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Internet-Draft UPC
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Intended status: Standards Track Consultant
Expires: 6 January 2026 July 2025

Transmission of SCHC-compressed packets over IEEE 802.15.4 networks
draft-ietf-6lo-schc-15dot4-10

Abstract

A framework called Static Context Header Compression and fragmentation (SCHC) has been designed with the primary goal of supporting IPv6 over Low Power Wide Area Network (LPWAN) technologies [RFC8724]. One of the SCHC components is a header compression mechanism. If used properly, SCHC header compression allows a greater compression ratio than that achievable with traditional 6LoWPAN header compression [RFC6282]. For this reason, it may make sense to use SCHC header compression in some 6LoWPAN environments, including IEEE 802.15.4 networks. This document specifies how a SCHC-compressed packet can be carried over IEEE 802.15.4 networks. The document also enables the transmission of SCHC-compressed UDP/CoAP headers over 6LoWPAN-compressed IPv6 packets.

Status of This Memo

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1. Introduction

RFC 6282 is the main specification for IPv6 over Low power Wireless Personal Area Network (6LoWPAN) IPv6 header compression [RFC6282]. That RFC was designed assuming IEEE 802.15.4 as the layer below the 6LoWPAN adaptation layer, and it has also been reused by the IPv6 over Networks of Resource-constrained Nodes (6lo) working group (with proper adaptations) for IPv6 header compression over many other technologies relatively similar to IEEE 802.15.4 in terms of characteristics such as physical layer bit rate, layer 2 maximum payload size, etc. Examples of such technologies comprise BLE, DECT-ULE, ITU G.9959, MS/TP, NFC, and PLC. RFC 6282 provides additional functionality, such as a mechanism for UDP header compression.

In the best cases, RFC 6282 allows to compress a 40-byte IPv6 header down to a 2-byte compressed header (for link-local interactions) or a 3-byte compressed header (when global IPv6 addresses are used). On the other hand, RFC 6282 typically compresses a UDP header to a size of 2 to 4 bytes. Therefore, in advantageous conditions, a 48-byte uncompressed IPv6/UDP header may be compressed down to a 4- to 6-byte format (when using link-local addresses) or a 5- to 7-byte format (for global interactions) by using RFC 6282.

Recently, a framework called Static Context Header Compression (SCHC) has been designed with the primary goal of supporting IPv6 over Low Power Wide Area Network (LPWAN) technologies [RFC8724]. SCHC comprises header compression and fragmentation functionality tailored to the extraordinary constraints of LPWAN technologies, which are more severe than those exhibited by IEEE 802.15.4 or other relatively similar technologies. SCHC header compression allows a greater compression ratio than that of RFC 6282. If used properly, SCHC allows to compress an IPv6/UDP header down to e.g. a single byte. In addition, SCHC can be used to compress Constrained Application Protocol (CoAP) headers [RFC7252][RFC8824], which further increases the achievable performance improvement of using SCHC header compression, since there is no 6LoWPAN header compression mechanism defined for CoAP. Therefore, it may make sense to use SCHC header compression in some 6LoWPAN environments, including IEEE 802.15.4 networks, considering its greater efficiency.

This document specifies how a SCHC-compressed packet can be carried over IEEE 802.15.4 networks. In order to ease a transition from existing 6LoWPAN/6Lo implementations to support SCHC header compression, the document also enables the transmission of SCHC-compressed UDP/CoAP headers over 6LoWPAN-compressed IPv6 packets. Further transition approaches are also described.

The mechanism to be used to provide the SCHC header compression context to the nodes in an IEEE 802.15.4 network is out of the scope of this document.

Note that, as per this document, and while SCHC defines fragmentation mechanisms as well, 6LoWPAN/6lo fragmentation is used when necessary to transport SCHC-compressed packets over IEEE 802.15.4 networks [RFC4944][RFC8930][RFC8931].

In order to properly adapt to the requirements of supporting SCHC-compressed packets over IEEE 802.15.4 networks, this specification updates RFC 8138, RFC 8724, and RFC 9008.

2. Terminology

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 BCP14 [RFC2119], [RFC8174], when, and only when, they appear in all capitals, as shown here.

2.2. Background on previous specifications

The reader is expected to be familiar with the terms and concepts defined in specifications of 6LoWPAN frame formats [RFC4944], Neighbor Discovery for 6LoWPANs [RFC6775][RFC8505], RPL [RFC6550] and companion documents [RFC6553][RFC6554][RFC9008], 6LoWPAN Routing Header [RFC8138], SCHC [RFC8724], SCHC for CoAP [RFC8824], and SCHC architecture [I-D.ietf-schc-architecture].

RFC 8724 defines the Rule concept, whereby a Rule may be used to support header compression or fragmentation functionality. In the present document, Rules are only used for header compression.

RFC 6775 defines the term 6LoWPAN Node (6LN) as the following: "A 6LoWPAN node is any host or router participating in a LoWPAN. This term is used when referring to situations in which either a host or router can play the role described." In this document, as in RFC 9008, 6LN acts as a leaf.

2.3. New term

SCHC-Lo network: a 6LoWPAN network where SCHC is used for header compression/decompression. Note: "SCHC-Lo" is pronounced as "sheek-low", since it inherits the pronunciation of "SCHC" as "sheek" in English (see RFC 8724).

3. Architecture

3.1. Protocol stacks

3.1.1. Main protocol stack

The traditional 6LoWPAN-based protocol stack for constrained devices (Figure 1, left) places the 6LoWPAN adaptation layer between IPv6 and an underlying technology such as IEEE 802.15.4. Suitable upper layer protocols include CoAP [RFC7252] and UDP. (Note that, while CoAP has also been specified over TCP, and TCP may play a significant role in IoT environments [RFC9006], 6LoWPAN header compression has not been defined for TCP, as of the writing.)

6LoWPAN can be envisioned as a set of two main sublayers, where the upper one provides header compression, while the lower one offers fragmentation.

This document defines an alternative approach for packet header compression over IEEE 802.15.4, which leads to a modified protocol stack (Figure 1, right). Fragmentation functionality remains the one defined by 6LoWPAN [RFC4944] and 6lo [RFC8930][RFC8931].

```
        +------------+          +------------+
        | CoAP, other|          | CoAP, other|
        +------------+          +------------+
        | UDP, other |          | UDP, other |
        +------------+          +------------+
        |    IPv6    |          |    IPv6    |
        +------------+          +------------+
        | 6LoWPAN HC |          |  SCHC HC   |  <-- NEW
        +------------+          +------------+
        |6LoWPAN Frag|          |6LoWPAN Frag|
        +------------+          +------------+
        |  802.15.4  |          |  802.15.4  |
        +------------+          +------------+
```

Figure 1: Traditional 6LoWPAN-based protocol stack over IEEE 802.15.4 (left) and alternative protocol stack using SCHC for header compression (right). HC and Frag stand for Header Compression and Fragmentation, respectively.

SCHC header compression may be applied to the headers of different protocols or sets of protocols. Some examples include: i) IPv6 packet headers, ii) joint IPv6 and UDP packet headers, iii) joint IPv6, UDP and CoAP packet headers, etc.

3.1.2. Transition protocol stacks

In order to ease a transition from existing 6LoWPAN implementations to support SCHC header compression, the present document also: i) illustrates two possible protocol stacks, where 6LoWPAN header compression is used to compress IPv6/UDP headers while SCHC compresses CoAP headers (see Figure 2 and Section 5.1), and ii) enables the transmission of SCHC-compressed UDP/CoAP headers over 6LoWPAN-compressed IPv6 packets (see Figure 3 and Section 5.2). However, note that the greatest header compression performance can be achieved by using SCHC to also compress the UDP header.

RFC 8824 and draft-ietf-schc-8824-update define how SCHC can be used to compress CoAP headers, including Object Security for Constrained RESTful Environments (OSCORE)-protected messages [RFC8613]. On the other hand, it is possible to carry SCHC-compressed CoAP headers over UDP by means of using SCHC UDP ports [I-D.ietf-schc-protocol-numbers]. Figure 2 (left) shows the resulting protocol stack, where 6LoWPAN header compression is applied to UDP and IPv6. When Datagram Transport Layer Security (DTLS) [RFC9147] is preferred to protect SCHC-compressed CoAP messages, the DTLS layer sits between the SCHC and UDP layers (Figure 2, right).

```
                                    +------------+
                                    |    CoAP    |
            +------------+          +------------+
            |    CoAP    |          |    SCHC    |
            +------------+          +------------+
            |    SCHC    |          |    DTLS    |
            +------------+          +------------+
            |     UDP    |          |     UDP    |
            +------------+          +------------+
            |    IPv6    |          |    IPv6    |
            +------------+          +------------+
            | 6LoWPAN HC |          | 6LoWPAN HC |
            +------------+          +------------+
            |6LoWPAN Frag|          |6LoWPAN Frag|
            +------------+          +------------+
            |  802.15.4  |          |  802.15.4  |
            +------------+          +------------+
```

Figure 2: Transition protocol stacks where 6LoWPAN header compression is applied to UDP and IPv6. The leftmost protocol stack supports the use of OSCORE, whereas the rightmost one corresponds to the use of DTLS to protect SCHC-compressed CoAP messages. HC and Frag stand for Header Compression and Fragmentation, respectively.

