6lo P. Thubert, Ed.
Internet-Draft Cisco
Updates: 4944 (if approved) C. Bormann
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Expires: May 29, 2015 L. Toutain
IMT-TELECOM Bretagne
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A Routing Header Dispatch for 6LoWPAN
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Abstract

This specification provides a new 6LoWPAN dispatch type for use in Route-over and mixed Mesh-under and Route-over topologies, that reuses the encoding of the mesh type defined in RFC 4944 for pure Mesh-under topologies. This specification also defines a method to compress RPL Option (RFC6553) information and Routing Header type 3 (RFC6554), an efficient IP-in-IP technique and opens the way for further routing techniques. This extends 6LoWPAN Transmission of IPv6 Packets (RFC4944), and is applicable to new link-layer types where 6LoWPAN is being defined.

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1. Introduction

The design of Low Power and Lossy Networks (LLNs) is generally focused on saving energy, which is the most constrained resource of all. The other constraints, such as the memory capacity and the duty cycling of the LLN devices, derive from that primary concern. Energy is often available from primary batteries that are expected to last for years, or is scavenged from the environment in very limited quantities. Any protocol that is intended for use in LLNs must be designed with the primary concern of saving energy as a strict requirement.

Controlling the amount of data transmission is one possible venue to save energy. In a number of LLN standards, the frame size is limited to much smaller values than the IPv6 maximum transmission unit (MTU) of 1280 bytes. In particular, an LLN that relies on the classical Physical Layer (PHY) of IEEE 802.14.5 [IEEE802154] is limited to 127 bytes per frame. The need to compress IPv6 packets over IEEE

802.14.5 led to the 6LoWPAN Header Compression [RFC6282] work (6LoWPAN-HC).

Innovative Route-over techniques have been and are still being developed for routing inside a LLN. In a general fashion, such techniques require additional information in the packet to provide loop prevention and to indicate information such as flow identification, source routing information, etc.

For reasons such as security and the capability to send ICMP errors back to the source, an original packet must not be tampered with, and any information that must be inserted in or removed from an IPv6 packet must be placed in an extra IP-in-IP encapsulation. This is the case when the additional routing information is inserted by a router on the path of a packet, for instance a mesh root, as opposed to the source node. This is also the case when some routing information must be removed from a packet that will flow outside the LLN.

As an example, the Routing Protocol for Low Power and Lossy Networks [RFC6550] (RPL) is designed to optimize the routing operations in constrained LLNs. As part of this optimization, RPL requires the addition of RPL Packet Information (RPI) in every packet, as defined in Section 11.2 of [RFC6550].

The RPL Option for Carrying RPL Information in Data-Plane Datagrams [RFC6553] specification indicates how the RPI can be placed in a RPL Option for use in an IPv6 Hop-by-Hop header. This representation demands a total of 8 bytes when in most cases the actual RPI payload requires only 19 bits. Since the Hop-by-Hop header must not flow outside of the RPL domain, it must be removed from packets that leave the domain, and be inserted in packets entering the domain. In both cases, this operation implies an IP-in-IP encapsulation.

```
             ------+---------                            ^
                   |          Internet                   |
                   |                                     | Native IPv6
                +-----+                                  |
                |     | Border Router (RPL Root)    ^    |    ^
                |     |                             |    |    |
                +-----+                             |    |    | IPv6 in
                   |                                |    |    | IPv6
             o    o   o    o                        |    |    | + RPI
         o o   o  o   o  o  o o   o                 |    |    |   or RH3
        o  o o  o o    o   o   o  o  o              |    |    |
        o   o    o  o     o  o    o  o  o           |    |    |
       o  o   o  o   o         o   o o              v    v    v
       o          o             o     o
                         LLN
```

Figure 1: IP-in-IP Encapsulation within the LLN

Additionally, in the case of the Non-Storing Mode of Operation (MOP), RPL requires a Routing Header type 3 (RH3) as defined in the IPv6 Routing Header for Source Routes with RPL [RFC6554] specification, for all packets that are routed down a RPL graph. With Non-Storing RPL, even if the source is a node in the same LLN, the packet must first reach up the graph to the root so that the root can insert the RH3 to go down the graph. In any fashion, whether the packet was originated in a node in the LLN or outside the LLN, and regardless of whether the packet stays within the LLN or not, as long as the source of the packet is not the root itself, the source-routing operation also implies an IP-in-IP encapsulation at the root to insert the RH3.

