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LPWAN Static Context Header Compression (SCHC) for ICMPv6
draft-barthel-icmpv6-schc-00

Abstract

ICMPv6 is a companion protocol to IPv6. It defines messages that inform the source of IPv6 packets of errors during packet delivery. It also defines the Echo Request/Reply messages that are used for basic network troubleshooting (ping command). ICMPv6 messages are transported on IPv6.

This document describes how to adapt ICMPv6 to Low Power Wide Area Networks (LPWANs) by compressing ICMPv6/IPv6 headers and by protecting the LPWAN network and the Device from undesirable ICMPv6 traffic.

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1. Introduction

ICMPv6 [RFC4443] is a companion protocol to IPv6 [RFC8200].

[RFC4443] defines a generic message format. This format is used for messages to be sent back to the source of an IPv6 packet to inform it about errors during packet delivery.

More specifically, [RFC4443] defines 4 error messages: Destination Unreachable, Packet Too Big, Time Exceeded and Parameter Problem.

[RFC4443] also defines the Echo Request and Echo Reply messages, which provide support for the ping application.

Other ICMPv6 messages are defined in other RFCs, such as an extended format of the same messages [RFC4884] and other messages used by the Neighbor Discovery Protocol [RFC4861].

This document focuses on using Static Context Header Compression (SCHC) to compress [RFC4443] messages that need to be transmitted over the LPWAN network, and on having the LPWAN gateway proxying the Device to save it the unwanted traffic.

LPWANs' salient characteristics are described in [I-D.ietf-lpwan-overview]

2. Terminology

This draft re-uses the Terminology defined in [I-D.ietf-lpwan-ipv6-static-context-hc].

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

3. Use cases

In the LPWAN architecture, we can distinguish the following cases:

- o the Device is the (purported) source of an ICMP error message, mainly in response to an incorrect incoming IPv6 message, or in response to a ping request. In this case, as much as possible, the core SCHC C/D should act as a proxy and originate the ICMP message, so that the Device and the LPWAN network are protected from this unwanted traffic.
- o the Device is the destination of the ICMP message, mainly in response to a packet sent by the Device to the network that generates an error. In this case, we want the ICMP message to reach the Device, and this document describes in section Section 4.2.1 what SCHC compression should be applied.
- o the Device is the originator of an Echo Request message, and therefore the destination of the Echo Reply message.
- o the Device is the destination of an Echo Request message, and therefore the purported source of an Echo Reply message.

These cases are further described in Section 4.

4. Detailed behavior

4.1. Device is the source of an ICMPv6 error message

As stated in [RFC4443], a node should generate an ICMPv6 message in response to an IPv6 packet that is malformed or which cannot be processed due to some incorrect field value.

The general intent of this document is to spare both the Device and the LPWAN network this un-necessary traffic. The incorrect packets should be caught at the core SCHC C/D and the ICMPv6 notification should be sent back from there.

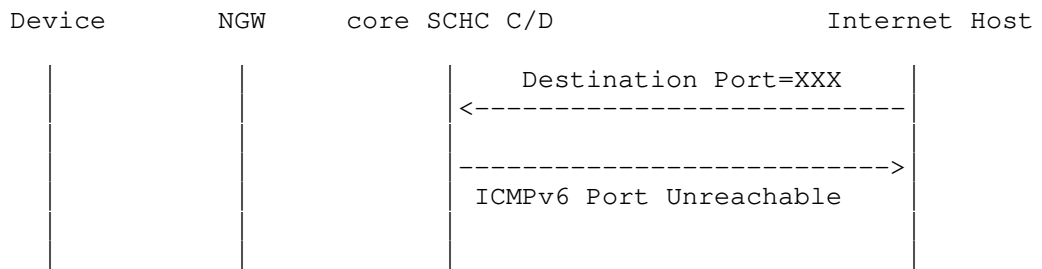


Figure 1: Example of ICMPv6 error message sent back to the Internet

Figure 1 shows an example of an IPv6 packet trying to reach a Device. Let's assume that the port number used as destination port is not "known" (needs better definition) from the core SCHC C/D. Instead of sending the packet over the LPWAN and having this packet rejected by the Device, the core SCHC C/D issues an ICMPv6 error message "Destination Unreachable" (Type 1) with Code 1 ("Port Unreachable") on behalf of the Device.

TODO: This assumes that all ports that the Device listens to will be matched by a SCHC rule. Is this the basic assumption of SCHC that all packets that do not match a rule are rejected? If yes, why do have fragmentation also for uncompressed packets?

TODO: discuss the various Type/Code that are expected to be generated in response to various errors.

4.2. Device is the destination of an ICMPv6 error message

In this situation, we assume that a Device has been configured to send information to a server on the Internet. If this server becomes no longer accessible, an ICMPv6 message will be generated back

towards the Device by an intermediate router. This information can be useful to the Device, for example for reducing the reporting rate in case of periodic reporting of data. Therefore, we compress the ICMPv6 message using SCHC and forward it to the Device over the LPWAN.

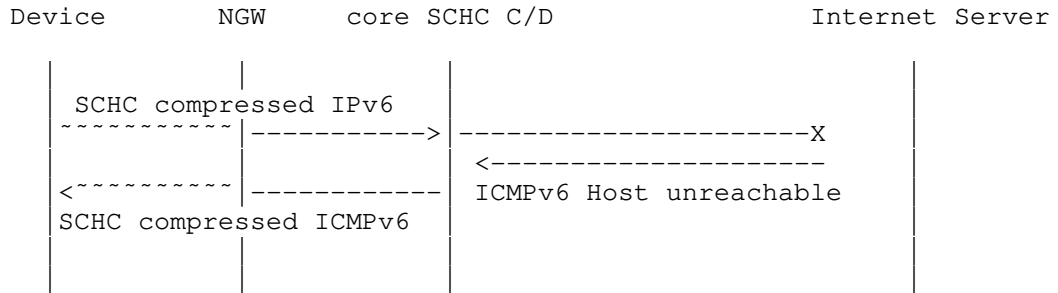


Figure 2: Example of ICMPv6 error message sent back to the Device

Figure 2 illustrates this behavior. The ICMPv6 error message is compressed as described in Section 4.2.1 and forwarded over the LPWAN to the Device.

4.2.1. ICMPv6 error message compression.

The ICMPv6 error messages defined in [RFC4443] contain the fields shown in Figure 3.

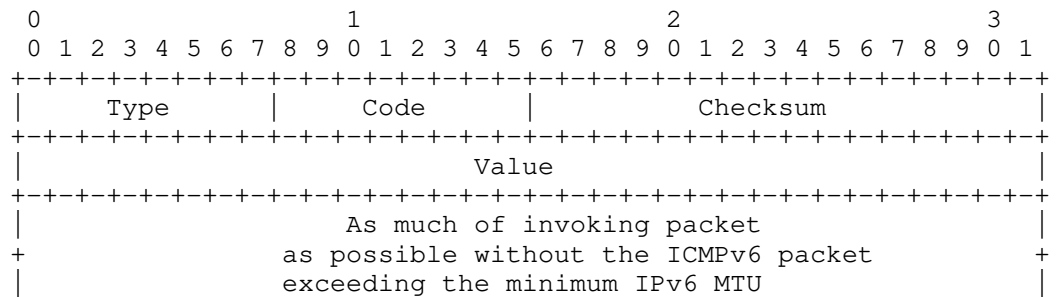


Figure 3: ICMPv6 Error Message format

[RFC4443] states that Type can take the values 1 to 4, and Code can be set to values between 0 and 6. Value is unused for the Destination Unreachable and Time Exceeded messages. It contains the MTU for the Packet Too Big message and a pointer to the byte causing

the error for the Parameter Error message. Therefore, Value is never expected to be greater than 1280 in LPWAN networks.

The following generic rule can therefore be used to compress all ICMPv6 error messages as defined today. More specific rules can also be defined to achieve better compression of some error messages.

The Type field can be associated to a matching list [1, 2, 3, 4] and is therefore compressed down to 2 bits. Code can be reduced to 3 bits using the LSB CDA. Value can be sent on 11 bits using the LSB CDA, but if the Device is known to send smaller packets, then the size of this field can be further reduced.

