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J. Hui, Ed.
Arch Rock Corporation
P. Thubert
Cisco

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# Compression Format for IPv6 Datagrams in 6LoWPAN Networks
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Abstract

This document specifies an IPv6 header compression format for IPv6 packet delivery in 6LoWPAN networks. The compression format relies on shared context to allow compression of arbitrary prefixes. This document specifies compression of multicast addresses and a framework for compressing next headers. This framework specifies UDP compression and is prepared for additional transports.

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## 1. Introduction

The [IEEE 802.15.4] standard specifies an MTU of 128 bytes, yielding about 80 octets of actual MAC payload once security is turned on, on a wireless link with a link throughput of 250 kbps or less. The 6LoWPAN adaptation format [RFC4944] was specified to carry IPv6 datagrams over such constrained links, taking into account limited bandwidth, memory, or energy resources that are expected in applications such as wireless Sensor Networks. [RFC4944] defines a Mesh Addressing header to support sub-IP forwarding, a Fragmentation header to support the IPv6 minimum MTU requirement [RFC2460], and stateless header compression for IPv6 datagrams (LOWPAN_HC1 and LOWPAN_HC2) to reduce the relatively large IPv6 and UDP headers down to (in the best case) several bytes.

LOWPAN_HC1 and LOWPAN_HC2 are insufficient for most practical uses of 6LoWPAN networks. LOWPAN_HC1 is most effective for link-local unicast communication, where IPv6 addresses carry the link-local prefix and an Interface Identifier (IID) directly derived from IEEE 802.15.4 addresses. In this case, both addresses may be completely elided. However, though link local addresses are commonly used for local protocol interactions such as IPv6 ND [RFC4861], DHCPv6 [RFC3315] or routing protocols, they are usually not used for application layer data traffic, so the actual value of this compression mechanism is limited.

Routable addresses must be used when communicating with devices external to the LoWPAN or in a route-over configuration where IP forwarding occurs within the LoWPAN. For routable addresses, LOWPAN_HC1 requires both IPv6 source and destination addresses to carry the prefix in-line. In cases where the Mesh Addressing header is not used, the IID of a routable address must be carried in-line. However, LOWPAN_HC1 requires 64-bits for the IID when carried in-line and cannot be shortened even when it is derived from the IEEE 802.15.4 16-bit short address.

When the destination is an IPv6 multicast address, LOWPAN_HC1 requires the full 128-bit address to be carried in-line. This specification provides an additional mechanism to compress Unique Local, Global and multicast IPv6 Addresses based on shared states within contexts. It also introduces a number of additional improvements over [RFC4944].

LOWPAN_HC1 cannot elide the IPv6 Hop Limit in the IPv6 header, even though a limited set of values are useful in many practical cases. For instance, if the LoWPAN is a mesh-under stub, a Hop Limit of 1 for inbound and a default value such as 64 for outbound are usually enough for application layer data traffic. Compressing that field

enables saving one octet per packet.

LOWPAN_HC1 can be extended to include a LOWPAN_HC2 octet to support compression of UDP, TCP, or ICMPv6; that LOWPAN_HC2 octet is placed right after the LOWPAN_HC1 octet and before the uncompressed IP fields. This specification moves the transport control octet after the uncompressed IP fields for a more properly layered structure.

[RFC4944] defines a compression mechanism for UDP, but that mechanism does not enable checksum compression when rendered possible by additional upper layer mechanisms such as upper layer Message Integrity Check (MIC). This specification adds the capability to compress the UDP checksum over the LoWPAN, which enables to save an additional pair of octets.

Finally, LOWPAN_HC1 lacks the flexibility to support the compression of additional transport mechanisms that could be introduced in the future.

This document specifies a header compression format for IPv6 datagrams. This format improves on the header compression format defined in [RFC4944] by generalizing it to support a broader range of communication paradigms, including both mesh-under and route-over configurations; communication to nodes internal and external to the 6LoWPAN network; and multicast communication. This document also defines a flexible framework for compressing arbitrary next headers and defines UDP header compression within this framework. This compression format carries forward the design concepts in RFC 4944 [RFC4944], minimizing any state and relying on shared context among all nodes in a 6LoWPAN network.