6TiSCH [I-D.ietf-6tisch-architecture] specifies the operation of IPv6 over the TimeSlotted Channel Hopping [I-D.ietf-6tisch-tsch] (TSCH) mode of operation of IEEE 802.14.5. The architecture requires the use of both RPL and the 6lo adaptation layer framework ([RFC4944], [RFC6282]) over IEEE 802.14.5. Because it inherits the constraints on the frame size from the MAC layer, 6TiSCH cannot afford to spend 8 bytes per packet on the RPI. Hence the requirement for a 6LoWPAN header compression of the RPI.

The type of information that needs to be present in a packet inside the LLN but not outside of the LLN varies with the routing operation, but there is overall a need for an extensible compression technique that would simplify the IP-in-IP encapsulation, when needed, and optimally compress existing routing artifacts found in LLNs.

This specification extends 6LoWPAN [RFC4944] and in particular reuses the Mesh Header formats that are defined for the Mesh-under use cases so as to carry routing information for Route-over use cases. The

specification includes the formats necessary for RPL and is extensible for additional formats.

2. Terminology

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 [RFC2119].

The Terminology used in this document is consistent with and incorporates that described in `Terminology in Low power And Lossy Networks' [RFC7102] and [RFC6550].

The terms Route-over and Mesh-under are defined in [RFC6775].

Other terms in use in LLNs are found in [RFC7228].

The term "byte" is used in its now customary sense as a synonym for "octet".

3. Updating RFC 4944

Section 5.1 of the IPv6 over IEEE 802.15.4 [RFC4944] specification defines various Dispatch Types and Headers, and in particular a Mesh Header that corresponds to a pattern 10xxxxxx and effectively consumes one third of the whole 6LoWPAN dispatch space for Mesh-under specific applications.

This specification reuses the Dispatch space for Route-over and mixed operations. This means that a device that use the Mesh Header as specified in [RFC4944] should not be placed in a same network as a device which operates per this update. This is generally not a problem since a network is classically either Mesh-under OR Route-over.

A new implementation of Mesh-under MAY support both types of encoding, and if so, it SHOULD provide a management toggle to enable either mode and it SHOULD use this specification as the default mode.

4. General Format

The 6LoWPAN Routing Header (6LoRH) reuses the bit patterns that are defined in [RFC4944] for the Mesh Header, specifically the Dispatch Value Bit Pattern of 10xxxxxx. It may contain source routing information such as a compressed form of RH3, or other sorts of routing information such as the RPL RPI, source and/or destination

address, and is extensible for future uses, with the given example of BIER bitmap encoding in Section 9.

```
    0                   1
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+    ....    +-+
   |1|0|I| Size/Fmt|    Type       |                |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+    ....    +-+
                                    <--  Length  -->
```

Figure 2: 6LoWPAN Routing Header

I Flag:
The I flag is set to indicate that a 6LoWPAN Routing Header may be ignored and skipped in parsing. If it is ignored, the 6LoRH is forwarded with no change inside the LLN.

A 6LoWPAN Routing Header is shaped as a TLV. The first byte contains an I flag that is set if the 6LoRH can safely be ignored, and a Size/ Format field that is used to compute the Length of the remainder of the Header and eventually carry additional information.

If the I Flag is set, the Size / Format field contains the Length of the 6LoRH expressed in bytes. This is done to enable a node to skip a 6LoRH that it does not support and cannot parse, for instance if the Type is unknown.

If the I flag is not set, then a node that does not support the Type MUST drop the packet. Because further parsing of the packet implies that the Type is supported, it is possible to optimize the encoding of the Size / Format field in a fashion that depends on the Type. In some cases, the left side of the field may be used for control bits, and the length may be expressed in units that are not necessarily bytes but must be specified for a given Type as an integer number of bytes.

The second byte contains the Type and eventually some flags which depend on the Type.

If the Type is not understood and the I flag is not set, then the packet MUST be dropped. (Note that there is no provision for the exchange of error messages; such a situation should be avoided by judicious use of administrative control and/or capability indications.)

One or more 6LoWPAN Routing Headers MAY be placed in a 6LoWPAN packet.

Any 6LoWPAN Routing Headers MUST always be placed before the LOWPAN_IPHC [RFC6282].

