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Internet-Draft UPC
Intended status: Standards Track A. Minaburo
Expires: 12 May 2023 Acklio
November 2022

Transmission of SCHC-compressed packets over IEEE 802.15.4 networks
draft-gomez-6lo-schc-15dot4-05

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.

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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]. This RFC was designed assuming IEEE 802.15.4 as the layer below the 6LoWPAN adaptation layer, and it has also been reused (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, an RFC 6282 compressed UDP header has a typical size of 4 bytes. Therefore, in advantageous conditions, a 48-byte uncompressed IPv6/UDP header may be compressed down to a 6-byte format (when using link-local addresses) or a 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 as well [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 [I-D.toutain-6lo-6lo-and-schc], including IEEE 802.15.4 networks, considering its greater efficiency.

If SCHC header compression is added to the panoply of header compression mechanisms used in 6LoWPAN environments, then there is a need to signal when a packet header has been compressed by using SCHC. To this end, the present document specifies a 6LoWPAN Dispatch Type for SCHC header compression [RFC4944].

This document specifies how a SCHC-compressed packet can be carried over IEEE 802.15.4 networks. 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].

TO-DO: indicate here any specific updates of previous RFCs due to this specification.

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 RPL [RFC6550] and companion documents [RFC6553][RFC6554][RFC9008], 6LoWPAN Routing Header [RFC8138], and SCHC [RFC8724].

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.

3. Architecture

3.1. 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.)

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.

3.2. 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-lpwan-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.

3.3. 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.

3.3.1. Straightforward Route-Over approach

SCHC header compression MAY be used in a Route-Over network in a straightforward approach, whereby all network nodes MUST store all the Rules in use by any nodes in the network. In this case, 6LoWPAN routers are able to decompress (if needed) received packet headers and compress packet headers before being forwarded.

The frame format to be used to carry a SCHC-compressed packet in the straightforward Route-Over approach is described in Section 4.1.

3.3.2. Tunneled, RPL-based Route-Over approach

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. Traffic between two 6LNs traverses an Upward tunnel to the root and a Downward tunnel from the root.

In this approach, a network node MUST store the Rules defined for its communication with other endpoints. A 6LR is thus relieved to store Rules used by pairs of endpoints that do not include the 6LR itself. A 6LBR MUST store all the Rules used by all nodes in the network.

RFC 9008 describes how the communication between a 6LN and another endpoint (another 6LN or the root of the same RPL domain, or an external node, e.g., on the Internet) is performed. 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) or at the last 6LR (if the 6LN is a RUL). For Upward traffic, IPv6-in-IPv6 encapsulation is performed by the first 6LR when the 6LN is a RUL 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 that sends packets to the same destinations, IPv6-in-IPv6 encapsulation may be performed (by the RAL). 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 the tunneled, RPL-based Route-Over approach, 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.

(TO-DO: address the case when the 6LN is a RUL.)

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 the tunneled, RPL-based Route-Over approach is described in Section 4.3.

3.3.3. Mesh-Under approach

When SCHC header compression is used in a Mesh-Under 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 4.3.

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

In this case, a RuleID MAY be reused across disjoint pairs of endpoints, to identify different Rules used by such disjoint pairs of endpoints, at the expense of increased RuleID management and device configuration complexity.

4. Frame Format

This section defines the frame format to be used when a SCHC-compressed packet is carried over IEEE 802.15.4. Such format is carried as IEEE 802.15.4 frame payload.

4.1. Single-hop or straightforward Route-Over frame format

This subsection defines the frame format for carrying SCHC-compressed packets over IEEE 802.15.4 for single-hop communication or when the straightforward Route-Over approach (see 3.3.1) is used. This format comprises a SCHC Dispatch Type, a SCHC Packet (i.e. a SCHC-compressed packet (RFC 8724), and Padding bits, if any). Figure 2 illustrates the described frame format.