### 1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

## 2. IPv6 Header Compression

In this section, we define the LOWPAN_IPHC encoding format for compressing the IPv6 header. To enable effective compression LOWPAN_IPHC relies on information pertaining to the entire 6LoWPAN network. LOWPAN_IPHC assumes the following will be the common case for 6LoWPAN communication: Version is 6; Traffic Class and Flow Label are both zero; Payload Length can be inferred from lower layers from either the 6LoWPAN Fragmentation header or the IEEE 802.15.4 header; Hop Limit will be set to a well-known value by the source; addresses

assigned to 6LoWPAN interfaces will be formed using the link-local prefix or a single routable prefix assigned to the entire 6LoWPAN network; addresses assigned to 6LoWPAN interfaces are formed with an IID derived directly from either the 64-bit extended or 16-bit short IEEE 802.15.4 addresses.

```
+-------------------------------------+-----------------------
| Dispatch + LOWPAN_IPHC (2-3 octets) | Compressed IPv6 Header
+-------------------------------------+-----------------------
```

Figure 1: LOWPAN_IPHC Header

The LOWPAN_IPHC encoding utilizes 11 bits, 3 of which are taken from the rightmost bit of the dispatch type. The encoding may be extended by another octet to support additional contexts. Uncompressed IPv6 header fields follow the LOWPAN_IPHC encoding, as shown in Figure 1. With the above scenario, the LOWPAN_IPHC can compress the IPv6 header down to two octets (the dispatch octet and the LOWPAN_IPHC encoding) with link-local communication. When routing over multiple IP hops, LOWPAN_IPHC can compress the IPv6 header down to 7 octets (1-octet dispatch, 1-octet LOWPAN_IPHC, 1-octet Hop Limit, 2-octet Source Address, and 2-octet Destination Address).

## 2.1. LOWPAN_IPHC Encoding Format

### 2.1.1. Base Format

```
  0   1   2   3   4   5   6   7   8   9   0   1   2   3   4   5
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
| 0 | 1 | 0 | 0 | 1 |   TF   |NH | HLIM  |   CM    |  SAM  |  DAM  |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
```

Figure 2: LOWPAN_IPHC Encoding

TF: Traffic Class, Flow Label:
   00:  4-bit Pad + Traffic Class + Flow Label (4 bytes)
   01:  ECN + 2-bit Pad + Flow Label (3 bytes)
   10:  Traffic Class (1 byte)
   11:  Version, Traffic Class, and Flow Label are compressed.
NH: Next Header:

      0: Full 8 bits for Next Header are carried in-line.
      1: The Next Header field is compressed and the next header is
         compressed using LOWPAN_NHC, which is discussed in Section 3.
   HLIM: Hop Limit:
      00:  The Hop Limit field is carried in-line.
      01:  The Hop Limit field is compressed and the the hop limit is 1.
      10:  The Hop Limit field is compressed and the the hop limit is
         64.
      11:  The Hop Limit field is compressed and the hop limit is 255.
   CM: Compression Mode:
      00:  Stateful compression using a default context.  In this case
         the context for SAM and DAM is the default context.
      01:  Stateful compression using an indexed context; In this case
         the context for SAM and DAM is indicated in additional context
         octets that extends the LOWPAN_IPHC field to disambiguate an
         elided prefix or address described by the SAM or DAM fields.
      10:  Stateless compression using a well-know (Link-Local) prefix;
         In this case, the context is the Link Local context and the
         prefix is FE80::/64.  This compression mode is used for link
         local to link local communication.
      11:  Stateless compression using a well-know pattern; In this
         case, the context for the source address is the Link Local
         context and the prefix is FE80::/64.  The compression for the
         destination address does not use a context but a well-known
         pattern used in multicast addresses.  This compression mode is
         used for link local to link scoped multicast group
         communication.
   SAM & DAM: Source and Destination Address Mode:  The values for the
      SAM field are generally are generically as follows:
      00:  128 bits: The whole Address is carried in-line.
      01:  64 bits: the first 64 bits of the Address are elided.  The
         value of those bits are taken from the context and padded with
         zeroes.  The remaining 64 bits are carried inline.
      10:  16 bits: the first 112 bits of the Address are elided.  The
         value of those bits is taken from the context and padded with
         zeroes.  The remaining 16 bits are carried inline.
      11:  0 bit.  The Address is fully elided.  The first 64 bits of
         the Address are elided taken from the context.  The remaining
         64 bits are computed from the link layer address as defined in
         [RFC4944].
      This generic rule applies depending on the CM field and with
      exceptions as follows:
      CM field of 10 (well-known prefix):  The value of 00 is reserved
         for SAM and DAM.