Finally, the transition protocol stack enabled by this document (Section 5), which allows the transmission of 6LoWPAN-compressed IPv6 packets containing SCHC-compressed UDP/CoAP data units, is shown in Figure 3 (rightmost). Hereinafter, this transition protocol stack will be referred to as "TPS".

```
                                                 +------------+
                                                 |    CoAP    |
    +------------+   +------------+              +------------+
    | CoAP, other|   | CoAP, other|              |     UDP    |
    +------------+   +------------+              +------------+
    | UDP, other |   | UDP, other |              |   SCHC HC  |  <-- NEW
    +------------+   +------------+              +------------+
    |    IPv6    |   |    IPv6    |              |    IPv6    |
    +------------+   +------------+              +------------+
    | 6LoWPAN HC |   |  SCHC HC   |  <-- NEW     | 6LoWPAN HC |
    +------------+   +------------+              +------------+
    |6LoWPAN Frag|   |6LoWPAN Frag|              |6LoWPAN Frag|
    +------------+   +------------+              +------------+
    |  802.15.4  |   |  802.15.4  |              |  802.15.4  |
    +------------+   +------------+              +------------+
```

Figure 3: Traditional 6LoWPAN-based protocol stack over IEEE 802.15.4 (left), alternative protocol stack using SCHC for header compression (middle), and transition protocol stack using SCHC for header compression of UDP/CoAP headers (right). HC and Frag stand for Header Compression and Fragmentation, respectively.

3.2. SCHC architecture concepts

This section describes how SCHC architecture concepts (such as "SCHC Stratum", "Discriminator", "SCHC Stratum Header end point", "SCHC Payload end point", and "Set of Rules" (SoR)) [draft-ietf-schc-architecture] are applied when SCHC is used to compress IPv6 packet headers over IEEE 802.15.4 networks. In addition, the concepts of Single-end point networks and Multiple-end point networks are introduced. Note: in the present document, "Single-end point networks" and "Multiple-end point networks" are used for brevity to refer to "Single-end point SCHC-Lo networks" and "Multiple-end point SCHC-Lo networks".

3.2.1. SCHC Stratum and Discriminator

When SCHC is used to compress IPv6 packets over IEEE 802.15.4 networks, the SCHC Stratum is located on top of layer 2 and below layer 3 (that is, at layer 2.5). Note that the compressed data of the SCHC Stratum may also comprise upper layer packet headers. For example, SCHC may be used to compress IP headers, IP/UDP headers or IP/UDP/CoAP headers (all at once).

In both Single-end point and Multiple-end point networks, the Discriminator is a 6LoWPAN Dispatch Type set to the SCHC Dispatch or to the SCHC Pointer Dispatch (see Section 4).

3.2.2. Single-end point networks

In Single-end point networks, all network nodes that use SCHC for C/D have a single SCHC Payload end point, and thus a single SoR for SCHC Packet C/D. For this reason, in Single-end point networks, the SCHC Stratum Header is fully compressed (i.e., the SCHC Stratum Header requires 0 bits to be transmitted over the air).

In Single-end point networks, all network nodes that use SCHC for C/D have a single SCHC Stratum Header end point, and therefore a single SoR for SCHC Stratum Header C/D, which in this case comprises a single, implicit Rule for SCHC Stratum Header C/D.

3.2.3. Multiple-end point networks

In Multiple-endpoint networks, at least some of the network nodes that use SCHC for C/D have more than one SCHC Payload end point, and thus one SoR associated to each SCHC Payload end point. Therefore, in Multiple-end point networks, the SCHC Stratum Header end point cannot generally be fully compressed (i.e., in compressed form, a SCHC Stratum Header of more than 0 bits is generally required to be transmitted over the air).

In Multiple-end point networks, all network nodes that use SCHC for C/D have a single SCHC Stratum Header end point, and therefore a single SoR for SCHC Stratum Header C/D, which may comprise several Rules for SCHC Stratum Header C/D.

3.3. Network topologies

IEEE 802.15.4 supports two main network topologies: the star topology, and the peer-to-peer (i.e., mesh) topology.

SCHC has been designed for LPWAN technologies, which are typically based on a star topology where constrained devices (e.g., sensors) communicate with a less constrained, central network gateway [RFC 8376]. However, as stated in [draft-ietf-schc-architecture], SCHC is generic and it can also be used in networking environments beyond the ones originally considered for SCHC.

SCHC compression is applicable to both star topology and mesh topology IEEE 802.15.4 networks. The mechanism to be used to provide the SCHC header compression context to the nodes in an IEEE 802.15.4 network is out of the scope of this document.

3.4. Single-hop communication

In order to support the transmission of SCHC-compressed packets between two nodes that are single-hop neighbors, both nodes MUST store the Rules intended for the communication between those two endpoints.

The frame format to be used to carry a SCHC-compressed packet in single-hop communication is described in Section 4.1.

3.5. Multihop communication

6LoWPAN defines two approaches for multihop communication: Route-Over and Mesh-Under [RFC6606]. In Route-Over, routing is performed at the IP layer. In Mesh-Under, routing functionality is located at the adaptation layer, below IP. This section describes how SCHC-compressed packets are transmitted over a multihop IEEE 802.15.4 network, for both Route-Over and Mesh-Under.

3.5.1. Straightforward Route-Over (SRO)

SCHC header compression MAY be used in a Route-Over network in a straightforward approach, whereby all routers (i.e., all 6LRs and 6LBRs) MUST store all the Rules in use by any nodes in the SCHC-Lo network, whereas a host MUST store the Rules defined for its communication with other nodes. This approach is called Straightforward Route-Over (SRO). In this case, 6LoWPAN routers are able to decompress (if needed) received packet headers and compress packet headers before being forwarded. In SRO, in Single-end point networks, a RuleID and the Rule it identifies MUST be unique SCHC-Lo network-wide (note: the means to ensure so are out of the scope of this document). In order to simplify the management of RuleIDs in the SCHC-Lo network, in SRO, all nodes in the SCHC-Lo network MAY share the same SoR. In SRO, in Multiple-endpoint networks, a not fully compressed SCHC Stratum Header MUST be used.

Figure 4 illustrates an example Single-end point network with the Rules that need to be stored by the nodes in SRO. In this example, RuleID 1 is intended for communication between Host A and Host B, RuleID 2 is intended for communication between Host A and Host C, and RuleID 3 is used for the communication between Host A and an external node called Host E.

```
                                                 Host E
                                                /
                    (RuleID 1)        +--------+
                    (RuleID 2)    --- |Internet|
                    (RuleID 3)   /    +--------+
                   6LBR ---------
                 /      \
                /        \
              6LR         6LR ------------+                      Pair of nodes
     (RuleID 1) |         | (RuleID 1)    |          RuleID 1:       A, B
     (RuleID 2) |         | (RuleID 2)    |          RuleID 2:       A, C
     (RuleID 3) |         | (RuleID 3)    |          RuleID 3:       A, E
                |         |               |
             Host A      Host B         Host C
              (RuleID 1)    (RuleID 1)     (RuleID 2)
              (RuleID 2)
              (RuleID 3)
```

Figure 4: Rules stored by each node in an example Single-end point network using SRO.

Figure 5 illustrates an example Multiple-end point network with the Rules that need to be stored by the nodes in SRO. In this example, in addition to the Rules used in Figure 4, which correspond to a SCHC Payload end point called E1 in this example, there is a second RuleID 2, which corresponds to communication between A and B, in a second SCHC Payload end point (E2). Note that, for simplicity, Figure 5 shows the same end point identifier (e.g., E1 or E2) for two end points that share a Rule.

```
                                                   Host E
                    (RuleID 2, E2)                /
                    (RuleID 1, E1)      +--------+
                    (RuleID 2, E1)  --- |Internet|
                    (RuleID 3, E1) /    +--------+
                   6LBR -----------
                 /      \
                /        \
              6LR         6LR -------------+                Nodes | End point
(RuleID 1, E1) |         | (RuleID 1, E1)  |      RuleID 1:   A, B      E1
(RuleID 2, E1) |         | (RuleID 2, E1)  |      RuleID 2:   A, C      E1
(RuleID 3, E1) |         | (RuleID 3, E1)  |      RuleID 3:   A, E      E1
(RuleID 2, E2) |         | (RuleID 2, E2)  |      RuleID 2:   A, B      E2
               |         |                 |
              Host A      Host B         Host C
        (RuleID 1, E1)    (RuleID 1, E1)   (RuleID 2, E1)
        (RuleID 2, E1)    (RuleID 2, E2)
        (RuleID 3, E1)
        (RuleID 2, E2)
```

Figure 5: Rules stored by each node in an example Multiple-end point network using SRO.

The frame format to be used to carry a SCHC-compressed packet in SRO is described in Section 4.1.

3.5.2. Tunneled, RPL-based Route-Over (TRO)

In a Route-Over network that uses the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) [RFC6550], the RPL non-storing mode [RFC6550, RFC 6554] and [RFC8138] MAY be exploited in order to efficiently transmit SCHC-compressed packets. In this approach, packets sent by a 6LN are tunneled to the root, and packets intended for 6LNs are tunneled from the root (note: a tunnel is not needed when the root itself is the source). Traffic between two 6LNs traverses an Upward tunnel to the root and a Downward tunnel from the root. The present document defines the described approach as Tunneled, RPL-based Route-Over approach (TRO).

In TRO, each 6LoWPAN node (i.e., a host, a 6LR or a 6LBR) MUST store the Rules defined for its communication with other peer nodes. A 6LR is relieved to store Rules used by nodes that do not include the 6LR itself. A 6LBR MUST store all the Rules used by all nodes in the SCHC-Lo network.