By [RFC4443], the rest of the ICMPv6 message must contain as much as possible of the IPv6 offending (invoking) packet that triggered this ICMPv6 error message. This information is used to try and identify the SCHC rule that was used to decompress the offending IPv6 packet. If the rule can be found then the Rule Id is added at the end of the compressed ICMPv6 message. Otherwise the compressed packet ends with the compressed Value field.

[RFC4443] states that the "ICMPv6 error message MUST include as much of the IPv6 offending (invoking) packet ... as possible". In order to comply with this requirement, if there is enough information in the incoming ICMPv6 message for the core SCHC C/D to identify the rule that has been used to decompress the erroneous IPv6 packet, this Rule Id must be sent in the compressed ICMPv6 message to the Device. TODO: the erroneous IPv6 packet header (not just the Rule Id) should be sent back. This includes the Rule Id and the compression residue. This means the SCHC C/D uses the context backwards (in the reverse direction). How does the Device know it must also use the context backwards?

TODO: how does one know that the "payload" of a compressed-header packet is in fact another compressed header?

4.3. Device does a ping

If a ping request is generated by a Device, then SCHC compression applies.

The format of an ICMPv6 Echo Request message is described in Figure 4, with Type=128 and Code=0.

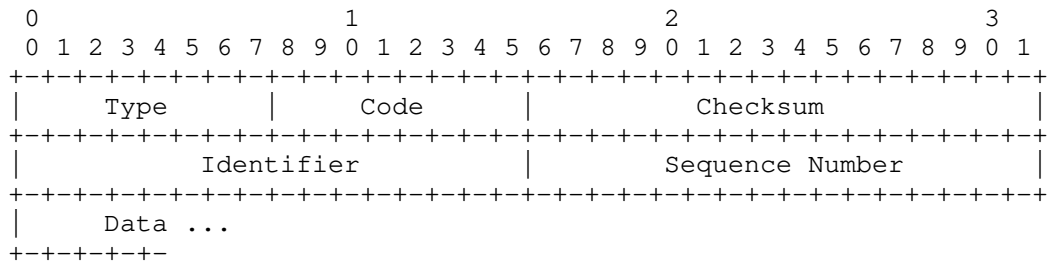


Figure 4: ICMPv6 Echo Request message format

If we assume that one rule will be devoted to compressing Echo Request messages, then Type and Code are known in the rule to be 128 and 0 and can therefore be elided with the not-sent CDA.

Checksum can be reconstructed with the compute-checksum CDA and therefore is not transmitted.

[RFC4443] states that Identifier and Sequence Number are meant to "aid in matching Echo Replies to this Echo Request" and that they "may be zero". Data is "zero or more bytes of arbitrary data".

We recommend that Identifier be zero, Sequence Number be a counter on 3 bits, and Data be zero bytes (absent). Therefore, Identifier is elided with the not-sent CDA, Sequence Number is transmitted on 3 bits with the LSB CDA and no Data is transmitted.

The transmission cost of the Echo Request message is therefore the size of the Rule Id + 3 bits.

When the destination receives the Echo Request message, it will respond back with a Echo Reply message. This message bears the same format as the Echo Request message but with Type = 129 (see Figure 4).

[RFC4443] states that the Identifier, Sequence Number and Data fields of the Echo Reply message shall contain the same values as the invoking Echo Request message. Therefore, a rule shall be used similar to that used for compressing the Echo Request message.

TODO: how about a shared rule for Echo Request and Echo Reply with an LSB(1) CDA on the Type field? Or exploiting the Up/Down direction field in the rule?

4.4. Device is ping'ed

If the Device is ping'ed (i.e., is the destination of an Echo Request message), the default behavior is to avoid propagating the Echo Request message over the LPWAN.

This is the recommended behavior with the Code 0 (default value) of the Echo Request message. In addition, this document defines two other Code values to achieve two other behaviors.

The resulting three behaviors are shown on Figure 5 and described below:

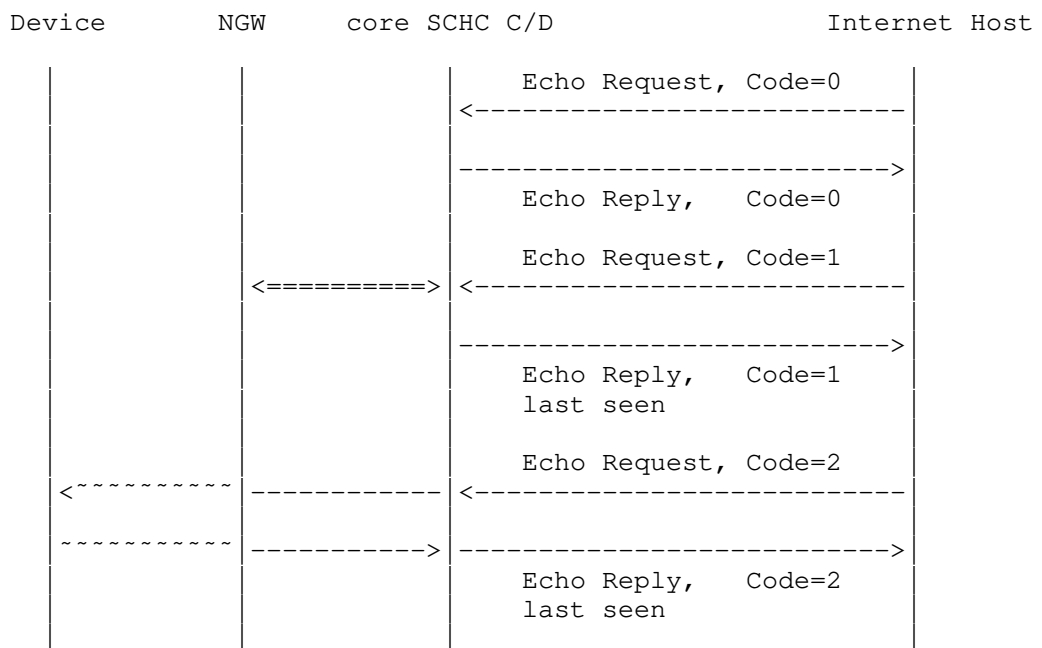


Figure 5: Examples of ICMPv6 Echo Request/Reply

- o Code = 0: The Echo Request message is not propagated on the LPWAN to the Device. If the SCHC C/D finds a rule in the context with the IPv6 address of the Device, it responds with an Echo Reply on behalf of the Device. If no rule is found with that IPv6 address, the SCHC C/D does not respond.

TODO: again, we are assuming that no compression rule is equivalent to the device not providing the service.

- o Code = 1: the SCHC C/D queries the NGW (or maintains a local database) and answers with the number of seconds since the Device last transmission.

TODO: what does it mean to answer "with the number of seconds ..."? There is no such field in an Echo Reply message. Do we overwrite one of the fields (Identifier, Sequencer Number, Data)? They are all supposed to be copied from the Echo Request. Do we change their definition with Code==1 or Code==2?

- o Code = 2: the SCHC C/D compresses the ICMPv6 message and forwards it to the Device. The Echo Reply message sent by the Device is also compressed. Since the Echo Request message comes from the Internet, the values of the Identifier, Sequence Number and Data fields cannot be known in advance, and therefore must be transmitted. However, it is likely that the Echo Request with Code 2 will be firewalled from the Internet and restricted to authorized users. Therefore, the Echo Request message can be assumed to have the same content as recommended in Section 4.3, and the same compression rules apply.

5. Traceroute

The `traceroute6` program sends successive probe packets destined to a chosen target but with the Hop Limit value successively incremented from the initial value 1.

It expects to receive a "Time Exceeded" (Type = 3) "Hop Limit" (Code = 0) ICMPv6 error message back from the successive routers along the path to the destination.

The probe packet is usually a UDP datagram, but can also be a TCP datagram or even an ICMPv6 message. The destination port is chosen in the unassigned range in hope that the destination, when eventually reached, will respond with a "Destination Unreachable" (Type = 1) "Port Unreachable" (Code = 4) ICMPv6 error message.

It is not anticipated that a Device will want to traceroute a destination on the Internet.

By contrast, a host on the Internet may attempt to traceroute an IPv6 address that is assigned to an LPWAN device. This is described in Figure 6.