A Fragmentation Type and Header [RFC4944] MAY be placed in any position before, after or in between 6LoWPAN Routing Headers. [XXX: Now what does that mean?] [YYY: I mean to say that we can have 0..n 6LoRH before a frag header, and 0..n 6LoRH after. If the frag header is preceded by 1..n RH then the RH(s) may be used to route the fragment]

Headers are processed in order so if 6LoWPAN Routing Headers located before the Fragmentation Type and Header and / or the LOWPAN_IPHC are sufficient to route a packet or a 6LoWPAN fragment over the LLN, then there is no need to parse the LOWPAN_IPHC or to recompose the fragmented packet at every LLN hop.

5. The Routing Header type 3 (RH3) 6LoRH

The Routing Header type 3 (RH3) 6LoRH (RH3-6LoRH) provides a compressed form for the Routing Header defined in [RFC6554] for use by RPL routers. Routers that need to forward a packet with a RH3-6LoRH are expected to be RPL routers and expected to support this specification. If a non-RPL router receives a packet with a RPI-6LoRH, this means that there was a routing error and the packet should be dropped so the Type cannot be ignored.

```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-    -+-    -+ ... +-    -+
|1|0|0|  Size   |6LoRH Type 0..4| Hop1 | Hop2 |     | HopN |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-    -+-    -+ ... +-    -+

      Size indicates the number of compressed addresses
```

Figure 3: The RH3-6LoRH

The values for the RH3-6LoRH Type are an enumeration, 0 to 4. The form of compression is indicated by the Type as follows:

Type	Size Unit
0	1
1	2
2	4
3	8
4	16

Figure 4: The RH3-6LoRH Types

The Size field encodes the number of hops minus 1, so a Size of 0 means one hop, and the maximum that can be encoded is 32 hops. (If more than 32 hops need to be expressed, a sequence of RH3-6LoRH can be employed.)

The next Hop is indicated in the first entry of the first RH3-6LoRH. Upon reception, the entry is checked whether it refers to the processing router itself. If it so, the entry is removed from the RH3-6LoRH and the Size is decremented. If the Size is now zero, the whole RH3-6LoRH is removed. If there is no more RH3-6LoRH, the processing node is the last router on the way, which may or may not be collocated with the final destination. [XXX: This doesn't work with hosts.] [YYY: which pleads towards saying that the final dest is in the IP header and only the intermediate hops are in the 6loRH.] [YYY2: I changed the sentence above and the below. But then, there might be an issue with routing fragments.]

The last hop in the last RH3-6LoRH is the last router prior to the destination in the LLN. So even when there is a RH3-6LoRH in the frame, the address of the final destination is in the LOWPAN_IPHC.

Each address in the list is decompressed by replacing the last size-unit bytes of the destination address derived from the LoWPAN_IPHC [RFC6282] decompression by the bytes given in the RH3-6LoRH.

All addresses in a RH3-6LoRH are compressed in a same fashion, down to the same number of bytes per address. In order to get different forms of compression, multiple consecutive RH3-6LoRH must be used.

6. The RPL Packet Information 6LoRH

[RFC6550], Section 11.2, specifies the RPL Packet Information (RPI) as a set of fields that are to be added to the IP packets for the purpose of Instance Identification, as well as Loop Avoidance and Detection.

In particular, the SenderRank, which is the scalar metric computed by an specialized Objective Function such as [RFC6552], indicates the Rank of the sender and is modified at each hop. The SenderRank allows to validate that the packet progresses in the expected direction, either upwards or downwards, along the DODAG.

RPL defines the RPL Option for Carrying RPL Information in Data-Plane Datagrams [RFC6553] to transport the RPI, which is carried in an IPv6 Hop-by-Hop Options Header [RFC2460], typically consuming eight bytes per packet.

With [RFC6553], the RPL option is encoded as six Octets; it must be placed in a Hop-by-Hop header that consumes two additional octets for a total of eight. In order to limit its range to the inside the RPL domain, the Hop-by-Hop header must be added to (or removed from) packets that cross the border of the RPL domain.

The 8-bytes overhead is detrimental to the LLN operation, in particular with regards to bandwidth and battery constraints. These bytes may cause a containing frame to grow above maximum frame size, leading to Layer 2 or 6LoWPAN [RFC4944] fragmentation, which in turn cause even more energy spending and issues discussed in the LLN Fragment Forwarding and Recovery [I-D.thubert-6lo-forwarding-fragments].