In a TRO Single-end point network, a RuleID and the Rule it identifies MUST be unique SCHC-Lo network-wide (note: the means to ensure so are out of the scope of this document). In a TRO Multiple-end point network, a not fully compressed SCHC Stratum Header MUST be used.

Figure 6 illustrates the Rules that need to be stored by the nodes in TRO, based on the same example Single-end point network and sets of peer nodes shown in Figure 4.

```
                                                 Host E
                                                /
                    (RuleID 1)        +--------+
                    (RuleID 2)    --- |Internet|
                    (RuleID 3)   /    +--------+
                   6LBR ---------
                 /      \
                /        \
              6LR         6LR ------------+                      Pair of nodes
     (no Rules) |         | (no Rules)    |           RuleID 1:      A, B
                |         |               |           RuleID 2:      A, C
                |         |               |           RuleID 3:      A, E
                |         |               |
             Host A      Host B         Host C
              (RuleID 1)    (RuleID 1)     (RuleID 2)
              (RuleID 2)
              (RuleID 3)
```

Figure 6: Rules stored by each node in an example Single-end point network using TRO.

Figure 7 illustrates an example Multiple-end point network with the Rules that need to be stored by the nodes in TRO. In this example, in addition to the Rules used in Figure 6, which correspond to a SCHC Payload end point called E1 in this example, there is a second RuleID 2, which corresponds to communication between A and B, in a second SCHC Payload end point (E2).

```
                                                  Host E
                    (RuleID 2, E2)               /
                    (RuleID 1, E1)      +--------+
                    (RuleID 2, E1)  --- |Internet|
                    (RuleID 3, E1) /    +--------+
                   6LBR -----------
                 /      \
                /        \
              6LR         6LR -------------+                 Nodes | End point
    (No Rules) |         | (No Rules)      |      RuleID 1:   A, B      E1
               |         |                 |      RuleID 2:   A, C      E1
               |         |                 |      RuleID 3:   A, E      E1
               |         |                 |      RuleID 2:   A, B      E2
               |         |                 |
              Host A      Host B         Host C
        (RuleID 1, E1)    (RuleID 1, E1)   (RuleID 2, E1)
        (RuleID 2, E1)    (RuleID 2, E2)
        (RuleID 3, E1)
        (RuleID 2, E2)
```

Figure 7: Rules stored by each node in an example Multiple-end point network using TRO.

RFC 9008 describes how the communication between a 6LN and another node (another 6LN or the root of the same RPL domain, or an external node, e.g., on the Internet) is performed. For the sake of description clarity, Figure 6 (adapted from Figure 3 in RFC 9008) provides a reference topology including nodes referred to in the remainder of this subsection.

```
                        +------------+
                        |  INTERNET  |---------+
                        +------------+         |
                                             Z |
                                         +-------+
                                         | 6LBR  |
                             +-----------|(root) |--------+
                             |           +-------+        |
                             |                            |
                             | Y                          |X
                         +---|---+                    +---|---+
                         |  6LR  |                    |  6LR  |
                 +-------|       |--+              +--|       |--+
                 |       +-------+  |              |  +-------+  |
                 | W                |  V           |             |
             +---|---+          +---|---+          |             |
             |  6LR  |          |  6LR  |          |             |
             |       |          |       |          |             |
             +---|---+          +-|---|-+          |             |
                 |                |   |            |             |
                 |           +----+   |            |             |
              U  |         T |        | S        R |           Q |
           +-----+-+   +-------+  +---|--+     +---|---+     +---|---+
           |  RAL  |   | RUL   |  | RAL  |     |  RAL  |     | RUL   |
           |  6LN  |   |  6LN  |  | 6LN  |     |  6LN  |     |  6LN  |
           +-------+   +-------+  +------+     +-------+     +-------+
```

Figure 8: Reference topology to support the description of TRO.

In RPL non-storing mode, for Downward traffic, the root adds a source-routing header. The root also performs IPv6-in-IPv6 encapsulation, except when the root itself is the packet source. The IPv6-in-IPv6 encapsulation terminates at the 6LN (if it is a RAL, e.g., U, S or R) or at the last 6LR, e.g., V or X, (if the 6LN is a RUL, e.g., T or Q). For Upward traffic, IPv6-in-IPv6 encapsulation is performed by the first 6LR, e.g. V or X, when the 6LN is a RUL, e.g., T or Q, that sends a packet to an external node or to another 6LN in the same RPL domain, but not to the root. When the 6LN is a RAL (e.g., U, S or R) that sends packets to the same destinations, IPv6-in-IPv6 encapsulation may be performed (by the RAL itself). The destination in the outer header of the IPv6-in-IPv6 encapsulation for Upward traffic is the root.

This document updates RFC 9008 by specifying that, in TRO, when a 6LN transmits an IPv6 packet whose header is compressed by means of SCHC instead of 6LoWPAN header compression (RFC 6282), the SCHC-compressed packet MUST be tunneled by means of IPv6-in-IPv6 encapsulation up to the root. This applies regardless of the inner, SCHC-compressed packet destination.

For Upward traffic, when the 6LN is a RAL (e.g., U, S or R), the 6LN itself performs the IPv6-in-IPv6 encapsulation. However, if the 6LN is a RUL (e.g., T or Q), IPv6-in-IPv6 encapsulation is performed by the first 6LR (e.g., E or C, respectively). In the latter case, in order to enable efficient packet transmission in the first hop from the 6LN, the first 6LR SHOULD be provided with SCHC Rules allowing efficient header compression of packets sent by that 6LN.

For Downward traffic, when the 6LN is a RUL (e.g., G or J), in order to enable efficient packet transmission in the last hop to the 6LN, the last 6LR (e.g., V or X, respectively) SHOULD be provided with SCHC Rules allowing efficient header compression of packets sent to that 6LN.

Not providing such SCHC Rules to the first or last 6LR (for Upward or Downward traffic, respectively) should only happen if it is not practical or possible to do so (e.g., due to lack of available memory at the 6LR).

For the sake of efficiency, RFC 8138 MUST be used to compress IPv6-in-IPv6 headers, the RPL Option (RFC 6553) and the source routing header (RPL Routing Header type 3, RFC 6554).

The frame format to be used to carry a SCHC-compressed packet in TRO is described in Section 4.2.

3.5.3. Pointer-based Route-Over (PRO)

In the previous SCHC-Lo route-over approach, TRO, intermediate nodes do not have to know the IPv6 destination address of a SCHC-compressed IPv6 packet to be able to forward it. Another approach where intermediate nodes do not have to store the compression/decompression Rules used by other nodes, which in addition does not require the artifacts used in TRO (i.e., IPv6-in-IPv6 encapsulation, non-storing mode RPL and RFC 8138 compression), is called Pointer-based Route-Over (PRO).

In PRO, a pointer (called "SCHC Pointer") is prepended to the SCHC-compressed packet, in order to indicate the location and length of the Hop Limit and the destination address residues in the SCHC-compressed header. Therefore, a 6LR is able to determine the IPv6 destination address of a SCHC-compressed packet, decrement its Hop Limit and route the packet, without the need to store the corresponding Rules. Note that, in PRO, each 6LoWPAN node (i.e., a host, a 6LR, or a 6LBR) MUST store the Rules defined for its communication with other peer nodes. A 6LBR MUST store the Rules used by any SCHC-Lo network node for communication with external nodes.

In a PRO Single-end point network, a RuleID MAY be used to identify different Rules used by different sets of peer nodes within the SCHC-Lo network. In a PRO Multiple-end point network, a not fully compressed SCHC Stratum Header MUST be used.

Figure 9 illustrates the Rules that are stored by the nodes in an example Single-end point network based using PRO. Note that, in this example, the SCHC-Lo network exploits the fact that PRO allows a given RuleID to be used by different pairs of nodes.

```
                                                   Host E
                                                  /
                                        +--------+- Host F
                (RuleID 3)       --- |Internet|
                (RuleID 4)      /    +--------+
                6LBR -----------
              /      \
             /        \
           6LR         6LR ------------+                Pair of nodes
  (no Rules)/|         | (no Rules)    |          RuleID 1:       A, B
          / |         |               |          RuleID 2:       A, C
         /  |         |               |          RuleID 2:       D, B
        /   |         |               |          RuleID 3:       A, E
    Host D  Host A     Host B         Host C      RuleID 4:       B, F
(RuleID 2)   (RuleID 1)  (RuleID 1)    (RuleID 2)
             (RuleID 2)  (RuleID 2)
             (RuleID 3)  (RuleID 4)
```

Figure 9: Rules stored by each node in an example Single-end point network using PRO. In this example, both RuleID 2 and RuleID 3 are used by two pairs of nodes each.

PRO is compatible with RPL storing mode, as well as with other routing protocols.