CM field of 11 (well-known pattern): The SAM value of 00 indicates that the Source Address is the unspecified address. The compression of the Destination Address relies on well-known patterns for multicast addresses as follows:

- 00: 8 bits. Used to compress the most used permanently-assigned multicast addresses. A prefix of FF02::/120 is elided. The remaining 8 bits are carried inline.
- 01: 24 bits. Used to compress Solicited-Node multicast addresses. A prefix of FF02::1:FF00:0/104 is elided. The remaining 24 bits are carried inline.
- 10: 16 bits: The Compressed Multicast address fsmg where f is 4-bit flags, s is 4-bit scope, and mg is the least significant 8 bits of the multicast group identifier FFfs::00mg. The 16 bits of fsmg are carried inline.
- 11: 24 bits: The Compressed Multicast address fsmgmg where f is 4-bit flags, s is 4-bit scope, and mgmg is the least significant 16 bits of the multicast group identifier FFfs::mgmg. The 24 bits of fsmgmg are carried inline.

### 2.1.2. Context Identifier Extension

This specification expects that a concept of context is shared between the node that compresses a packet and the node(s) that need to expand it. The specification enables a node to use of up to 16 contexts. How the contexts are shared and maintained is out of scope. Actions in response to unknown and/or invalid contexts are out of scope.

If the CM field is set to '01' in the LOWPAN_HC encoding, then an additional octet extends the LOWPAN_HC encoding following the DAM bits but before the IPv6 header fields that are carried in-line. The additional octet identifies the prefix when the IPv6 source and/or destination address is compressed. The context identifier is 4 bits for each address, supporting up to 16 contexts. The encoding is shown in Figure 3.

```
  0   1   2   3   4   5   6   7
+---+---+---+---+---+---+---+---+
|      SAC      |      DAC      |
+---+---+---+---+---+---+---+---+
```

Figure 3: LOWPAN_IPHC Encoding

SAC: Source Address Context  Identifies the prefix that is used when the IPv6 source address is compressed.
DAC: Destination Address Context  Identifies the prefix that is used when the IPv6 destination address is compressed.

### 2.2. IPv6 Header Encoding

Fields carried in-line (in part or in whole) appear in the same order as they do in the IPv6 header format [RFC2460].  The Version field is always elided.  Unicast IPv6 addresses may be compressed to 64 or 16 bits or completely elided.  Multicast IPv6 addresses may be compressed to 8, 16, or 24 bits.  The IPv6 Payload Length field MUST always be elided and inferred from lower layers using the 6LoWPAN Fragmentation header or the IEEE 802.15.4 header.

#### 2.2.1. Traffic Class and Flow Label Encoding

The TF field in the LOWPAN_HC encoding indicate whether the Traffic Class and Flow Label are carried in-line in the compressed IPv6 header.  When Flow Label is included while the Traffic Class is compressed, an additional 4 bits are included to maintain byte-alignment.  Two of the 4 bits contain the ECN bits from the Traffic Class field.