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

                <----- SCHC Packet ----->
+---------------+-------------+---------+ - - - - +
| SCHC Dispatch | SCHC Header | Payload | Padding |
+---------------+-------------+---------+ - - - - +
```

Figure 2: Encapsulated, SCHC-compressed packet, for single-hop or straightforward Route-Over 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-compressed header (SCHC Header in Figure 2, see 4.2)).

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 Header

SCHC Header (Figure 2) corresponds to a packet header that has been compressed by using SCHC. As defined in [RFC8724], the SCHC 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 network, the trade-off between (compressed) header overhead and the number of Rules needs to be carefully assessed.

4.1.3. Padding

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

4.2. Tunneled, RPL-based Route-Over frame format

This subsection defines the frame formats for carrying SCHC-compressed packets over IEEE 802.15.4 in the tunneled, RPL-based Route-Over approach (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-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 tunneled, RPL-based Route-Over frame formats, the SCHC-compressed header is preceded by the SCHC Dispatch (in this case, in Page 1).

The frame format for Downward transmission is shown in Figure 3:

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

                                                  <- SCHC pkt ->
+-- ... -+-- ... --+- ... -+--- ... --+---- ... -+-----+-------+ - - +
|11110001|SRH-6LoRH| RPI-  | IP-in-IP |  01000100 |SCHC |payload| pad |
|Page 1  |         | 6LoRH |  6LoRH   |SCHCDsptch| hdr |       |     |
+-- ... -+-- ... --+- ... -+--- ... --+---- ... -+-----+-------+ - - +
                                        (Page 1)

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

Figure 3: Downward frame format for SCHC-compressed packets in the tunneled, RPL-based Route-Over approach.

The frame format for Upward transmission is shown in Figure 4 (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 pkt ->
+-- ... -+- ... -+--- ... --+---- ... -+-----+-------+ - - +
|11110001| RPI-  | IP-in-IP |  01000100 |SCHC |payload| pad |
|Page 1  | 6LoRH |  6LoRH   |SCHCDsptch| hdr |       |     |
+-- ... -+- ... -+--- ... --+---- ... -+-----+-------+ - - +
                            (Page 1)

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

Figure 4: Upward frame format for SCHC-compressed packets in the tunneled, RPL- based Route-Over approach.

4.3. Mesh-Under frame format

This subsection describes the frame format for carrying SCHC-compressed packets over IEEE 802.15.4 in the Mesh-Under approach (see 3.3.3).

TO-DO: show the formats, based on RFC 4944, but with SCHC-compressed headers.

5. 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.

Each Rule defines the set of protocols whose headers are compressed. For example, in a given deployment, RuleIDs 1 to 3 may be defined for IPv6 header compression only, RuleIDs 4 to 7 may be used for IPv6/UDP header compression, and RuleIDs 8 to 15 may be used for IPv6/UDP/CoAP header compression.

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

5.1. 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 endpoint it communicates with before such communication occurs [I-D.ietf-lpwan-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 pair of endpoints.

5.1.1. 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.

5.2. 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 endpoint it communicates with before such communication occurs [I-D.ietf-lpwan-architecture]. Therefore, in such cases, direction information will be specific to each pair of endpoints.

6. Fragmentation and reassembly

After applying SCHC header compression to a packet intended for transmission, if the size of the resulting SCHC Packet (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 multihop 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 network, e.g., if at least one of the caveats described in Section 6 of RFC 8930 is unacceptable or cannot be addressed.

7. IANA Considerations

This document requests the allocation of the Dispatch Type Field bit pattern 01000100 (in Pages 0 and 1) as SCHC Dispatch Type.

8. 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 headers is REQUIRED.

9. Acknowledgments

Ana Minaburo and Laurent Toutain suggested for the first time the use of SCHC in environments where 6LoWPAN has traditionally been used. Laurent Toutain, Pascal Thubert, Dominique Barthel, Guangpeng Li, and Carsten Bormann made comments that helped shape this document.

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

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Appendix A. Header compression examples

TO-DO: provide examples for IPv6-only, IPv6/UDP and IPv6/UDP/CoAP.

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