Figure 10 illustrates an example Multiple-end point network with the Rules that need to be stored by the nodes in PRO. In this example, in addition to the Rules used in Figure 9, which correspond to a SCHC

Packet Instance called E1 in this example, there is an additional RuleID 2, which corresponds to communication between A and D, in a second SCHC Payload end point (E2).

```
                                                 Host E
                                                /
                                      +--------+- Host F
                 (RID 3, E1)  --- |Internet|
                 (RID 4, E1) /    +--------+
                 6LBR -------
               /      \
              /        \
            6LR         6LR ------------+                Nodes  |  End point
  (no Rules)/|          | (no Rules)    |         RID 1:  A, B        E1
           / |          |               |         RID 2:  A, C        E1
          /  |          |               |         RID 2:  D, B        E1
         /   |          |               |         RID 3:  A, E        E1
     Host D  Host A     Host B         Host C     RID 4:  B, F        E1
 (RID 2, E1)  (RID 1, E1)  (RID 1, E1)  (RID 2, E1)  RID 2:  A, D        E2
 (RID 2, E2)  (RID 2, E1)  (RID 2, E1)
              (RID 3, E1)  (RID 3, E1)
              (RID 2, E2)
```

Figure 10: Rules stored by each node in an example Multiple-end point network using PRO. 'RID' stands for RuleID.

The frame format to be used to carry a SCHC-compressed packet in PRO is described in Section 4.3.

3.5.4. Mesh-Under

When Mesh-Under is used in a SCHC-Lo network, Mesh-Under operates as described in RFC 4944. The frame format to be used to carry a SCHC-compressed packet in the Mesh-Under approach is described in Section 4.4.

For header compression in a Mesh-Under SCHC-Lo network, a SCHC-Lo network node MUST store the Rules defined for its communication with other peer nodes.

In Mesh-Under, in a Single-end point network, a RuleID MAY be used to identify different Rules used by different sets of peer nodes. In a Mesh-Under Multiple-end point network, a fully compressed SCHC Stratum Header MAY be used as long as it is possible to determine the SCHC Payload end point needed to decompress a SCHC-compressed packet based on the packet source identifier (which is present in the Mesh-Under header [RFC 4944]).

Figure 11 illustrates the Rules that need to be stored by the nodes when SCHC is used for header compression in a Single-end point Mesh-Under network, based on the same example network and node pairs shown in Figure 9. Note that, in this example, the network exploits the fact that Mesh-under allows a given RuleID to be reused by different sets of peer nodes, even if the Rules sharing the same RuleID are different. Nodes denoted "m" in Figure 8 correspond to Mesh-Under forwarders [RFC 6606].

```
                                                 Host E
                                                /
                                      +---------+- Host F
                (RuleID 3)       --- |Internet|
                (RuleID 4)      /    +---------+
                6LBR -----------
               /     \
              /       \
             m         m ---------------+                   Pair of nodes
   (no Rules)/|        | (no Rules)    |          RuleID 1:    A, B
           / |         |               |          RuleID 2:    A, C
          /  |         |               |          RuleID 2:    D, B
         /   |         |               |          RuleID 3:    A, E
     Host D  Host A     Host B          Host C      RuleID 4:    B, F
 (RuleID 2)   (RuleID 1)  (RuleID 1)    (RuleID 2)
              (RuleID 2)  (RuleID 2)
              (RuleID 3)  (RuleID 4)
```

Figure 11: Rules stored by each node in an example Single-end point network using Mesh-Under. In this example, RuleID 2 is used by different pairs of nodes.

Figure 12 illustrates an example Multiple-end point network with the Rules that need to be stored by the nodes in PRO. In this example, in addition to the Rules used in Figure 9, which correspond to a SCHC Payload end point called E1 in this example, there is an additional RuleID 2, which corresponds to communication between A and D, in a second SCHC Payload end point (E2).

```
                                                Host E
                                              /
                                    +--------+- Host F
                   (RID 3, E1)  --- |Internet|
                   (RID 4, E1) /    +--------+
                   6LBR -------
                 /      \
                /        \
                m         m --------------+                   Nodes | End point
     (no Rules)/|         | (no Rules)    |            RID 1:  A, B       E1
              / |         |               |            RID 2:  A, C       E1
             /  |         |               |            RID 2:  D, B       E1
            /   |         |               |            RID 3:  A, E       E1
       Host D  Host A     Host B         Host C        RID 4:  B, F       E1
   (RID 2, E1)  (RID 1, E1)  (RID 1, E1)  (RID 2, E1)  RID 2:  A, D       E2
   (RID 2, E2)  (RID 2, E1)  (RID 2, E1)
                (RID 3, E1)  (RID 2, E2)
                (RID 2, E2)
```

Figure 12: Rules stored by each node in an example Multiple-end point network using Mesh-Under. 'RID' stands for RuleID.

4. Frame Format

This section defines the frame formats that can be used when a SCHC-compressed packet is carried over IEEE 802.15.4. Such formats are carried as IEEE 802.15.4 frame payload.

4.1. Single-hop or SRO frame format

This subsection defines the frame format for carrying SCHC-compressed packets over IEEE 802.15.4 for single-hop communication (see 3.3) or when SRO is used for multihop communication (see 3.4.1). This format comprises a SCHC Dispatch Type, a SCHC datagram, and Padding bits, if any. The SCHC datagram is composed of a SCHC Stratum Header (which in some cases is fully elided), a SCHC Payload (i.e., the SCHC-compressed header of the packet being carried over IEEE 802.15.4), and user payload (i.e., the payload of the packet being carried over IEEE 802.15.4) [draft-ietf-schc-architecture]. Figure 13 illustrates the described frame format.

```
      <--------------- IEEE 802.15.4 frame payload -------------------->

                      <----------- SCHC datagram ------------>
      +---------------+--------+-------------+-------------+ - - - - +
      | SCHC Dispatch |SCHC Hdr| SCHC Payload | user payload | Padding |
      +---------------+--------+-------------+-------------+ - - - - +
```

Figure 13: Encapsulated, SCHC-compressed packet, for single-hop or SRO transmission. Padding bits are added if needed.

4.1.1. SCHC Dispatch

Adding SCHC header compression to the panoply of header compression mechanisms used in 6LoWPAN/6Lo environments creates the need to signal when a packet header has been compressed by using SCHC. To this end, the present document specifies the SCHC Dispatch. The SCHC Dispatch indicates that the next field in the frame format is a SCHC Sratum header ("SCHC Hdr" in Figure 13, see 4.1.2)).

This document defines the SCHC Dispatch as a 6LoWPAN Dispatch Type for SCHC header compression [RFC4944]. With the aim to minimize overhead, the present document allocates a 1-byte pattern in Page 0 [RFC8025] for the SCHC Dispatch Type:

SCHC Dispatch Type bit pattern: 01000100 (Page 0) (Note: to be confirmed by IANA))

4.1.2. SCHC Stratum Header

The SCHC Stratum Header ("SCHC Hdr" in Figure 13 and subsequent figures) determines the SCHC Payload end point to be used to decompress the next field (SCHC Payload, see 4.1.3).

The SCHC Stratum Header format, and some examples of possible corresponding Rules for SCHC Stratum Header C/D, are shown in Figure 14.

```
      Uncompressed SCHC Stratum Header format:
      +------------------+
      | SCHC Instance ID |
      +------------------+

      Compressed SCHC Stratum Header format:
      +--------+- - - - - - - - - - -+
      | RuleID | Compression Residue |
      +--------+- - - - - - - - - - -+

      Example C/D Rules for the SCHC Stratum Header:

      RuleID 1
      +-------------+--+---+--+-----+------+-----------+
      |     FID     |FL|POS|DI| TV  |  MO  |     CDA   |
      +-------------+--+---+--+-----+------+-----------+
      | SCHC.instid | 8| 1 |Bi|value|equal | not-sent  |
      +-------------+--+---+--+-----+------+-----------+

      RuleID 2
      +-------------+--+---+--+-----+------+-----------+
      |     FID     |FL|POS|DI| TV  |  MO  |    CDA    |
      +-------------+--+---+--+-----+------+-----------+
      | SCHC.instid | 8| 1 |Bi|0x00 |MSB(7)|    LSB    |
      +-------------+--+---+--+-----+------+-----------+
```

Figure 14: SCHC Stratum Header Format and examples of corresponding C/D Rules for the SCHC Stratum Header

The uncompressed SCHC Stratum Header format comprises a single field, called the SCHC Instance ID. This field is an unsigned integer that identifies the session between SCHC end points in two or more peer nodes using a common SoR. The SCHC Instance ID size is RECOMMENDED to be between 1 and 8 bits.

As described in the SCHC architecture draft, in compressed form, the SCHC Stratum Header comprises a RuleID and a compression residue [draft-ietf-schc-architecture]. The RuleID size of the compressed SCHC Stratum Header is RECOMMENDED to be between 0 and 8 bits. In the examples shown in Figure 14, the best match between a SCHC Instance ID and the Rules with RuleID 1 and RuleID 2 lead to compression residues of 0 bits and 1 bit, respectively.

In Single-end point networks, the SCHC Stratum Header MUST be fully compressed, i.e., its size in compressed form is 0 bits. In Multiple-end point networks, the SCHC Stratum Header cannot always be fully compressed; in this case, the RuleID size (of the Rule used to compress the SCHC Stratum Header) is RECOMMENDED to be between 1 and 8 bits.

4.1.3. SCHC Payload

The SCHC Payload is a packet header that has been compressed by using a SCHC Payload end point. It is the compressed form of the header of the original packet being carried over IEEE 802.15.4. As defined in [RFC8724], a SCHC-compressed header comprises a RuleID, and a compression residue. As per the present specification, a RuleID size between 1 and 16 bits is RECOMMENDED. In order to decide the RuleID size to be used in a SCHC-Lo network, the trade-off between (compressed) header overhead and the number of Rules needs to be carefully assessed.