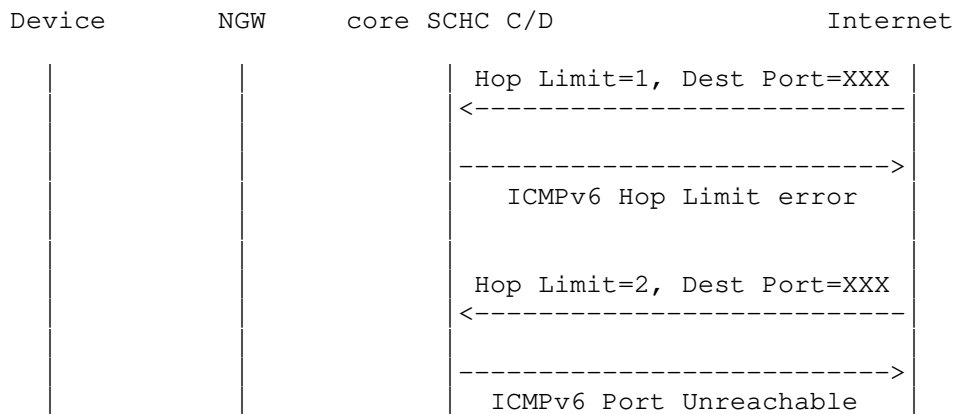


Figure 6: Example of traceroute to the LPWAN Device

When the probe packet first reaches the core SCHC C/D, its remaining Hop Limit is 1. The core SCHC C/D will respond back with a "Time Exceeded" (Type = 3) "Hop Limit" (Code = 0) ICMPv6 error message. Later on, when the probe packet reaches the core SCHC C/D with a Hop Limit value of 2, the core SCHC C/D will, as explained in Section 4.1, answer back with a "Destination Unreachable" (Type = 1) "Port Unreachable" (Code = 4) ICMPv6 error message. This is what the traceroute6 command expects. Therefore, the traceroute6 command will work with LPWAN IPv6 destinations, except for the time displayed for the destination, which is actually the time to its proxy.

However, if the probe packet happens to hit a port that matches a SCHC rule for that Device, the packet will be compressed with this rule and sent over the LPWAN, which is unfortunate. Forwarding of packets to the Device over the LPWAN should only be done from authenticated/trusted sources anyway. Rate-limitation on top of authentication will mitigate this nuisance.

6. Security considerations

TODO

7. IANA Considerations

TODO

8. References

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Static Context Header Compression (SCHC) and fragmentation for LPWAN,
application to UDP/IPv6
draft-ietf-lpwan-ipv6-static-context-hc-24

Abstract

This document defines the Static Context Header Compression (SCHC) framework, which provides both a header compression mechanism and an optional fragmentation mechanism. SCHC has been designed for Low Power Wide Area Networks (LPWAN).

SCHC compression is based on a common static context stored both in the LPWAN device and in the network infrastructure side. This document defines a generic header compression mechanism and its application to compress IPv6/UDP headers.

This document also specifies an optional fragmentation and reassembly mechanism. It can be used to support the IPv6 MTU requirement over the LPWAN technologies. Fragmentation is needed for IPv6 datagrams that, after SCHC compression or when such compression was not possible, still exceed the layer-2 maximum payload size.

The SCHC header compression and fragmentation mechanisms are independent of the specific LPWAN technology over which they are used. This document defines generic functionalities and offers flexibility with regard to parameter settings and mechanism choices. This document standardizes the exchange over the LPWAN between two SCHC entities. Settings and choices specific to a technology or a product are expected to be grouped into profiles, which are specified in other documents. Data models for the context and profiles are out of scope.

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1. Introduction

This document defines the Static Context Header Compression (SCHC) framework, which provides both a header compression mechanism and an optional fragmentation mechanism. SCHC has been designed for Low Power Wide Area Networks (LPWAN).

LPWAN technologies impose some strict limitations on traffic. For instance, devices sleep most of the time and may only receive data during short periods of time after transmission, in order to preserve battery. LPWAN technologies are also characterized by a greatly reduced data unit and/or payload size (see [RFC8376]).

Header compression is needed for efficient Internet connectivity to a node within an LPWAN network. The following properties of LPWAN networks can be exploited to get an efficient header compression:

- o The network topology is star-oriented, which means that all packets between the same source-destination pair follow the same path. For the needs of this document, the architecture can simply be described as Devices (Dev) exchanging information with LPWAN Application Servers (App) through a Network Gateway (NGW).
- o Because devices embed built-in applications, the traffic flows to be compressed are known in advance. Indeed, new applications are less frequently installed in an LPWAN device, than they are in a general-purpose computer or smartphone.

SCHC compression uses a Context (a set of Rules) in which information about header fields is stored. This Context is static: the values of the header fields and the actions to do compression/decompression do not change over time. This avoids the need for complex resynchronization mechanisms. Indeed, a return path may be more restricted/expensive, sometimes completely unavailable [RFC8376]. A compression protocol that relies on feedback is not compatible with the characteristics of such LPWANs.

In most cases, a small Rule identifier is enough to represent the full IPv6/UDP headers. The SCHC header compression mechanism is independent of the specific LPWAN technology over which it is used.

Furthermore, some LPWAN technologies do not provide a fragmentation functionality; to support the IPv6 MTU requirement of 1280 bytes [RFC8200], they require a fragmentation protocol at the adaptation layer below IPv6. Accordingly, this document defines an optional fragmentation/reassembly mechanism for LPWAN technologies to support the IPv6 MTU requirement.

This document defines generic functionality and offers flexibility with regard to parameters settings and mechanism choices. Technology-specific settings are expected to be grouped into Profiles specified in other documents.

2. Requirements Notation

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

3. LPWAN Architecture

LPWAN network architectures are similar among them, but each LPWAN technology names architecture elements differently. In this document, we use terminology from [RFC8376], which identifies the following entities in a typical LPWAN network (see Figure 1):

- o Devices (Dev) are the end-devices or hosts (e.g., sensors, actuators, etc.). There can be a very high density of devices per radio gateway.
- o The Radio Gateway (RGW) is the end point of the constrained link.
- o The Network Gateway (NGW) is the interconnection node between the Radio Gateway and the Internet.

- o Application Server (App) is the end point of the application level protocol on the Internet side.

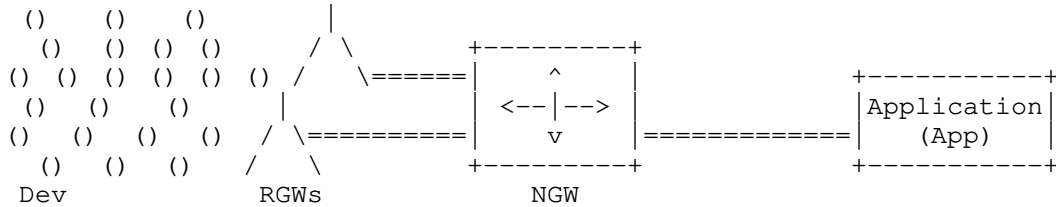


Figure 1: LPWAN Architecture, simplified from that shown in RFC8376

4. Terminology

This section defines the terminology and acronyms used in this document. It extends the terminology of [RFC8376].

The SCHC acronym is pronounced like "sheek" in English (or "chic" in French). Therefore, this document writes "a SCHC Packet" instead of "an SCHC Packet".

- o App: LPWAN Application, as defined by [RFC8376]. An application sending/receiving packets to/from the Dev.
- o AppIID: Application Interface Identifier. The IID that identifies the application server interface.
- o Bi: Bidirectional. Characterizes a Field Descriptor that applies to headers of packets traveling in either direction (Up and Dw, see this glossary).
- o CDA: Compression/Decompression Action. Describes the pair of actions that are performed at the compressor to compress a header field and at the decompressor to recover the original value of the header field.
- o Compression Residue. The bits that remain to be sent (beyond the Rule ID itself) after applying the SCHC compression.
- o Context: A set of Rules used to compress/decompress headers.
- o Dev: Device, as defined by [RFC8376].
- o DevIID: Device Interface Identifier. The IID that identifies the Dev interface.