To ensure that the ECN bits appear in the same location for all encodings that include them, the Traffic Class field is rotated right by 2 bits in the compressed IPv6 header.  The encodings are shown below:

```
                     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
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |ECN|   DSCP    |  rsv  |             Flow Label                |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

                            TF = 00


                     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
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |ECN|rsv|             Flow Label                |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

TF = 01

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|ECN|   DSCP    |
+-+-+-+-+-+-+-+-+
```

TF = 10

### 2.2.2. IPv6 Address Encoding for Unicast Destinations

IPv6 unicast addresses may be carried in-line in full or or compressed to 64, 16, or 0 bits. When compressed, the bits carried in-line represent the least significant bits of the suffix. The value of the prefix depends on the value of the DDF field and possibly the SAC field in the Context Identifier Extension.

Destination is Global with No Context ID (DDF = 00): When the source and/or destination addresses are compressed, the prefix is identified by context 0.

Destination is Global with Context ID (DDF = 01): When the source and/or destination addresses are compressed, the prefix is identified by the SAC and DAC fields in the Context Identifier Extension, respectively.

Destination is Link-Local Unicast (DDF = 10): When the source and/or destination addresses are compressed, the prefix is the link-local unicast prefix (FE80::/10).

When an address is completely elided, the lower bits are inferred from lower layers (either from the 6LoWPAN Mesh Addressing header or from the IEEE 802.15.4 header). Specifically, if the lower-layer header contains an extended 802.15.4 address, then a 64-bit suffix is derived from the lower-layer header. If the lower-layer header contains short 802.15.4 address, then a 16-bit suffix is derived from the lower-layer header.

### 2.2.3. IPv6 Address Encoding for Multicast Destinations

IPv6 source addresses with link-local scope may be compressed when the destination address is a multicast address. The IPv6 source address may be compressed to 64, 16, or 0 bits. The encoding also supports the compression of the unspecified address (::).

SAM = 00: Source Address is the unspecified address and all 128 bits are elided.

SAM = 01: 64-bit prefix is elided and is the link-local (FE80::/10). 64-bit Suffix is carried in-line.

SAM = 10: 112-bit prefix is elided and is the link-local (FE80::/10). 16-bit Suffix is carried in-line.

SAM = 11: All 128 bits of Source Address are elided. The prefix is the link-local prefix (FE80::/10). The suffix is derived from lower-layer headers.

IPv6 multicast addresses may be comrpessed down to 24, 16, or 8 bits. The format supports compression of the Solicited-Node Multicast Address (FF02::1:FFXX:XXXX) as well as any IPv6 multicast address where the upper 104 bits of the multicast group identifier are zero (FFXX::XXXX). The encoding format also compressed link-local multicast addresses of the form (FF02::00XX) down to a single byte. The compressed form only carries least-significant bits of the multicast group identifier.

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|   Group ID    |
+-+-+-+-+-+-+-+-+
```

DAM = 00. 8-bit Compressed Multicast Address (FF02::00mg)

```
                     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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Last 24 bits of Group ID           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

DAM = 01. Compressed Solicited-Node Address (FF02::1:FFXX:XXXX).

```
                     1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Flags | Scope |   Group ID    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

DAM = 10. 16-bit Compressed Multicast Address (FFfs::00mg).

```
                     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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Flags | Scope |    Last 16 bits of Group ID    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

DAM = 11. 24-bit Compressed Multicast Address (FFfs::mgmg).

## 3. IPv6 Next Header Compression

LOWPAN_IPHC elides the IPv6 Next Header field when the NH bit is set to 1. It also indicates the use of 6LoWPAN next header compression, LOWPAN_NHC. The value of IPv6 Next Header is recovered from the first bits in the LOWPAN_NHC encoding. The following bits are specific to the IPv6 Next Header value. Figure 4 shows the structure of an IPv6 datagram compressed using LOWPAN_IPHC and LOWPAN_NHC.

```
+-------------+-------------+-------------+-----------------+--------
| LOWPAN_IPHC | In-line     | LOWPAN_NHC  | In-line Next    | Payload
|   Encoding  |   IP Fields |   Encoding  |   Header Fields |
+-------------+-------------+-------------+-----------------+--------
```