4.1.4. User payload

The user payload is the payload of the original packet being carried over IEEE 802.15.4, which is unaffected by the SCHC stratum [draft-ietf-schc-architecture].

4.1.5. Padding

If SCHC header compression leads to a SCHC datagram size of a non-integer number of bytes, padding bits of value equal to zero MUST be appended to the SCHC datagram as appropriate to align to an octet boundary.

4.2. TRO frame format

This subsection defines the frame formats for carrying SCHC-compressed packets over IEEE 802.15.4 in TRO (see 3.3.2). Such formats are based on RFC 8138; however, instead of RFC 6282 header compression, this specification uses SCHC header compression. Accordingly, this specification updates RFC 8138 by stating that a 6LoRH header MUST always be placed before the LOWPAN_IPHC as defined in RFC 6282 [RFC6282] or the SCHC Dispatch, followed by the SCHC Stratum Header and the SCHC-compressed packet, as defined in the present specification.

Since 6LoRH uses Dispatch Types in Page 1, the present specification also defines a SCHC Dispatch Type in Page 1, with the same bit pattern as the one in Page 0: 01000100 (to be confirmed by IANA).

In the TRO frame formats, the SCHC Header is preceded by the SCHC Dispatch (in this case, in Page 1).

The frame format for Downward transmission, except when the SCHC-compressed packet source is a RPL root, is shown in Figure 15:

```
    <----------------- IEEE 802.15.4 frame payload -------------------------->
                                                     <- SCHC datagram ->
    +-- ... -+-- ... --+- ... -+--- ... --+---- ... -+----+-----+------+ - - +
    |11110001|SRH-6LoRH| RPI-  | IP-in-IP | 01000100 |SCHC|SCHC | user | pad |
    |Page 1  |         | 6LoRH |  6LoRH   |SCHCDsptch| Hdr| Pld |  pld |     |
    +-- ... -+-- ... --+- ... -+--- ... --+---- ... -+----+-----+------+ - - +
                                            (Page 1)

                                          <-------- This specification ------->
```

Figure 15: Downward frame format for SCHC-compressed packets in
TRO, when the source is not a RPL root.

The frame format for Downward transmission, when the SCHC-compressed packet source is a RPL root, is shown in Figure 16:

```
         <---------------- IEEE 802.15.4 frame payload ---------------->
                                               <- SCHC datagram ->
         +-- ... -+-- ... --+- ... -+---- ... -+----+-----+------+ - - +
         |11110001|SRH-6LoRH| RPI-  | 01000100 |SCHC|SCHC | user | pad |
         |Page 1  |         | 6LoRH |SCHCDsptch| Hdr| Pld |  pld |     |
         +-- ... -+-- ... --+- ... -+---- ... -+----+-----+------+ - - +
                                      (Page 1)

                                    <----- This specification ----->
```

Figure 16: Downward frame format for SCHC-compressed packets in
TRO, when the source is a RPL root.

The frame format for Upward transmission is shown in Figure 17 (note that it does not include the source routing header that is present in the Downward frame format):

```
        <--------------- IEEE 802.15.4 frame payload ----------------->

                                        <- SCHC datagram ->
        +-- ... -+- ... -+--- ... --+---- ... -+----+-----+------+ - - +
        |11110001| RPI-  | IP-in-IP | 01000100 |SCHC|SCHC | user | pad |
        |Page 1  | 6LoRH |  6LoRH   |SCHCDsptch| Hdr| Pld |  pld |     |
        +-- ... -+- ... -+--- ... --+---- ... -+----+-----+------+ - - +
                                     (Page 1)

                                   <----- This specification ---->
```

Figure 17: Upward frame format for SCHC-compressed packets in TRO.

4.3. PRO frame format

This subsection describes the frame format for carrying SCHC-compressed packets over IEEE 802.15.4 in PRO (see 3.3.3). Such format is shown in Figure 18:

```
              <------------ IEEE 802.15.4 frame payload ------------->

              +--------------+-------------+-------------+ - - - - +
              |  PRO Header  | SCHC Payload | user payload | Padding |
              +--------------+-------------+-------------+ - - - - +
                      v              <->
                      |               |
                      +---------------+
                        SCHC Pointer
```

Figure 18: frame format for SCHC-compressed packets in PRO.

The PRO Header format is shown in Figure 19:

```
            0 1 2 3 4 5 6 7 0 1 2 3 4 .... 5 6 7 0 1 2 3 4 5 6 7 0 1 2 3
           +---------------+-+ - - - +----+-------------+-+-------------+
           |      SCHC     |C|       |    |             |H|             |
           |     Pointer   |I|  DCI  |SCHC| Bit Pointer |L|   Address   |
           |    Dispatch   |D|       | Hdr|             |M|    Length   |
           +---------------+-+ - - - +----+-------------+-+-------------+
```

Figure 19: PRO Header format.

The first field in Figure 19 is defined as the SCHC Pointer Dispatch, which signals the start of a PRO Header format. This document defines the SCHC Pointer Dispatch as a 6LoWPAN Dispatch Type [RFC4944] for SCHC header compression.

With the aim to minimize header overhead, the present document allocates a 1-byte pattern in the 6LoWPAN Dispatch Type Page 0 [RFC8025] for the SCHC Pointer Dispatch Type:

SCHC Pointer Dispatch Type bit pattern: 01000101 (Page 0) (Note: to be confirmed by IANA))

The next field in the PRO Header is the Context IDentifier (CID) flag, which is set to 1 to signal that the Destination Context Identifier (DCI) field (see PRO_header_format) is present in the frame. When CID is set to 0, the DCI field is not present.

The DCI field is optional. When present, it has a size of 4 bits. Similarly to RFC 6282, this field identifies the prefix of the IPv6 destination address. How such prefix context is distributed and maintained is out of the scope of the present document.

The next field is the SCHC Stratum Header ("SCHC Hdr" in Figure 18), which has been defined in section 4.1.2. As shown in Figure 18, in the PRO Header, the SCHC Stratum Header is not immediately followed by the SCHC Packet.

The Bit pointer gives the starting position of the Hop Limit followed by the IPv6 destination address in the SCHC residue of the SCHC-compressed IPv6 header (in bits), starting after the Address Length field and before the first field of the SCHC-compressed IPv6 header (i.e., the RuleID). For example, if the Hop Limit and the IPv6 destination address residue are the only residues in a SCHC-compressed IPv6 packet header (i.e., such residue starts right after the RuleID in the SCHC-compressed header), then the Bit pointer will have a value of RuleID length in bits.

The Hop Limit (HLM) flag is 1 bit that indicates the length of the Hop Limit field residue in the SCHC-compressed IPv6 header. When HLM equals 0, the Hop Limit compression residue has a size of 4 bits. In this case, the 4 most significant bits of the uncompressed Hop Limit field are equal to 0. Therefore, Hop Limit compression applies only to Hop Limit values between 15 and 0. When HLM is set to 1, the Hop Limit compression residue has a size of 8 bits (i.e., it is uncompressed).

Address Length indicates the size of the IPv6 destination address residue (in bits). It can be up to 128 bits to allow representing the complete destination address, if needed.

PRO requires a special SCHC Rule design where the FIDs of the IPv6 Destination and Source addresses are swapped (see 6.1.1).

4.4. Mesh-Under frame format

This subsection describes the frame formats for carrying SCHC-compressed packets over IEEE 802.15.4 in the Mesh-Under approach (see 3.3.3). Note that the formats are provided in this section for the sake of clarity and completeness, since they are the same as those defined for Mesh-Under in RFC 4944, except for the fact that SCHC-compressed packets are carried.

The frame format for a SCHC-compressed packet to be sent by means of Mesh-Under, when fragmentation is not needed, is shown in Figure 20:

```
 <-------------------- IEEE 802.15.4 frame payload -------------------->

                                  <------ SCHC datagram ----->
 +-----------+----------+------------+--------+--------+--------+ - - +
 | Mesh Type | Mesh Hdr | SCHC Dsptch |SCHC Hdr|SCHC Pld|User pld| pad |
 +-----------+----------+------------+--------+--------+--------+ - - +
```

Figure 20: Encapsulated, SCHC-compressed packet, for Mesh-Under transmission (without fragmentation). Padding bits are added if needed.

The frame format for a SCHC-compressed packet to be sent by means of Mesh-Under, which also requires fragmentation, is shown in Figure 21:

```
<----------------------- IEEE 802.15.4 frame payload ----------------------->

                                          <----- SCHC datagram ------>
+-------+-------+-------+-------+----------+--------+--------+--------+ - - +
| M Typ | M Hdr | F Typ | F Hdr | SCHC Dsp |SCHC Hdr|SCHC Pld|User pld| Pad |
+-------+-------+-------+-------+----------+--------+--------+--------+ - - +
```

Figure 21: Encapsulated, SCHC-compressed packet, for Mesh-Under transmission (with fragmentation). Padding bits are added if needed.

The frame format for a SCHC-compressed packet to be sent by means of Mesh-Under, which also requires a broadcast header to support mesh broadcast/multicast, is shown in Figure 22:

```
<----------------------- IEEE 802.15.4 frame payload ----------------------->

                                            <------ SCHC datagram ----->
+-------+-------+-------+-------+----------+--------+--------+--------+ - - +
| M Typ | M Hdr | B Typ | B Hdr | SCHC Dsp |SCHC Hdr|SCHC Pld|User pld| Pad |
+-------+-------+-------+-------+----------+--------+--------+--------+ - - +
```

Figure 22: Encapsulated, SCHC-compressed packet, for mesh broadcast/multicast in Mesh-Under transmission (without fragmentation). Padding bits are added if needed. 'B Dsp' and 'B Hdr' stand for 'Broadcast Dispatch' and 'Broadcast Header', respectively.