An additional overhead comes from the need, in certain cases, to add an IP-in-IP encapsulation to carry the Hop-by-Hop header. This is needed when the router that inserts the Hop-by-Hop header is not the source of the packet, so that an error can be returned to the router. This is also the case when a packet originated by a RPL node must be stripped from the Hop-by-Hop header to be routed outside the RPL domain.

This specification defines an IPinIP-6LoRH in Section 7 for that purpose, but it must be noted that stripping a 6LoRH does not require a manipulation of the packet in the LOWPAN_IPHC, and thus, if the source address in the LOWPAN_IPHC is the node that inserted the IPinIP-6LoRH then this alone does not mandate an IPinIP-6LoRH.

As a result, an RPL packet may bear only a RPI-6LoRH and no IPinIP-6LoRH. In that case, the source and destination of the packet are located in the LOWPAN_IPHC.

As with [RFC6553], the fields in the RPI include an 'O', an 'R', and an 'F' bit, an 8-bit RPLInstanceID (with some internal structure), and a 16-bit SenderRank.

The remainder of this section defines the RPI-6LoRH, that is a new 6LoWPAN Routing Header designed to transport the RPI in 6LoWPAN LLNs.

6.1. Compressing the RPLInstanceID

RPL Instances are discussed in [RFC6550], Section 5. A number of simple use cases will not require more than one instance, and in such a case, the instance is expected to be the global Instance 0. A global RPLInstanceID is encoded in a RPLInstanceID field as follows:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|0|     ID      |  Global RPLInstanceID in 0..127
+-+-+-+-+-+-+-+-+
```

Figure 5: RPLInstanceID Field Format for Global Instances

For the particular case of the global Instance 0, the RPLInstanceID field is all zeros. This specification allows to elide a RPLInstanceID field that is all zeros, and defines a I flag that, when set, signals that the field is elided.

6.2. Compressing the SenderRank

The SenderRank is the result of the DAGRank operation on the rank of the sender; here the DAGRank operation is defined in [RFC6550], Section 3.5.1, as:

DAGRank(rank) = floor(rank/MinHopRankIncrease)

If MinHopRankIncrease is set to a multiple of 256, the least significant 8 bits of the SenderRank will be all zeroes; by eliding those, the SenderRank can be compressed into a single byte. This idea is used in [RFC6550] by defining DEFAULT_MIN_HOP_RANK_INCREASE as 256 and in [RFC6552] that defaults MinHopRankIncrease to DEFAULT_MIN_HOP_RANK_INCREASE.

This specification allows to encode the SenderRank as either one or two bytes, and defines a K flag that, when set, signals that a single byte is used.

6.3. The Overall RPI-6LoRH encoding

The RPI-6LoRH provides a compressed form for the RPL RPI. Routers that need to forward a packet with a RPI-6LoRH are expected to be RPL routers and expected to support this specification. If a non-RPL router receives a packet with a RPI-6LoRH, this means that there was

a routing error and the packet should be dropped so the Type cannot be ignored.

Since the I flag is not set, the Size / Format field does not need to be a length expressed in bytes. The field is fully reused for control bits so as to encode the O, R and F flags from the RPI, and the I and K flags that indicate the compression that is taking place.

The Type for the RPI-6LoRH is 5.

The RPI-6LoRH is immediately followed by the RPLInstanceID field, unless that field is fully elided, and then the SenderRank, which is either compressed into one byte or fully in-lined as the whole 2 bytes. The I and K flags in the RPI-6LoRH indicate whether the RPLInstanceID is elided and/or the SenderRank is compressed and depending on these bits, the Length of the RPI-6LoRH may vary as described hereafter.