Figure 4: Typical LOWPAN_IPHC/LOWPAN_NHC Header Configuration

### 3.1. LOWPAN_NHC Format

Compression formats for different next headers are identified by a variable length bit-pattern immediately following the LOWPAN_IPHC compressed header. When defining a next header compression format, the number of bits used SHOULD be determined by the perceived frequency of using that format. However, the number of bits and any remaining encoding bits SHOULD respect octet alignment. The following bits are specific to the next header compression format. In this document, we define a compression format for UDP headers.

```
+----------------+---------------------------
| var-len NHC ID | compressed next header...
+----------------+---------------------------
```

Figure 5: LOWPAN_NHC Encoding

## 3.2. UDP Header Compression

This document defines a compression format for UDP headers using LOWPAN_NHC. The UDP compression format is shown in Figure 6. Bits 0 through 4 represent the NHC ID and '11110' indicates the specific UDP header compression encoding defined in this section.

```
  0   1   2   3   4   5   6   7
+---+---+---+---+---+---+---+---+
| 1 | 1 | 1 | 1 | 0 | C |   P   |
+---+---+---+---+---+---+---+---+
```

Figure 6: UDP Header Encoding

C: Checksum:
- 0: All 16 bits of Checksum are carried in-line. The Checksum MUST be included if there are no other end-to-end integrity checks that are stronger than what is provided by the UDP checksum. Such an integrity check MUST be end-to-end and cover the IPv6 pseudo-header, UDP header, and UDP payload.
- 1: All 16 bits of Checksum are elided. The Checksum is recovered by recomputing it.

P: Ports:
- 00: All 16 bits for both Source Port and Destination Port are carried in-line.
- 01: All 16 bits for Source Port are carried in-line. First 8 bits of Destination Port is 0xF0 and elided. The remaining 8 bits of Destination Port are carried in-line.
- 10: First 8 bits of Source Port are 0xF0 and elided. The remaining 8 bits of Source Port are carried in-line. All 16 bits for Destination Port are carried in-line.
- 11: First 12 bits of both Source Port and Destination Port are 0xF0B and elided. The remaining 4 bits for each are carried in-line.

Fields carried in-line (in part or in whole) appear in the same order as they do in the IPv6 header format [RFC2460]. IPv6 addresses may be compressed to 64 or 16 bits or completely elided. The UDP Length field MUST always be elided and is inferred from lower layers using the 6LoWPAN Fragmentation header or the IEEE 802.15.4 header.

## 4. IANA Considerations

This document defines a new IPv6 header compression format for 6LoWPAN networks. The document allocates Dispatch type values of 0x08-0x0F (TBD) for LOWPAN_IPHC.

## 5. Security Considerations

The definition of LOWPAN_IPHC permits the compression of header information on communication that could take place in its absence, albeit in a less efficient form. It recognizes that a IEEE 802.15.4 PAN may have associated with it a number of prefixes through shared context. How the shared context is assigned and managed is beyond the scope of this document.

## 6. Acknowledgements

Thanks to Julien Abeille, Carsten Bormann, Christos Polyzois, and Jay Werb for useful feedback and discussion.

## 7. Changes

Draft 02:

- Updated wording with compression mode to clarify that a compression mode does not enforce what kind of destination address is being used. Specifically changed Destination Dependent Field to Compression Mode.
- Specify that the configuration and management of contexts is out of scope of this document.

Draft 01:

- HC back to 1 byte by default by stealing a few bits from the dispatch field.
- Added better support for multicast address compression.
- Fixed alignment for UDP port compression.
- Better support for Traffic Class and Flow Label compression.
- Pascal joined as an author.

## 8. References

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Authors' Addresses

Jonathan W. Hui (editor)
Arch Rock Corporation
501 2nd St. Ste. 410
San Francisco, California 94107
USA

Phone: +415 692 0828
Email: jhui@archrock.com

Pascal Thubert
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

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