As in RFC 4944, when more than one LoWPAN header is used in the same packet, they MUST appear in the following order: Mesh Addressing Header, Broadcast Header, Fragmentation Header.

4.5. Summary

A summary of the formats and main features for the different transmission alternatives enabled by the present documentis shown in Figure 23:

```
+-------------+-----------------------------------------------------------+
|  Single-hop |                        Multihop                           |
+-------------+-------------------------------------------+---------------+
|             |                Route-Over                 |               |
|             +-----------+----------------+--------------+  Mesh-Under   |
|             |    SRO    |      TRO       |     PRO      |               |
+-------------+-----------+----------------+--------------+---------------+
|SCHC Dispatch| SCHC Disp |IP-in-IP, 6LoRH,|SCHC Ptr Disp,| Mesh Headers,|
|             |           | SCHC Dispatch  | SCHC Pointer | SCHC Dispatch|
+-------------+-----------+----------------+--------------+--------------+
|   see 4.1   |  see 4.1  |    see 4.2     |   see 4.3    |   see 4.4    |
+-------------+-----------+----------------+--------------+--------------+
```

Figure 23: Summary of formats and main features for the transmission of SCHC- compressed packets over IEEE 802.15.4 enabled by the present document, and corresponding artifacts

5. Enabling the TPS

This section describes functionality that enables the TPS, i.e., the transition protocol stack that keeps using 6LoWPAN/6lo header compression [RFC6282][RFC8138] for the IPv6 header, while using SCHC for UDP and CoAP header compression (Section 3.1.2).

SCHC uses a SCHC Stratum Header to identify the SCHC-compressed protocol header(s), along with further information to support SCHC operation (when needed). SCHC may also need a Discriminator to identify the SoR to be used for header decompression [draft-ietf-schc-architecture].

In order to support SCHC-compressed UDP/CoAP headers over 6LoWPAN-compressed IPv6 packets, the present document exploits the work that is being done by the SCHC WG to define a new Internet Protocol Number for SCHC [I-D.ietf-schc-protocol-numbers]. In this approach, the NH field of the RFC 6282-compressed IPv6 header format is set to 0. The Next Header field of the IPv6 header remains an 8-bit (uncompressed) field carrying the SCHC Internet Protocol Number. The resulting protocol encapsulation and corresponding format for an unfragmented packet, which is carried as IEEE 802.15.4 frame payload, is shown in Figure 24. Padding is added as needed to align the format to an octet boundary.

```
<---------------- IEEE 802.15.4 frame payload ------------------>
+-----------------------+------------------+--------------+ - - +
| RFC6282-compressed    | SCHC-compressed  |              |     |
|     IPv6 header       | UDP/CoAP headers | CoAP Payload | Pad |
|(NH=0,Next Header=SCHC)| (includes SCHC   |              |     |
|                       | Stratum Header)  |              |     |
+-----------------------+------------------+--------------+ - - +
```

Figure 24: Protocol data unit encapsulation and format for the TPS, using a SCHC Internet Protocol Number

For RPL-based networks that use the TPS, the formats defined in RFC 8138 may also be used for the sake of efficiency, as shown in Figure 25. In this figure, the first field is the Page switch with value 1, followed by RFC 8138-compressed routing artifacts, then followed by the RFC 6282-compressed IPv6 header (which indicates that the next header data unit is a SCHC datagram).

```
<------------------------- IEEE 802.15.4 frame payload ------------------------>
+--------+------------+------------------+----------------+--------------+ - - +
|11110001|8138-cmprssd|  6282-compressed | SCHC-comprssd  |              |     |
|(Page 1)|  routing   |    IPv6 header   | UDP/CoAP hdrs  | CoAP Payload | Pad |
|        | artifacts  |(NH=0,NxtHdr=SCHC)| (incl. SCHC    |              |     |
|        |            |                  | Stratum Header)|              |     |
+--------+------------+------------------+----------------+--------------+ - - +
```

Figure 25: Protocol data unit encapsulation and format for the TPS using a SCHC Internet Protocol Number and RFC 8138-compressed routing artifacts

5.1. SCHC compression for the TPS

Over the IP layer, SCHC compression may be used for UDP only, UDP and CoAP jointly, or any other protocol or combination of protocols. For the TPS, which assumes both UDP and CoAP, a SCHC Stratum is used for joint UDP/CoAP header C/D.

The SCHC-compressed UDP/CoAP headers field has the format detailed in Figure 26. Such field comprises in turn two fields: the SCHC Stratum Header for UDP and CoAP, and the corresponding SCHC Payload (i.e., a RuleID followed by the compression residue of the UDP/CoAP header). If there is a single SoR for UDP/CoAP header C/D, the SCHC Stratum Header for UDP and CoAP is fully elided (i.e., it requires zero bits when the packet is transmitted).

```
<---------------- IEEE 802.15.4 frame payload ------------------>
+------------------------+------------------+--------------+ - - +
| RFC6282-compressed     | SCHC-compressed  |              |     |
|     IPv6 header        | UDP/CoAP headers | CoAP Payload | Pad |
|(NH=0,Next Header=SCHC)|(includes SCHC     |              |     |
|                        | Stratum Header(s)|              |     |
+------------------------+------------------+--------------+ - - +
                        /                  \
              |-------/                     \-----------|
              +------------------+---------------------+
              |   SCHC Stratum   |     SCHC Payload    |
              |      Header      | (RuleID + cmp. rsd. |
              | for UDP and CoAP | of UDP/CoAP header) |
              +------------------+---------------------+
```

Figure 26: Detailed view of the SCHC-compressed UDP and CoAP headers. A single SCHC Stratum is used jointly for UDP and CoAP.

The SCHC Stratum Header for joint UDP and CoAP header C/D, and the Rule to compress/decompress the SCHC Stratum Header itself for devices that only support the TPS, are defined in Figure 27. When a TPS-only device transmits a CoAP data unit, the SCHC Stratum Header is fully compressed and it incurs no transmission overhead (i.e., it is compressed down to 0 bits when transmitted), since the SoR of the SCHC Stratum end point contains exactly one Rule. When receiving a data unit, a TPS-only device also assumes that the SCHC Stratum Header is fully compressed (down to 0 bits).

A SCHC-Lo network may comprise TPS-only nodes and other nodes that also use 6LoWPAN/6lo to compress IPv6 headers (and routing protocol artifacts when needed) but support other protocol combinations on top of IPv6, in addition to UDP/CoAP. The latter nodes MUST also use/assume a fully compressed SCHC Stratum Header (down to 0 bits when transmitted) to send/receive UDP/CoAP data units to/from nodes that only implement the TPS, but will need to use/assume a not fully compressed SCHC Stratum Header when sending/receiving to/from other devices that support further protocols atop IPv6. In that case, the SCHC Stratum Header format will also be the one shown in Figure 27, but using the appropriate Protocol ID and Port number values. In such a mixed network, a receiving node can determine whether the SCHC Stratum Header has been fully compressed (down to 0 bits) based on prior knowledge that the sender is a TPS-only node. In this case, the IPv6 address of the sender is used as a Discriminator.

```
+-----------+-----------+
|Protocol ID|Port number| Non-Compressed SCHC Stratum Header for joint UDP/CoAP C/D
+-----------+-----------+
Protocol ID = 17 (UDP)
Port number = 5683 (CoAP)

+---------+- - - - - - - - - - -+
| Rule ID | Compression Residue | SCHC-Compressed Stratum Header for joint UDP/CoAP C/D
+---------+- - - - - - - - - - -+
```

Note: for devices that only implement the TPS (i.e., the only protocols carried over IP are UDP and CoAP), the SCHC-Compressed Stratum Header is fully compressed (down to 0 bits when transmitted over the air) since there is only one Rule in the SoR for the SCHC Stratum end point for such devices.

Rule to compress/decompress the SCHC Stratum Header for joint UDP/CoAP header C/D for devices that only implement the TPS:

RuleID

FID	FL	POS	DI	TV	MO	CDA
SCHC.proto	8	1	Bi	17	equal	not-sent
SCHC.portnum	16	1	Bi	5683	equal	not-sent

Figure 27: SCHC Stratum Header for joint UDP/CoAP header C/D in non-compressed and in SCHC-compressed form, and corresponding Rule.

6. SCHC compression for IPv6, UDP, and CoAP headers

SCHC header compression may be applied to the headers of different protocols or sets of protocols. Some examples include: i) IPv6 packet headers, ii) joint IPv6 and UDP packet headers, iii) joint IPv6, UDP and CoAP packet headers, etc.

This section describes how IPv6, UDP, and CoAP header fields are compressed.

6.1. SCHC compression for IPv6 and UDP headers

IPv6 and UDP header fields MUST be compressed as per Section 10 of RFC 8724.

IPv6 addresses are split into two 64-bit-long fields; one for the prefix and one for the Interface Identifier (IID).

To allow for a single Rule being used for both directions, RFC 8724 identifies IPv6 addresses and UDP ports by their role (Dev or App) and not by their position in the header (source or destination). This optimization can be used as is in some IEEE 802.15.4 networks (e.g., an IEEE 802.15.4 star topology where the peripheral devices (Devs) send/receive packets to/from a network-side entity (App)).