```
    0                   1                   2
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+  ...  -+-+-+
   |1|0|0|O|R|F|I|K| 6LoRH Type=5  |   Compressed fields  |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+  ...  -+-+-+
```

Figure 6: The Generic RPI-6LoRH Format

O, R, and F bits:
    The O, R, and F bits as defined in [RFC6550], Section 11.2.

I bit:
    If it is set, the Instance ID is elided and the RPLInstanceID is the Global RPLInstanceID 0. If it is not set, the octet immediately following the type field contains the RPLInstanceID as specified in [RFC6550] section 5.1.

K bit:
    If it is set, the SenderRank is be compressed into one octet, and the lowest significant octet is elided. If it is not set, the SenderRank, is fully inlined as 2 octets.

In Figure 7, the RPLInstanceID is the Global RPLInstanceID 0, and the MinHopRankIncrease is a multiple of 256 so the least significant byte is all zeros and can be elided:

```
     0                   1                   2
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |1|0|0|O|R|F|1|1| 6LoRH Type=5  | SenderRank    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
              I=1, K=1
```

Figure 7: The most compressed RPI-6LoRH

In Figure 8, the RPLInstanceID is the Global RPLInstanceID 0, but both bytes of the SenderRank are significant so it can not be compressed:

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |1|0|0|O|R|F|1|0| 6LoRH Type=5  |        SenderRank             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
              I=1, K=0
```

Figure 8: Eliding the RPLInstanceID

In Figure 9, the RPLInstanceID is not the Global RPLInstanceID 0, and the MinHopRankIncrease is a multiple of 256:

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |1|0|0|O|R|F|0|1| 6LoRH Type=5  | RPLInstanceID |  SenderRank   |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
              I=0, K=1
```

Figure 9: Compressing SenderRank

In Figure 10, the RPLInstanceID is not the Global RPLInstanceID 0, and both bytes of the SenderRank are significant:

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |1|0|0|O|R|F|0|0| 6LoRH Type=5  | RPLInstanceID |    Sender-...
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      ...-Rank      |
    +-+-+-+-+-+-+-+-+
              I=0, K=0
```

Figure 10: Least compressed form of RPI-6LoRH

A typical packet in RPL non-storing mode going down the RPL graph requires an IPinIP encapsulating the RH3, whereas the RPI is usually omitted, unless it is important to indicate the RPLInstanceID. To match this structure, an optimized IPinIP 6LoRH is defined in Section 7.

7. The IP-in-IP 6LoRH

The IP-in-IP 6LoRH IPinIP-6LoRH provides a compressed form for the encapsulating IPv6 Header in the case of an IP-in-IP encapsulation.

An IPinIP encapsulation is used to insert a field such as a Routing Header or an RPI at a router that is not the source of the packet. In order to send an error back regarding the inserted field, the address of the router that performs the insertion must be provided.

The encapsulation can also enable a router down the path removing a field such as the RPI, but this can be done in the compressed form by removing the RPI-6LoRH, so an IPinIP-6LoRH encapsulation is not required for that sole purpose.

This field is not critical for routing so the Type can be ignored, and the Size / Format field contains the Length in bytes .

```
  0                   1                   2
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-       ...      -+
 |1|0|1| Length  | 6LoRH Type 6  |  Hop Limit    | Encaps. Address  |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-       ...      -+
```

Figure 11: The IPinIP-6LoRH

The Length of an IPinIP-6LoRH is expressed in bytes and MUST be at least 1, to indicate a Hop Limit (HL), that is decremented at each hop. When the HL reaches 0, the packet is dropped per [RFC2460]

If the Length of an IPinIP-6LoRH is exactly 1, then the Encapsulator Address is elided, which means that the Encapsulator is a well-known router, for instance the root in a RPL graph.

If the Length of an IPinIP-6LoRH is strictly more than 1, then an Encapsulator Address is placed in a compressed form after the Hop Limit field. The value of the Length indicates which compression is performed on the Encapsulator Address. For instance, a Size of 3 indicates that the Encapsulator Address is compressed to 2 bytes.

8. The Mesh Header 6LoRH

The Mesh Header 6LoRH (MH-6LoRH) provides an alternate form for the Mesh Addressing Type and Header defined in [RFC4944]. The MH-6LoRH is introduced as replacement for use in potentially mixed Route_Over and Mesh-under environments. LLN nodes that need to forward a packet with a MH-6LoRH are expected to support this specification. If a router that supports only Route-over receives a packet with a MH-6LoRH, this means that there was a routing error and the packet should be dropped, so the Type cannot be ignored.