- o DI: Direction Indicator. This field tells which direction of packet travel (Up, Dw or Bi) a Field Description applies to. This allows for asymmetric processing, using the same Rule.
- o Dw: Downlink direction for compression/decompression, from SCHC C/D in the network to SCHC C/D in the Dev.
- o Field Description. A tuple containing identifier, value, matching operator and actions to be applied to a field.
- o FID: Field Identifier. This identifies the protocol and field a Field Description applies to.
- o FL: Field Length is the length of the original packet header field. It is expressed as a number of bits for header fields of fixed lengths or as a type (e.g., variable, token length, ...) for field lengths that are unknown at the time of Rule creation. The length of a header field is defined in the corresponding protocol specification (such as IPv6 or UDP).
- o FP: when a Field is expected to appear multiple times in a header, Field Position specifies the occurrence this Field Description applies to (for example, first uri-path option, second uri-path, etc. in a CoAP header), counting from 1. The value 0 is special and means "don't care", see Section 7.3.
- o IID: Interface Identifier. See the IPv6 addressing architecture [RFC7136].
- o L2: Layer two. The immediate lower layer SCHC interfaces with. It is provided by an underlying LPWAN technology. It does not necessarily correspond to the OSI model definition of Layer 2.
- o L2 Word: this is the minimum subdivision of payload data that the L2 will carry. In most L2 technologies, the L2 Word is an octet. In bit-oriented radio technologies, the L2 Word might be a single bit. The L2 Word size is assumed to be constant over time for each device.
- o MO: Matching Operator. An operator used to match a value contained in a header field with a value contained in a Rule.
- o Padding (P). Extra bits that may be appended by SCHC to a data unit that it passes to the underlying Layer 2 for transmission. SCHC itself operates on bits, not bytes, and does not have any alignment prerequisite. See Section 9.

- o Profile: SCHC offers variations in the way it is operated, with a number of parameters listed in Appendix D. A Profile indicates a particular setting of all these parameters. Both ends of a SCHC communication must be provisioned with the same Profile information and with the same set of Rules before the communication starts, so that there is no ambiguity in how they expect to communicate.
- o Rule: A set of Field Descriptions.
- o Rule ID (Rule Identifier): An identifier for a Rule. SCHC C/D on both sides share the same Rule ID for a given packet. A set of Rule IDs are used to support SCHC F/R functionality.
- o SCHC C/D: SCHC Compressor/Decompressor. A mechanism used on both sides, at the Dev and at the network, to achieve Compression/Decompression of headers.
- o SCHC F/R: SCHC Fragmentation / Reassembly. A mechanism used on both sides, at the Dev and at the network, to achieve Fragmentation / Reassembly of SCHC Packets.
- o SCHC Packet: A packet (e.g., an IPv6 packet) whose header has been compressed as per the header compression mechanism defined in this document. If the header compression process is unable to actually compress the packet header, the packet with the uncompressed header is still called a SCHC Packet (in this case, a Rule ID is used to indicate that the packet header has not been compressed). See Section 7 for more details.
- o TV: Target value. A value contained in a Rule that will be matched with the value of a header field.
- o Up: Uplink direction for compression/decompression, from the Dev SCHC C/D to the network SCHC C/D.

Additional terminology for the optional SCHC Fragmentation / Reassembly mechanism (SCHC F/R) is found in Section 8.2.

5. SCHC overview

SCHC can be characterized as an adaptation layer between an upper layer (typically, IPv6) and an underlying layer (typically, an LPWAN technology). SCHC comprises two sublayers (i.e. the Compression sublayer and the Fragmentation sublayer), as shown in Figure 2.

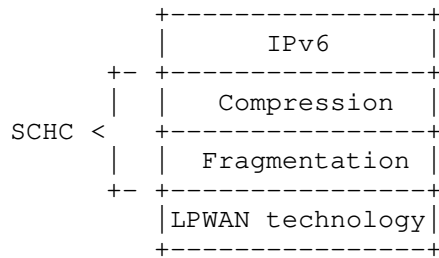


Figure 2: Protocol stack comprising IPv6, SCHC and an LPWAN technology

Before an upper layer packet (e.g., an IPv6 packet) is transmitted to the underlying layer, header compression is first attempted. The resulting packet is called a SCHC Packet, whether or not any compression is performed. If needed by the underlying layer, the optional SCHC Fragmentation MAY be applied to the SCHC Packet. The inverse operations take place at the receiver. This process is illustrated in Figure 3.

5.2. Functional mapping

Figure 5 maps the functional elements of Figure 3 onto the LPWAN architecture elements of Figure 1.

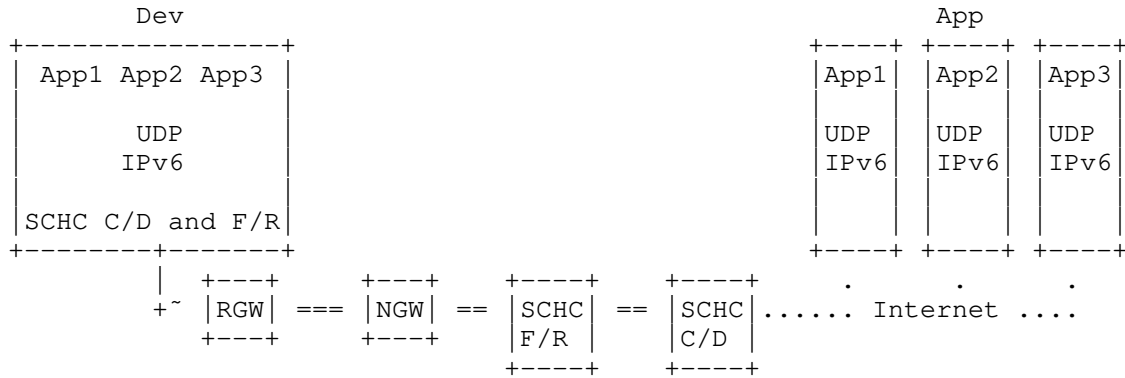


Figure 5: Architecture

SCHC C/D and SCHC F/R are located on both sides of the LPWAN transmission, hereafter called "the Dev side" and "the Network infrastructure side".

The operation in the Uplink direction is as follows. The Device application uses IPv6 or IPv6/UDP protocols. Before sending the packets, the Dev compresses their headers using SCHC C/D and, if the SCHC Packet resulting from the compression needs to be fragmented by SCHC, SCHC F/R is performed (see Section 8). The resulting SCHC Fragments are sent to an LPWAN Radio Gateway (RGW) which forwards them to a Network Gateway (NGW). The NGW sends the data to a SCHC F/R for re-assembly (if needed) and then to the SCHC C/D for decompression. After decompression, the packet can be sent over the Internet to one or several LPWAN Application Servers (App).

The SCHC F/R and C/D on the Network infrastructure side can be part of the NGW, or located in the Internet as long as a tunnel is established between them and the NGW. For some LPWAN technologies, it may be suitable to locate the SCHC F/R functionality nearer the NGW, in order to better deal with time constraints of such technologies.

The SCHC C/Ds on both sides MUST share the same set of Rules. So MUST the SCHC F/Rs on both sides.

The operation in the Downlink direction is similar to that in the Uplink direction, only reversing the order in which the architecture elements are traversed.

6. Rule ID

Rule IDs identify the Rules used for Compression/Decompression or for Fragmentation/Reassembly.

The scope of the Rule ID of a Compression/Decompression Rule is the link between the SCHC C/D in a given Dev and the corresponding SCHC C/D in the Network infrastructure side. The scope of the Rule ID of a Fragmentation/Reassembly Rule is the link between the SCHC F/R in a given Dev and the corresponding SCHC F/R in the Network infrastructure side. If such a link is bidirectional, the scope includes both directions.

Inside their scopes, Rules for Compression/Decompression and Rules for Fragmentation/Reassembly share the same Rule ID space.

The size of the Rule IDs is not specified in this document, as it is implementation-specific and can vary according to the LPWAN technology and the number of Rules, among others. It is defined in Profiles.

The Rule IDs are used:

- o For SCHC C/D, to identify the Rule (i.e., the set of Field Descriptions) that is used to compress a packet header.
 - * At least one Rule ID MUST be allocated to tagging packets for which SCHC compression was not possible (i.e., no matching compression Rule was found).
- o In SCHC F/R, to identify the specific mode and settings of F/R for one direction of traffic (Up or Dw).
 - * When F/R is used for both communication directions, at least two Rule ID values are needed for F/R, one per direction of traffic. This is because F/R may entail control messages flowing in the reverse direction compared to data traffic.

7. Compression/Decompression

Compression with SCHC is based on using a set of Rules, called the Context, to compress or decompress headers. SCHC avoids Context synchronization traffic, which consumes considerable bandwidth in other header compression mechanisms such as RoHC [RFC5795]. Since

the content of packets is highly predictable in LPWAN networks, static Contexts can be stored beforehand. The Contexts MUST be stored at both ends, and they can be learned by a provisioning protocol or by out of band means, or they can be pre-provisioned. The way the Contexts are provisioned is out of the scope of this document.