However, in some types of 6LoWPAN environments (e.g., when a sender and its destination are both peer nodes in a mesh topology network), additional functionality is needed to allow use of the Dev and App roles for C/D. In this case, each SCHC C/D entity needs to know its role (Dev or App) in addition to the Rule(s), and corresponding RuleIDs, for each node it communicates with before such communication occurs [I-D.ietf-schc-architecture]. In such cases, the terms Uplink and Downlink that have been defined in RFC 8724 need to be understood in the context of each specific set of peer nodes.

RFC 8724 (Section 7.1) states that "In a Rule, the Field Descriptors are listed in the order in which the fields appear in the packet header". The present specification updates RFC 8724 by stating that, in order to allow IPv6 header compression in PRO, the Field Descriptors of the IPv6 destination address (i.e., IPv6 DevPrefix and IPv6 DevIID) MUST appear before the Field Descriptors of the IPv6 source address (i.e., IPv6 AppPrefix and IPv6 AppIID), while the rest of fields appear in the same order as in the IPv6 packet header.

In PRO, in order to support SCHC-based IPv6 header compression, one Rule MUST be defined for each direction between the involved C/D nodes. In such a Rule, the IPv6 DevPrefix and IPv6 DevIID FIDs MUST refer to the destination address (i.e., the destination node takes the "Dev" role) of the SCHC-compressed IPv6 header. This allows a 6LR to read the compression residue of the Hop Limit and IPv6 destination address fields of the SCHC-compressed header by means of the Bit Pointer.

6.1.1. Compression of IPv6 addresses

Compression of IPv6 source and destination prefixes MUST be performed as per Section 10.7.1 of RFC 8724. Additional guidance is given in the present section.

Compression of IPv6 source and destination IIDs MUST be performed as per Section 10.7.2 of RFC 8724. One particular consideration when SCHC C/D is used in IEEE 802.15.4 networks is that, in contrast with some LPWAN technologies, IEEE 802.15.4 data frame headers include both source and destination fields. If the Dev or App IID are based on an L2 address, in some cases the IID can be reconstructed with information coming from the L2 header. Therefore, in those cases, DevIID and AppIID CDAs can be used.

RFC 8724 states that "If the Rule is intended to compress packets with different prefix values, match-mapping SHOULD be used" (Section 10.7.1 of RFC 8724) and "If several IIDs are possible, then the TV contains the list of possible IIDs, the MO is set to "match-mapping" and the CDA is set to "mapping-sent"" (Section 10.7.2 of RFC 8724). However, the present specification updates RFC 8724 by stating that, in PRO, a source node MUST NOT use the match-mapping operator or the "mapping-sent" CDA to compress the IPv6 destination address prefix or the IPv6 destination IID, because 6LRs do not store SCHC context, and therefore do not have the match-mapping index meaning information.

6.1.2. UDP checksum field

RFC 8724 states that "a SCHC compressor MAY elide the UDP checksum when another layer guarantees at least equal integrity protection for the UDP payload and the pseudo-header".

IEEE 802.15.4 frames carry a 16-bit Frame Check Sequence (FCS), which is computed by means of a 16-bit ITU-T CRC algorithm. Considering the FCS size, the greater error detection capabilities of CRC compared with checksum, and the fact that the IEEE 802.15.4 FCS will be checked at each hop in an IEEE 802.15.4 multihop network, the UDP checksum MUST be elided when using SCHC to compress UDP headers.

6.2. SCHC compression for CoAP headers

CoAP header fields MUST be compressed as per Sections 4 to 6 of RFC 8824. Additional guidance is given in this section.

For CoAP header compression/decompression, the SCHC Rules description uses direction information in order to reduce the number of Rules needed to compress headers.

As stated in 5.1, in some types of 6LoWPAN environments (e.g., when a sender and its destination are both peer nodes in a mesh topology network), each SCHC C/D entity needs to know its role (Dev or App), in addition to the Rule(s), and corresponding RuleIDs, for each node it communicates with before such communication occurs [I-D.ietf-schc-architecture]. Therefore, in such cases, direction information will be specific to each set of peer nodes.

7. Neighbor Discovery

A number of optimizations have been developed in order to efficiently support IPv6 Neighbor Discovery (ND) in 6LoWPAN environments (6LoWPAN ND) [RFC 6775][RFC 8505]. SCHC can also be used to compress 6LoWPAN ND packets. At the time of this writing, compression of ICMPv6 headers is being specified in the SCHC WG [draft-ietf-schc-icmpv6-compression]. Thus, it will be possible to compress the IPv6 header and the ICMPv6 header of a packet carrying a 6LoWPAN ND message.

8. Fragmentation and reassembly

After applying SCHC header compression to a packet intended for transmission, if the size of the resulting SCHC datagram (Section 4) exceeds the IEEE 802.15.4 frame payload space available, such SCHC Packet MUST be fragmented, carried and reassembled by means of the fragmentation and reassembly functionality defined by 6LoWPAN [RFC4944] or 6Lo [RFC8930][RFC8931].

In a Route-Over SCHC-Lo network, the 6LoWPAN fragment forwarding technique called Virtual Reassembly Buffer (VRB) [RFC8930] SHOULD be used. However, VRB might not be the best approach for a particular SCHC-Lo network, e.g., if at least one of the caveats described in Section 6 of RFC 8930 is unacceptable or cannot be addressed.

9. IANA Considerations

This document requests the allocation of the 6LoWPAN Dispatch Type Field Bit Patterns, on the Pages and with the Header Types shown next:

Bit Pattern	Page	Header Type	Reference
01000100	0	SCHC	[RFCthis]
01000100	1	SCHC	[RFCthis]
01000101	0	SCHC Pointer	[RFCthis]

Figure 28: Details of the 6LoWPAN Dispatch Type Field request

10. Security Considerations

This document does not define SCHC header compression functionality beyond the one defined in RFC 8724. Therefore, the security considerations in section 12.1 of RFC 8724 and in section 9 of RFC 8824 apply.

As a safety measure, a SCHC decompressor implementing the present specification MUST NOT reconstruct a packet larger than 1500 bytes [RFC8724].

IEEE 802.15.4 networks support link-layer security mechanisms such as encryption and authentication. As in RFC 8824, the use of a cryptographic integrity-protection mechanism to protect the SCHC-compressed headers is REQUIRED.

The addition of the pointer used in PRO creates new attack opportunities. A malicious node might be able to modify the related fields (i.e., Bit Pointer or Address Length) to prevent a router from correctly reconstructing the IPv6 destination field of a SCHC-compressed IPv6 packet, thus preventing delivery of the packet to its intended destination. Appropriate use of link-layer security should significantly reduce the probability of the described threat.

11. Acknowledgments

Ana Minaburo and Laurent Toutain suggested for the first time the use of SCHC in environments where 6LoWPAN has traditionally been used. Flavien Moullec is a contributor to this document. Laurent Toutain, Pascal Thubert, Dominique Barthel, Guangpeng Li, Carsten Bormann, Nathan Lecorchet, Stuart Cheshire, Kiran Makhijani, Georgios Z. Papadopoulos, and Peter Yee made comments that helped shape this document.

Carles Gomez has been funded in part by the Spanish Government through project PID2019-106808RA-I00 and PID2023-146378NB-I00, and by Secretaria d’Universitats i Recerca del Departament d’Empresa i Coneixement de la Generalitat de Catalunya 2017 through grant SGR 376 and 2021 throught grant SGR 00330.

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Appendix A. Header compression examples

Uplink packet

```
Source address: fd00::202:2:2:2 with port 8765
Destination address: 2001::1 with port 5678
Payload: "Hello 1" 68 65 6C 6C 6F 20 31

Uncompressed IPv6/UDP packet:
60 00 00 00 00 17 00 40    FD 00 00 00 00 00 00 00
02 02 00 02 00 02 00 02    20 01 00 00 00 00 00 00
00 00 00 00 00 00 00 01    22 3D 16 2E 00 0F 33 68
68 65 6C 6C 6F 20 31

IPv6/UDP header length: 48 bytes
Total length:           55 bytes
```

In this example, for SCHC compression of IPv6/UDP headers, RuleID 0x20 is used. The Rule corresponding to RuleID 0x20 is shown in Figure 29.