The HopsLft field defined in [RFC4944] is encoded in the MH-6LoRH Size, so this specification doubles the potential number of hops vs. [RFC4944].

```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-          ...                   -+
|1|0|0|  Size   |6LoRHType 8..11| originator address, final address
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-          ...                   -+

         Size indicates the number of compressed addresses
```

Figure 12: The MH-6LoRH

The V and F flags defined in [RFC4944] are encoded in the MH-6LoRH Type as follows:

Type	V	F
8	0	0
9	0	1
10	1	0
11	1	1

Figure 13: The MH-6LoRH Types

9. The BIER 6LoRH

(Note that the current contents of this section is a proof of concept only; the details for this encoding need to be developed in paralell with defining the semantics of a constrained version of BIER.)

The Bit Index Explicit Replication (BIER) 6LoRH (BIER-6LoRH) provides a variable-size container for a BIER Bitmap that is used to route

towards one or more LLN node, as discussed in the BIER Architecture [I-D.wijnands-bier-architecture] specification. The capability to parse the BIER Bitmap is necessary to forward the packet so the Type cannot be ignored.

```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ ... -+-+-+-    ...      -+
|1|0|0|  Size   |6LoRHType12..19| Control Fields |    bitmap     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ ... -+-+-+-    ...      -+
```

Figure 14: The BIER-6LoRH

The Type for a BIER-6LoRH indicates the size of words used to build the bitmap and whether the bitmap is operated as an uncompressed bit-by-bit mapping, or as a Bloom filter.

In the bit-by-bit case, each bit is mapped in an unequivocal fashion with a single addressable resource in the network. This may rapidly lead to large bitmaps, and BIER allows to divide a network into groups that partition the network so that a given bitmap is locally significant to one group only. This specification allows to encode a 1-byte Group ID in the BIER-6LoRH Control Fields.

A Bloom Filter can be seen as a compression technique for the bitmap. A Bloom Filter may generate false positives, which, in the case of BIER, result in undue forwarding of a packet down a path where no listener exists.

As an example, the Constrained-Cast [I-D.bergmann-bier-ccast] specification employs Bloom Filters as a compact representation of a match or non-match for elements in a large set.

In the case of a Bloom Filter, a number of Hash functions must be run to obtain a multi-bit signature of an encoded element. This specification allows to signal an Identifier of the Hash functions being used to generate a certain bitmap, so as to enable a migration scenario where Hash functions are renewed. A Hash ID is signaled as a 1-byte value, and, depending on the Type, there may be up to 2 or up to 8 Hash IDs passed in the BIER-6LoRH Control Fields associated with a Bloom Filter bitmap, as follows:

Type	encoding	Control Fields	Word Size
12	bit-by-bit	none	32 bits
13	Bloom filter	2* 1-byte HashID	32 bits
14	bit-by-bit	none	128 bits
15	Bloom filter	8* 1-byte HashID	128 bits
16	bit-by-bit	1-byte GroupID	128 bits

Figure 15: The BIER-6LoRH Types

In order to address a potentially large number of devices, the bitmap may grow very large. Yet, the maximum frame size for a given MAC layer may limit the number of bits that can be dedicated to routing. The Size indicates the number of words in the bitmap minus one, so a size of 0 means one word, a Size of 1 means 64 2 words, up to a size of 31 which means 32 words.

10. Security Considerations

The security considerations of [RFC4944], [RFC6282], and [RFC6553] apply.

Using a compressed format as opposed to the full inline RPL option is logically equivalent and does not create an opening for a new threat when compared to [RFC6553].

11. IANA Considerations

This document creates a IANA registry for the 6LoWPAN Routing Header Type, and assigns the following values:

0..4 : RH3-6LoRH [RFCthis]

5 : RPI-6LoRH [RFCthis]

6 : IPinIP-6LoRH [RFCthis]

8..11 : MH-6LoRH [RFCthis]

12..16 : BIER-6LoRH [RFCthis]

12. Acknowledgements

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13.1. Normative References

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Authors' Addresses

Pascal Thubert (editor)
Cisco Systems
Village d'Entreprises Green Side
400, Avenue de Roumanille
Batiment T3
Biot - Sophia Antipolis 06410
FRANCE

Phone: +33 4 97 23 26 34
Email: pthubert@cisco.com

Carsten Bormann
Universitaet Bremen TZI
Postfach 330440
Bremen D-28359
Germany

Phone: +49-421-218-63921
Email: cabo@tzi.org

Laurent Toutain
Institut MINES TELECOM; TELECOM Bretagne
2 rue de la Chataigneraie
CS 17607
Cesson-Sevigne Cedex 35576
France

Email: Laurent.Toutain@telecom-bretagne.eu