7.1. SCHC C/D Rules

The main idea of the SCHC compression scheme is to transmit the Rule ID to the other end instead of sending known field values. This Rule ID identifies a Rule that matches the original packet values. Hence, when a value is known by both ends, it is only necessary to send the corresponding Rule ID over the LPWAN network. The manner by which Rules are generated is out of the scope of this document. The Rules MAY be changed at run-time but the mechanism is out of scope of this document.

The Context is a set of Rules. See Figure 6 for a high level, abstract representation of the Context. The formal specification of the representation of the Rules is outside the scope of this document.

Each Rule itself contains a list of Field Descriptions composed of a Field Identifier (FID), a Field Length (FL), a Field Position (FP), a Direction Indicator (DI), a Target Value (TV), a Matching Operator (MO) and a Compression/Decompression Action (CDA).

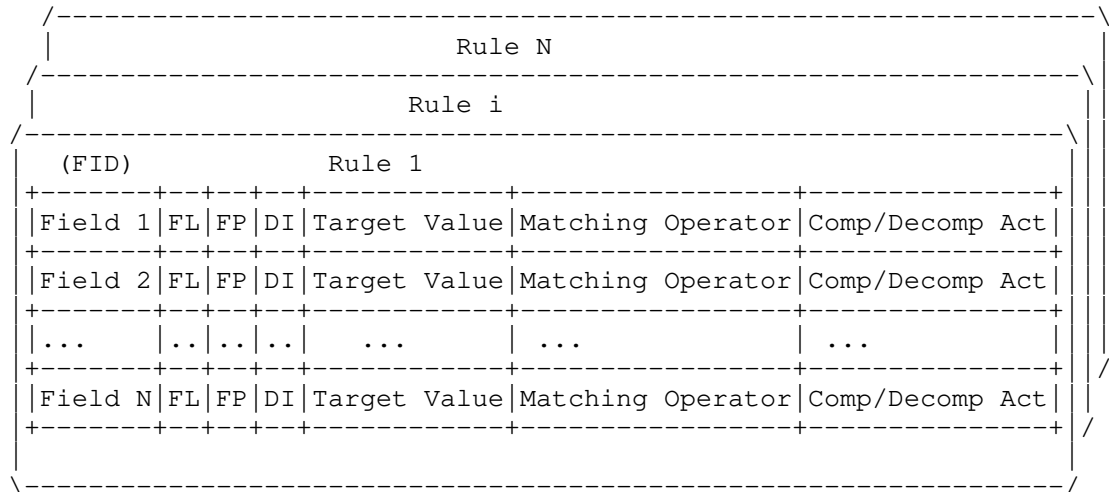


Figure 6: A Compression/Decompression Context

A Rule does not describe how the compressor parses a packet header to find and identify each field (e.g., the IPv6 Source Address, the UDP Destination Port or a CoAP URI path option). It is assumed that there is a protocol parser alongside SCHC that is able to identify all the fields encountered in the headers to be compressed, and to label them with a Field ID. Rules only describe the compression/decompression behavior for each header field, after it has been identified.

In a Rule, the Field Descriptions are listed in the order in which the fields appear in the packet header. The Field Descriptions describe the header fields with the following entries:

- o Field ID (FID) designates a protocol and field (e.g., UDP Destination Port), unambiguously among all protocols that a SCHC compressor processes. In the presence of protocol nesting, the Field ID also identifies the nesting.
- o Field Length (FL) represents the length of the original field. It can be either a fixed value (in bits) if the length is known when the Rule is created or a type if the length is variable. The length of a header field is defined by its own protocol specification (e.g., IPv6 or UDP). If the length is variable, the type defines the process to compute the length and its unit (bits, bytes...).
- o Field Position (FP): most often, a field only occurs once in a packet header. However, some fields may occur multiple times. An example is the uri-path of CoAP. FP indicates which occurrence this Field Description applies to. If FP is not specified in the Field Description, it takes the default value of 1. The value 1 designates the first occurrence. The value 0 is special. It means "don't care", see Section 7.3.
- o A Direction Indicator (DI) indicates the packet direction(s) this Field Description applies to. Three values are possible:
 - * UPLINK (Up): this Field Description is only applicable to packets sent by the Dev to the App,
 - * DOWNLINK (Dw): this Field Description is only applicable to packets sent from the App to the Dev,
 - * BIDIRECTIONAL (Bi): this Field Description is applicable to packets traveling both Up and Dw.
- o Target Value (TV) is the value used to match against the packet header field. The Target Value can be a scalar value of any type

(integer, strings, etc.) or a more complex structure (array, list, etc.). The types and representations are out of scope for this document.

- o Matching Operator (MO) is the operator used to match the Field Value and the Target Value. The Matching Operator may require some parameters. MO is only used during the compression phase. The set of MOs defined in this document can be found in Section 7.4.
- o Compression Decompression Action (CDA) describes the compression and decompression processes to be performed after the MO is applied. Some CDAs might use parameter values for their operation. CDAs are used in both the compression and the decompression functions. The set of CDAs defined in this document can be found in Section 7.5.

7.2. Rule ID for SCHC C/D

Rule IDs are sent by the compression function in one side and are received for the decompression function in the other side. In SCHC C/D, the Rule IDs are specific to the Context related to one Dev. Hence, multiple Dev instances, which refer to different header compression Contexts, MAY reuse the same Rule ID for different Rules. On the Network infrastructure side, in order to identify the correct Rule to be applied, the SCHC Decompressor needs to associate the Rule ID with the Dev identifier. Similarly, the SCHC Compressor on the Network infrastructure side first identifies the destination Dev before looking for the appropriate compression Rule (and associated Rule ID) in the Context of that Dev.

7.3. Packet processing

The compression/decompression process follows several phases:

- o Compression Rule selection: the general idea is to browse the Rule set to find a Rule that has a matching Field Descriptor (given the DI and FP) for all and only those header fields that appear in the packet being compressed. The detailed algorithm is the following:
 - * The first step is to check the Field Identifiers (FID). If any header field of the packet being examined cannot be matched with a Field Description with the correct FID, the Rule MUST be disregarded. If any Field Description in the Rule has a FID that cannot be matched to one of the header fields of the packet being examined, the Rule MUST be disregarded.

- * The next step is to match the Field Descriptions by their direction, using the Direction Indicator (DI). If any field of the packet header cannot be matched with a Field Description with the correct FID and DI, the Rule MUST be disregarded.
- * Then the Field Descriptions are further selected according to Field Position (FP). If any field of the packet header cannot be matched with a Field Description with the correct FID, DI and FP, the Rule MUST be disregarded.

The value 0 for FP means "don't care", i.e. the comparison of this Field Description's FP with the position of the field of the packet header being compressed returns True, whatever that position. FP=0 can be useful to build compression Rules for protocols headers in which some fields order is irrelevant. An example could be uri-queries in CoAP. Care needs to be exercised when writing Rules containing FP=0 values. Indeed, it may result in decompressed packets having fields ordered differently compared to the original packet.

- * Once each header field has been associated with a Field Description with matching FID, DI and FP, each packet field's value is then compared to the corresponding Target Value (TV) stored in the Rule for that specific field, using the matching operator (MO). If every field in the packet header satisfies the corresponding matching operators (MO) of a Rule (i.e. all MO results are True), that Rule is valid for use to compress the header. Otherwise, the Rule MUST be disregarded.

This specification does not prevent multiple Rules from matching the above steps and therefore being valid for use. Which Rule to use among multiple valid Rules is left to the implementation. As long as the same Rule set is installed at both ends, this degree of freedom does not constitute an interoperability issue.

- * If no valid compression Rule is found, then the packet MUST be sent uncompressed using the Rule ID dedicated to this purpose (see Section 6). The entire packet header is the Compression Residue (see Figure 4). Sending an uncompressed header is likely to require SCHC F/R.
- o Compression: if a valid Rule was found, each field of the header is compressed according to the Compression/Decompression Actions (CDAs) of the Rule. The fields are compressed in the order that the Field Descriptions appear in the Rule. The compression of each field results in a residue, which may be empty. The Compression Residue for the packet header is the concatenation of

the non-empty residues for each field of the header, in the order the Field Descriptions appear in the Rule. The order in which the Field Descriptions appear in the Rule is therefore semantically important.