FID	FL	FP	DI	TV	MO	CDA	Sent [bits]
IPv6 Version	4	1	Bi	6	ignore	not-sent	
IPv6 Diffserv	8	1	Bi	0	equal	not-sent	
IPv6 Flow Label	20	1	Bi	0	equal	not-sent	
IPv6 Length	16	1	Bi		ignore	compute-*	
IPv6 Next Header	8	1	Bi	17	equal	not-sent	
IPv6 Hop Limit	8	1	Bi	64	ignore	not-sent	
IPv6 DevPrefix	64	1	Bi	FD00::/64	equal	not-sent	
IPv6 DevIID	64	1	Bi		ignore	value-sent	64
IPv6 AppPrefix	64	1	Bi	2001::/64	equal	not-sent	
IPv6 AppIID	64	1	Bi	::1	equal	not-sent	
UDP DevPort	16	1	Bi	8765	equal	not-sent	
UDP AppPort	16	1	Bi	5678	equal	not-sent	
UDP Length	16	1	Bi		ignore	compute-*	
UDP checksum	16	1	Bi		ignore	compute-*	

Figure 29: Illustration of an example Rule with RuleID 0x20

A.1. Single-hop or SRO frame format

```
SCHC-compressed packet:
44 20 02 02 00 02 00 02
00 02 68 65 6C 6C 6F 20
31
```

Header length: 10 bytes
SCHC Dispatch: 44 (01000100)
SCHC RuleID: 0x20 (1 byte)
SCHC residue: 02 02 00 02 00 02 00 02
Payload: 68 65 6C 6C 6F 20 31
Total length: 17 bytes

A.2. TRO frame format

TO-DO

A.3. PRO frame format

```
SCHC-compressed packet:
45 88 40 20 02 02 00 02
00 02 00 02 68 65 6C 6C
6F 20 31
```

```
Header length: 12 bytes
SCHC Pointer Dispatch: 45 (01000101)
SCHC Pointer: 88 40
SCHC Pointer P: 1
SCHC Pointer Bit Pointer: 8
SCHC Address length: 64 bits
SCHC RuleID: 0x20 (1 byte)
SCHC residue: 02 02 00 02 00 02 00 02
Payload: 68 65 6C 6C 6F 20 31
Total length: 19 bytes
```

A.4. Mesh-Under frame format

TO-DO

A.5. Enabling the transition protocol stack

Uplink packet

```
Source address: fe80::201:1:1:1 with port 46487
Destination address: fe80::1 with port 5683
Payload (Temperature value): DA 8C E8 75 15 66 3B 00 1B 37
SCHC protocol number: 145 (0x91)

Uncompressed IPv6/UDP/CoAP packet:
60 0D 4E 65 00 25 11 40    FE 80 00 00 00 00 00 00
02 01 00 01 00 01 00 01    FE 80 00 00 00 00 00 00
00 00 00 00 00 00 00 01    B5 97 16 33 00 25 00 38
50 02 B6 F7 BA 74 65 6D    70 65 72 61 74 75 72 D1
EA 00 FF DA 8C E8 75 15    66 3B 00 1B 37

IPv6/UDP/CoAP header length: 67 bytes
Total length: 77 bytes
```

In this example, for SCHC compression of UDP/CoAP headers, RuleID 0x22 is used. The Rule corresponding to RuleID 0x22 is shown in Figure 30.

FID	FL	FP	DI	TV	MO	CDA	Sent [HEX]
UDP DevPort	16	1	Bi		ignore	value-sent	B5 97
UDP AppPort	16	1	Bi	5683	equal	not-sent	
UDP Length	16	1	Bi		ignore	compute-*	
UDP checksum	16	1	Bi		ignore	compute-*	
CoAP Version	16	1	Bi	1	equal	not sent	
CoAP Type	16	1	Up	01	equal	not sent	
CoAP TKL	32	1	Bi	0x00	equal	not sent	
CoAP Code	8	1	Up	0.02	equal	not-sent	
CoAP MID	16	1	Bi		ignore	value-sent	B6 F7
CoAP OptUri-Path	10	1	Up	/temperature	equal	not-sent	
CoAP Opt No-Resp	1	1	Up	00	equal	not-sent	
CoAP Opt EndOpt	8	1	Up	0xFF	equal	not-sent	

Figure 30: Illustration of an example Rule with RuleID 0x22

```
IPv6 packet (with uncompressed header) carrying the SCHC-compressed UDP/CoAP headers:
60 0D 4E 65 00 25 91 40    FE 80 00 00 00 00 00 00
02 01 00 01 00 01 00 01    FE 80 00 00 00 00 00 00
00 00 00 00 00 00 00 01    22 B5 97 B6 F7 DA 8C E8
75 15 66 3B 00 1B 37

   Compressed packet (IPv6 using 6LoWPAN + UDP/CoAP using SCHC):
   6A 11 0D 4E 65 91 02 01    00 01 00 01 00 01 00 00
   00 00 00 00 00 01 22 B5    97 B6 F7 DA 8C E8 75 15
   66 3B 00 1B 37
```

```
   Header length: 27 bytes
   IPHC: 6A 11
     Dispatch: 011
     TF: 01
     NH: 0
     HLIM: 10
     CID: 0
     SAC: 0
     SAM: 01
     M: 0
     DAC: 0
     DAM: 01

     Traffic Class: 0D4E65
     Next Header: 91
     Src. Address: 201:1:1:1
     Dst. Address: ::1

   Next Header: 91 (SCHC)
   SCHC RuleID: 0x22
   SCHC Residue:
     UDP Dev Port: B5 97 (46487)
     CoAP MID: B6 F7 (46839)

   Total length: 37 bytes
```

Appendix B. Analysis of route-over multihop approaches

This section provides an analysis of the features, pros and cons of the route-over multihop approaches defined in this document: i) SRO, ii) TRO, and iii) PRO.

B.1. SRO

SRO incurs the lowest header overhead among the considered Route-Over approaches, as it only requires the SCHC Dispatch (1 byte). However, it is the most demanding approach in terms of memory usage, since all SCHC-Lo network routers (i.e., 6LRs and 6LBRs) need to store all the Rules in use in the SCHC-Lo network. Therefore, it will be suitable for rather small networks and/or where nodes have sufficient memory. Also, SCHC context should be as static as possible, in order to avoid frequent stored SCHC context updates on the SCHC-Lo network routers.

B.2. TRO

TRO incurs a header overhead that includes a fixed part (a Page Switch plus the SCHC Dispatch, of 1 byte each), plus a variable part that comprises RFC 8138-compressed routing artifacts.

Regarding the latter, in a Downward transmission, it would include the SRH-6LoRH (of variable size, of 4 bytes in the best case, or e.g., 8 bytes as in Fig. 20 of RFC 8138), the RPI-6LoRH (3 bytes in the best case) and the IP-in-IP header (not present if the source is the Root, at least 3 bytes otherwise). In the cases considered, and when the Root is not the packet source, the total header overhead of TRO would be of at least 12-16 bytes.

For upward transmission, the variable part of the header overhead for this approach would include only the RPI-6LoRH (at least, 3 bytes) and the IP-in-IP header (at least, 3 bytes). Therefore, in the cases considered, the total header overhead of TRO would be of at least 8 bytes.

Note that, while the overhead of TRO may appear to be relatively high, tunnel-based structures like the one assumed in TRO may exist already in a network deployment. Therefore, in such cases, the additional overhead of TRO may be actually lower.

An advantage of TRO is that a node only has to store the Rules for the communications it is involved in as an endpoint, which minimizes memory requirements and the impact of potential SCHC context updates. For example, 6LRs do not have to store SCHC context.

Note that TRO requires the network to use RPL, non-storing mode. Furthermore, the paths for communication between two nodes in the same network or with external nodes will need to traverse the Root. For communication with external nodes, traversing the Root will be needed anyway, therefore this feature does not pose any issue. However, this constraint will preclude the usage of optimal routes in some cases.

B.3. PRO

PRO incurs the PRO header overhead (i.e., between 3 and 3.5 bytes). In addition, with PRO, the Hop Limit field will have to be carried fully inline (1 byte) or compressed down to a minimum size of 4 bits. Furthermore, PRO introduces a limit to the achievable IPv6 destination address compression performance, as described next (note that the size of the destination address compression residue will depend on and will need to be planned for the intended use case of the network):

A.- In special cases (e.g., if there is only one possible destination that is known beforehand), there will not be a destination address residue.

B.- For a given destination prefix known by the network nodes (e.g., when prefix contexts are used, or if there can only be one destination prefix), if there can be several possible destinations in that network, the destination address residue will be up to 8 bytes (it could be less depending on how the addresses in that network are built, for example, it could be just 2 bytes).

C.- For destination prefixes not covered by prefix contexts or a priori knowledge by the nodes, the destination address residue will have to be the whole address (16 bytes), since an intermediate node does not know which is the destination prefix.

An advantage of PRO, as in TRO, is that a node only has to store the Rules for the communications it is involved in as an endpoint, which minimizes memory requirements and the impact of potential SCHC context updates. For example, 6LRs do not have to store SCHC context. An exception is a 6LBR, which has to store the Rules for the communications of other endpoints with external nodes (if any).

A potential advantage of PRO is that, in contrast with TRO, paths for intranetwork communication are not necessarily constrained to traversing a root node. Another feature is that the routing solution to be used is not tied to RPL non-storing mode. However, the routing solution may involve other constraints and/or trade-offs.

B.4. Summary

Assessing the suitability of the different SCHC-Lo route-over multihop approaches requires considering the following dimensions: network size, node memory capabilities, header overhead, routing constraints / path optimality, and intra- or inter-network communication.

SRO is best suited for small and static-SCHC-context networks (SRO may be used in larger networks as well, although with a trade-off with header compression performance and/or SCHC context management cost). PRO and TRO offer greater network scalability, although TRO best applicability is limited to networks where upwards traffic is dominant.

Appendix C. Relationship with RFC 7973

As reported in RFC 7973, IEEE assigned an Ethertype (with value 0xA0ED) for "IPv6 datagrams using LoWPAN encapsulation". As per RFC 7973, any IPv6 datagram using the Dispatch octet as defined in Section 5.1 of RFC 4944, subsequently updated by RFC 6282, is regarded as using LoWPAN encapsulation.

The present document also uses LoWPAN encapsulation, as it uses the Dispatch octet as described in RFC 7973. Therefore, the functionality described in the present document can also benefit from the mentioned Ethertype.

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