A.2).

```
 ----------                 ----------                    ----------
|Node: S    |              |Node: I1   |                 |Node: I2   |
|Loopback:  |--------------|Loopback:  |-----------------|Loopback:  |
|2001:db8::a|              |2001:db8::1|                 |2001:db8::2|
 ----------                 ----------                    ----------
    |                                                        |
    |                      ----------                        |
    |                     |Node: D    |                      |
     --------------------|Loopback:   |--------------------
                          |2001:db8::b|
                           ----------
```
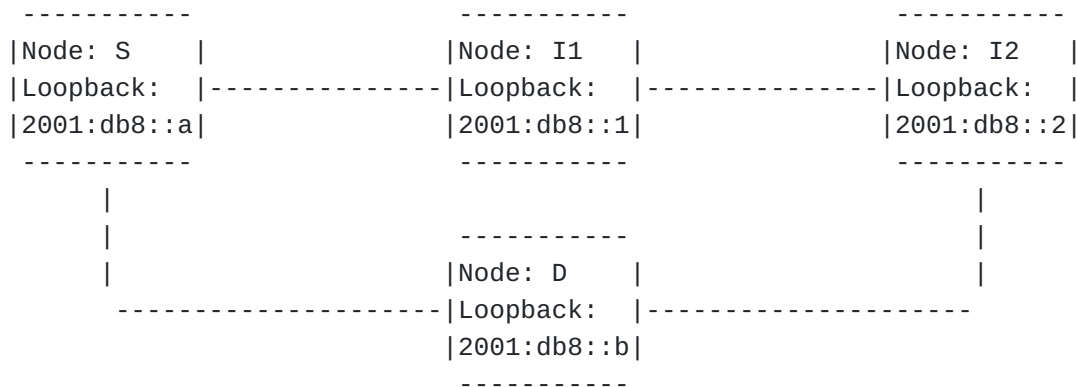
Figure 3: Reference Topology

Figure 3 provides a reference topology that is used in all examples.

SID	IPv6 Address	Forwarding Method
2	2001:db8::2	Least-cost path
11	2001:db8::b	Least-cost path

Table 1: Node SIDs

Table 1 describes two entries that appear in each node's CRH-FIB.

A.1. The SID List Contains One Entry For Each Segment In The Path

In this example, Node S sends a packet to Node D, via I2. In this example, I2 appears in the CRH segment list.

As the packet travels from S to I2:	
Source Address = 2001:db8::a	Segments Left = 1
Destination Address = 2001:db8::2	SID[0] = 11
	SID[1] = 2

Table 2

As the packet travels from I2 to D:	
Source Address = 2001:db8::a	Segments Left = 0
Destination Address = 2001:db8::b	SID[0] = 11
	SID[1] = 2

Table 3

A.2. The SID List Omits The First Entry In The Path

In this example, Node S sends a packet to Node D, via I2. In this
example, I2 does not appear in the CRH segment list.

As the packet travels from S to I2:	
Source Address = 2001:db8::a	Segments Left = 1
Destination Address = 2001:db8::2	SID[0] = 11

Table 4

As the packet travels from I2 to D:	
Source Address = 2001:db8::a	Segments Left = 0
Destination Address = 2001:db8::b	SID[0] = 11

Table 5

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