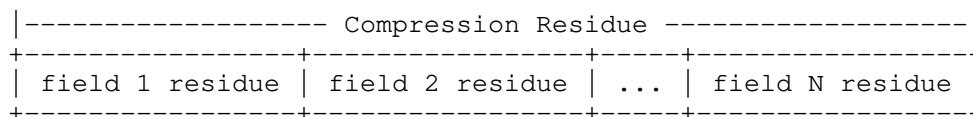


Figure 7: Compression Residue structure

- o **Sending:** The Rule ID is sent to the other end followed by the Compression Residue (which could be empty) or the uncompressed header, and directly followed by the payload (see Figure 4). The way the Rule ID is sent will be specified in the Profile and is out of the scope of the present document. For example, it could be included in an L2 header or sent as part of the L2 payload.
- o **Decompression:** when decompressing, on the Network infrastructure side the SCHC C/D needs to find the correct Rule based on the L2 address of the Dev; in this way, it can use the DevIID and the Rule ID. On the Dev side, only the Rule ID is needed to identify the correct Rule since the Dev typically only holds Rules that apply to itself.

This Rule describes the compressed header format. From this, the decompressor determines the order of the residues, the fixed-sized or variable-sized nature of each residue (see Section 7.5.2), and the size of the fixed-sized residues.

From the received compressed header, it can therefore retrieve all the residue values and associate them to the corresponding header fields.

For each field in the header, the receiver applies the CDA action associated to that field in order to reconstruct the original header field value. The CDA application order can be different from the order in which the fields are listed in the Rule. In particular, Compute-* MUST be applied after the application of the CDAs of all the fields it computes on.

7.4. Matching operators

Matching Operators (MOs) are functions used by both SCHC C/D endpoints. They are not typed and can be applied to integer, string

or any other data type. The result of the operation can either be True or False. MOs are defined as follows:

- o equal: The match result is True if the field value in the packet matches the TV.
- o ignore: No matching is attempted between the field value in the packet and the TV in the Rule. The result is always true.
- o MSB(x): A match is obtained if the most significant (leftmost) x bits of the packet header field value are equal to the TV in the Rule. The x parameter of the MSB MO indicates how many bits are involved in the comparison. If the FL is described as variable, the x parameter must be a multiple of the FL unit. For example, x must be multiple of 8 if the unit of the variable length is bytes.
- o match-mapping: With match-mapping, the Target Value is a list of values. Each value of the list is identified by an index. Compression is achieved by sending the index instead of the original header field value. This operator matches if the header field value is equal to one of the values in the target list.

7.5. Compression Decompression Actions (CDA)

The Compression Decompression Action (CDA) describes the actions taken during the compression of header fields and the inverse action taken by the decompressor to restore the original value.

Action	Compression	Decompression
not-sent	elided	use TV stored in Rule
value-sent	send	use received value
mapping-sent	send index	retrieve value from TV list
LSB	send LSB	concat. TV and received value
compute-*	elided	recompute at decompressor
DevIID	elided	build IID from L2 Dev addr
AppIID	elided	build IID from L2 App addr

Table 1: Compression and Decompression Actions

Table 1 summarizes the basic actions that can be used to compress and decompress a field. The first column shows the action's name. The second and third columns show the compression and decompression behaviors for each action.

7.5.1. processing fixed-length fields

If the field is identified in the Field Description as being of fixed length, then applying the CDA to compress this field results in a fixed amount of bits. The residue for that field is simply the bits resulting from applying the CDA to the field. This value may be empty (e.g., not-sent CDA), in which case the field residue is absent from the Compression Residue.

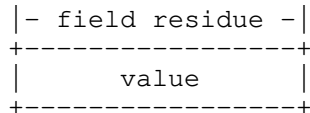


Figure 8: fixed sized field residue structure

7.5.2. processing variable-length fields

If the field is identified in the Field Description as being of variable length, then applying the CDA to compress this field may result in a value of fixed size (e.g., not-sent or mapping-sent) or of variable size (e.g., value-sent or LSB). In the latter case, the residue for that field is the bits that result from applying the CDA to the field, preceded with the size of the value. The most significant bit of the size is stored to the left (leftmost bit of the residue field).

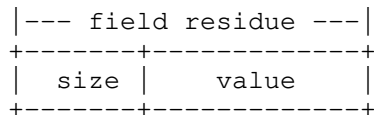


Figure 9: variable sized field residue structure

The size (using the unit defined in the FL) is encoded on 4, 12 or 28 bits as follows:

- o If the size is between 0 and 14, it is encoded as a 4 bits unsigned integer.
- o Sizes between 15 and 254 are encoded as 0b1111 followed by the 8 bits unsigned integer.
- o Larger sizes are encoded as 0xffff followed by the 16 bits unsigned integer.

If the field is identified in the Field Description as being of variable length and this field is not present in the packet header being compressed, size 0 MUST be sent to denote its absence.

7.5.3. not-sent CDA

The not-sent action can be used when the field value is specified in a Rule and therefore known by both the Compressor and the Decompressor. This action SHOULD be used with the "equal" MO. If MO is "ignore", there is a risk to have a decompressed field value different from the original field that was compressed.

The compressor does not send any residue for a field on which not-sent compression is applied.

The decompressor restores the field value with the Target Value stored in the matched Rule identified by the received Rule ID.

7.5.4. value-sent CDA

The value-sent action can be used when the field value is not known by both the Compressor and the Decompressor. The field is sent in its entirety, using the same bit order as in the original packet header.

If this action is performed on a variable length field, the size of the residue value (using the units defined in FL) MUST be sent as described in Section 7.5.2.

This action is generally used with the "ignore" MO.

7.5.5. mapping-sent CDA

The mapping-sent action is used to send an index (the index into the Target Value list of values) instead of the original value. This action is used together with the "match-mapping" MO.

On the compressor side, the match-mapping Matching Operator searches the TV for a match with the header field value. The mapping-sent CDA then sends the corresponding index as the field residue. The most significant bit of the index is stored to the left (leftmost bit of the residue field).

On the decompressor side, the CDA uses the received index to restore the field value by looking up the list in the TV.

The number of bits sent is the minimal size for coding all the possible indices.

The first element in the list MUST be represented by index value 0, and successive elements in the list MUST have indices incremented by 1.

7.5.6. LSB CDA

The LSB action is used together with the "MSB(x)" MO to avoid sending the most significant part of the packet field if that part is already known by the receiving end.

The compressor sends the Least Significant Bits as the field residue value. The number of bits sent is the original header field length minus the length specified in the MSB(x) MO. The bits appear in the residue in the same bit order as in the original packet header.

The decompressor concatenates the x most significant bits of Target Value and the received residue value.

If this action is performed on a variable length field, the size of the residue value (using the units defined in FL) MUST be sent as described in Section 7.5.2.

7.5.7. DevIID, AppIID CDA

These actions are used to process respectively the Dev and the App Interface Identifiers (DevIID and AppIID) of the IPv6 addresses. AppIID CDA is less common since most current LPWAN technologies frames contain a single L2 address, which is the Dev's address.

The IID value MAY be computed from the Device ID present in the L2 header, or from some other stable identifier. The computation is specific to each Profile and MAY depend on the Device ID size.

In the downlink direction (Dw), at the compressor, the DevIID CDA may be used to generate the L2 addresses on the LPWAN, based on the packet's Destination Address.

7.5.8. Compute-*

Some fields can be elided at the compressor and recomputed locally at the decompressor.

Because the field is uniquely identified by its Field ID (e.g., UDP length), the relevant protocol specification unambiguously defines the algorithm for such computation.

Examples of fields that know how to recompute themselves are UDP length, IPv6 length and UDP checksum.

8. Fragmentation/Reassembly

8.1. Overview

In LPWAN technologies, the L2 MTU typically ranges from tens to hundreds of bytes. Some of these technologies do not have an internal fragmentation/reassembly mechanism.

The optional SCHC Fragmentation/Reassembly (SCHC F/R) functionality enables such LPWAN technologies to comply with the IPv6 MTU requirement of 1280 bytes [RFC8200]. It is OPTIONAL to implement per this specification, but Profiles may specify that it is REQUIRED.

This specification includes several SCHC F/R modes, which allow for a range of reliability options such as optional SCHC Fragment retransmission. More modes may be defined in the future.

The same SCHC F/R mode MUST be used for all SCHC Fragments of a given SCHC Packet. This document does not specify which mode(s) must be implemented and used over a specific LPWAN technology. That information will be given in Profiles.

SCHC allows transmitting non-fragmented SCHC Packet concurrently with fragmented SCHC Packets. In addition, SCHC F/R provides protocol elements that allow transmitting several fragmented SCHC Packets concurrently, i.e. interleaving the transmission of fragments from different fragmented SCHC Packets. A Profile MAY restrict the latter behavior.

The L2 Word size (see Section 4) determines the encoding of some messages. SCHC F/R usually generates SCHC Fragments and SCHC ACKs that are multiples of L2 Words.

8.2. SCHC F/R Protocol Elements

This subsection describes the different elements that are used to enable the SCHC F/R functionality defined in this document. These elements include the SCHC F/R messages, tiles, windows, bitmaps, counters, timers and header fields.

The elements are described here in a generic manner. Their application to each SCHC F/R mode is found in Section 8.4.

8.2.1. Messages

SCHC F/R defines the following messages:

- o SCHC Fragment: A message that carries part of a SCHC Packet from the sender to the receiver.
- o SCHC ACK: An acknowledgement for fragmentation, by the receiver to the sender. This message is used to indicate whether or not the reception of pieces of, or the whole of the fragmented SCHC Packet, was successful.
- o SCHC ACK REQ: A request by the sender for a SCHC ACK from the receiver.
- o SCHC Sender-Abort: A message by the sender telling the receiver that it has aborted the transmission of a fragmented SCHC Packet.
- o SCHC Receiver-Abort: A message by the receiver to tell the sender to abort the transmission of a fragmented SCHC Packet.

The format of these messages is provided in Section 8.3.

8.2.2. Tiles, Windows, Bitmaps, Timers, Counters

8.2.2.1. Tiles

The SCHC Packet is fragmented into pieces, hereafter called tiles. The tiles MUST be non-empty and pairwise disjoint. Their union MUST be equal to the SCHC Packet.

See Figure 10 for an example.

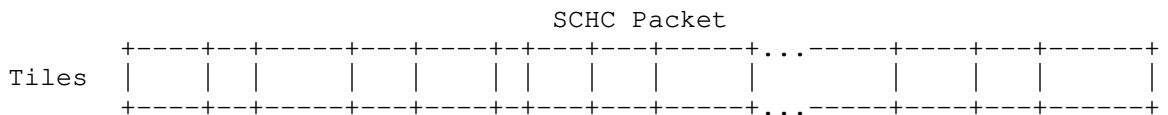


Figure 10: a SCHC Packet fragmented in tiles

Modes (see Section 8.4) MAY place additional constraints on tile sizes.

Each SCHC Fragment message carries at least one tile in its Payload, if the Payload field is present.

8.2.2.2. Windows

Some SCHC F/R modes may handle successive tiles in groups, called windows.

If windows are used

- o all the windows of a SCHC Packet, except the last one, MUST contain the same number of tiles. This number is WINDOW_SIZE.
- o WINDOW_SIZE MUST be specified in a Profile.
- o the windows are numbered.
- o their numbers MUST increment by 1 from 0 upward, from the start of the SCHC Packet to its end.
- o the last window MUST contain WINDOW_SIZE tiles or less.
- o tiles are numbered within each window.
- o the tile indices MUST decrement by 1 from WINDOW_SIZE - 1 downward, looking from the start of the SCHC Packet toward its end.
- o each tile of a SCHC Packet is therefore uniquely identified by a window number and a tile index within this window.

See Figure 11 for an example.

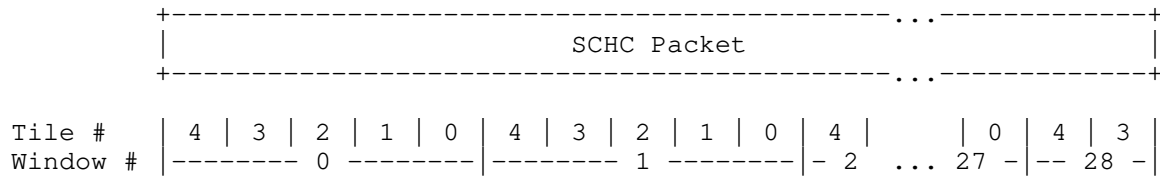


Figure 11: a SCHC Packet fragmented in tiles grouped in 29 windows, with WINDOW_SIZE = 5

Appendix E discusses the benefits of selecting one among multiple window sizes depending on the size of the SCHC Packet to be fragmented.

When windows are used

- o Bitmaps (see Section 8.2.2.3) MAY be sent back by the receiver to the sender in a SCHC ACK message.
- o A Bitmap corresponds to exactly one Window.

8.2.2.3. Bitmaps

Each bit in the Bitmap for a window corresponds to a tile in the window. Each Bitmap has therefore WINDOW_SIZE bits. The bit at the left-most position corresponds to the tile numbered WINDOW_SIZE - 1. Consecutive bits, going right, correspond to sequentially decreasing tile indices. In Bitmaps for windows that are not the last one of a SCHC Packet, the bit at the right-most position corresponds to the tile numbered 0. In the Bitmap for the last window, the bit at the right-most position corresponds either to the tile numbered 0 or to a tile that is sent/received as "the last one of the SCHC Packet" without explicitly stating its number (see Section 8.3.1.2).

At the receiver

- o a bit set to 1 in the Bitmap indicates that a tile associated with that bit position has been correctly received for that window.
- o a bit set to 0 in the Bitmap indicates that there has been no tile correctly received, associated with that bit position, for that window. Possible reasons include that the tile was not sent at all, not received, or received with errors.

8.2.2.4. Timers and counters

Some SCHC F/R modes can use the following timers and counters

- o Inactivity Timer: a SCHC Fragment receiver uses this timer to abort waiting for a SCHC F/R message.
- o Retransmission Timer: a SCHC Fragment sender uses this timer to abort waiting for an expected SCHC ACK.
- o Attempts: this counter counts the requests for SCHC ACKs, up to MAX_ACK_REQUESTS.

8.2.3. Integrity Checking

The integrity of the fragmentation-reassembly process of a SCHC Packet MUST be checked at the receive end. A Profile MUST specify how integrity checking is performed.

It is RECOMMENDED that integrity checking be performed by computing a Reassembly Check Sequence (RCS) based on the SCHC Packet at the sender side and transmitting it to the receiver for comparison with the RCS locally computed after reassembly.

The RCS supports UDP checksum elision by SCHC C/D (see Section 10.11).

The CRC32 polynomial 0xEDB88320 (i.e., the reversed polynomial representation, which is used in the Ethernet standard [ETHERNET]) is RECOMMENDED as the default algorithm for computing the RCS.

The RCS MUST be computed on the full SCHC Packet concatenated with the padding bits, if any, of the SCHC Fragment carrying the last tile. The rationale is that the SCHC reassembler has no way of knowing the boundary between the last tile and the padding bits. Indeed, this requires decompressing the SCHC Packet, which is out of the scope of the SCHC reassembler.

The concatenation of the complete SCHC Packet and any padding bits, if present, of the last SCHC Fragment does not generally constitute an integer number of bytes. CRC libraries are usually byte-oriented. It is RECOMMENDED that the concatenation of the complete SCHC Packet and any last fragment padding bits be zero-extended to the next byte boundary and that the RCS be computed on that byte array.

8.2.4. Header Fields

The SCHC F/R messages contain the following fields (see the formats in Section 8.3):

- o Rule ID: this field is present in all the SCHC F/R messages. The Rule identifies
 - * that a SCHC F/R message is being carried, as opposed to an unfragmented SCHC Packet,
 - * which SCHC F/R mode is used
 - * in case this mode uses windows, what the value of WINDOW_SIZE is,
 - * what other optional fields are present and what the field sizes are.

The Rule tells apart a non-fragmented SCHC Packet from SCHC Fragments. It will also tell apart SCHC Fragments of fragmented SCHC Packets that use different SCHC F/R modes or different parameters. Interleaved transmission of these is therefore possible.

All SCHC F/R messages pertaining to the same SCHC Packet MUST bear the same Rule ID.

- o Datagram Tag (DTag). This field allows differentiating SCHC F/R messages belonging to different SCHC Packets that may be using the same Rule ID simultaneously. Hence, it allows interleaving fragments of a new SCHC Packet with fragments of a previous SCHC Packet under the same Rule ID.

The size of the DTag field (called T, in bits) is defined by each Profile for each Rule ID. When T is 0, the DTag field does not appear in the SCHC F/R messages and the DTag value is defined as 0.

When T is 0, there can be no more than one fragmented SCHC Packet in transit for each fragmentation Rule ID.

If T is not 0, DTag

- * MUST be set to the same value for all the SCHC F/R messages related to the same fragmented SCHC Packet,
 - * MUST be set to different values for SCHC F/R messages related to different SCHC Packets that are being fragmented under the same Rule ID, and whose transmission may overlap.
- o W: The W field is optional. It is only present if windows are used. Its presence and size (called M, in bits) is defined by each SCHC F/R mode and each Profile for each Rule ID.

This field carries information pertaining to the window a SCHC F/R message relates to. If present, W MUST carry the same value for all the SCHC F/R messages related to the same window. Depending on the mode and Profile, W may carry the full window number, or just the least significant bit or any other partial representation of the window number.

- o Fragment Compressed Number (FCN). The FCN field is present in the SCHC Fragment Header. Its size (called N, in bits) is defined by each Profile for each Rule ID.

This field conveys information about the progress in the sequence of tiles being transmitted by SCHC Fragment messages. For example, it can contain a partial, efficient representation of a larger-sized tile index. The description of the exact use of the FCN field is left to each SCHC F/R mode. However, two values are reserved for special purposes. They help control the SCHC F/R process:

- * The FCN value with all the bits equal to 1 (called All-1) signals that the very last tile of a SCHC Packet has been

transmitted. By extension, if windows are used, the last window of a packet is called the All-1 window.

* If windows are used, the FCN value with all the bits equal to 0 (called All-0) signals the last tile of a window that is not the last one of the SCHC packet. By extension, such a window is called an All-0 window.

- o Reassembly Check Sequence (RCS). This field only appears in the All-1 SCHC Fragments. Its size (called U, in bits) is defined by each Profile for each Rule ID.

See Section 8.2.3 for the RCS default size, default polynomial and details on RCS computation.

- o C (integrity Check): C is a 1-bit field. This field is used in the SCHC ACK message to report on the reassembled SCHC Packet integrity check (see Section 8.2.3).

A value of 1 tells that the integrity check was performed and is successful. A value of 0 tells that the integrity check was not performed, or that it was a failure.

- o Compressed Bitmap. The Compressed Bitmap is used together with windows and Bitmaps (see Section 8.2.2.3). Its presence and size is defined for each F/R mode for each Rule ID.

This field appears in the SCHC ACK message to report on the receiver Bitmap (see Section 8.3.2.1).

8.3. SCHC F/R Message Formats

This section defines the SCHC Fragment formats, the SCHC ACK format, the SCHC ACK REQ format and the SCHC Abort formats.

8.3.1. SCHC Fragment format

A SCHC Fragment conforms to the general format shown in Figure 12. It comprises a SCHC Fragment Header and a SCHC Fragment Payload. The SCHC Fragment Payload carries one or several tile(s).

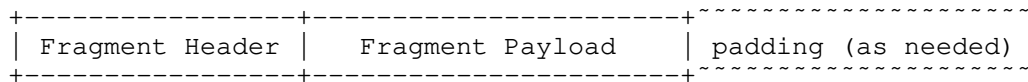


Figure 12: SCHC Fragment general format

8.3.1.1. Regular SCHC Fragment

The Regular SCHC Fragment format is shown in Figure 13. Regular SCHC Fragments are generally used to carry tiles that are not the last one of a SCHC Packet. The DTag field and the W field are OPTIONAL, their presence is specified by each mode and Profile.

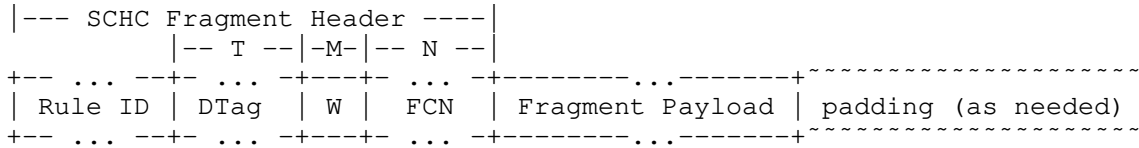


Figure 13: Detailed Header Format for Regular SCHC Fragments

The FCN field MUST NOT contain all bits set to 1.

Profiles MUST ensure that a SCHC Fragment with FCN equal to 0 (called an All-0 SCHC Fragment) is distinguishable by size, even in the presence of padding, from a SCHC ACK REQ message (see Section 8.3.3) with the same Rule ID value and with the same T, M and N values. This condition is met if the Payload is at least the size of an L2 Word. This condition is also met if the SCHC Fragment Header is a multiple of L2 Words.

8.3.1.2. All-1 SCHC Fragment

The All-1 SCHC Fragment format is shown in Figure 14. The sender uses the All-1 SCHC Fragment format for the message that completes the emission of a fragmented SCHC Packet. The DTag field, the W field, the RCS field and the Payload are OPTIONAL, their presence is specified by each mode and Profile. At least one of RCS field or Payload MUST be present. The FCN field is all ones.

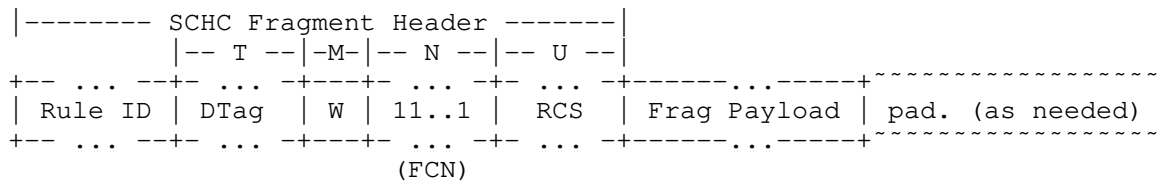


Figure 14: Detailed Header Format for the All-1 SCHC Fragment

Profiles MUST ensure that an All-1 SCHC Fragment message is distinguishable by size, even in the presence of padding, from a SCHC Sender-Abort message (see Section 8.3.4) with the same Rule ID value and with the same T, M and N values. This condition is met if the RCS is present and is at least the size of an L2 Word, or if the

- o While the scissors are not on an L2 Word boundary of the SCHC ACK message and there is a Bitmap bit on the right of the scissors, keep moving right, then stop.
- o At this point, cut and drop off any bits to the right of the scissors

When one or more bits have effectively been dropped off as a result of the above algorithm, the SCHC ACK message is a multiple of L2 Words, no padding bits will be appended.

Because the SCHC Fragment sender knows the size of the original Bitmap, it can reconstruct the original Bitmap from the Compressed Bitmap received in the SCH ACK message.

Figure 16 shows an example where L2 Words are actually bytes and where the original Bitmap contains 17 bits, the last 15 of which are all set to 1.

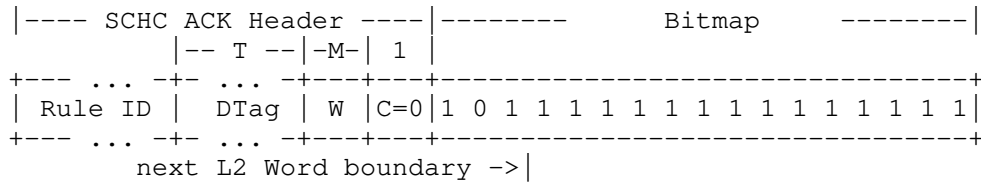


Figure 16: SCHC ACK Header plus uncompressed Bitmap

Figure 17 shows that the last 14 bits are not sent.

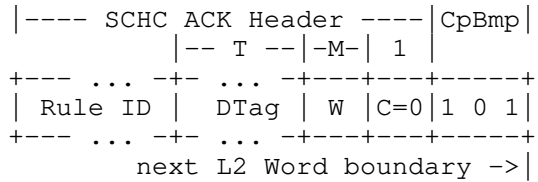


Figure 17: Resulting SCHC ACK message with Compressed Bitmap

Figure 18 shows an example of a SCHC ACK with tile indices ranging from 6 down to 0, where the Bitmap indicates that the second and the fourth tile of the window have not been correctly received.

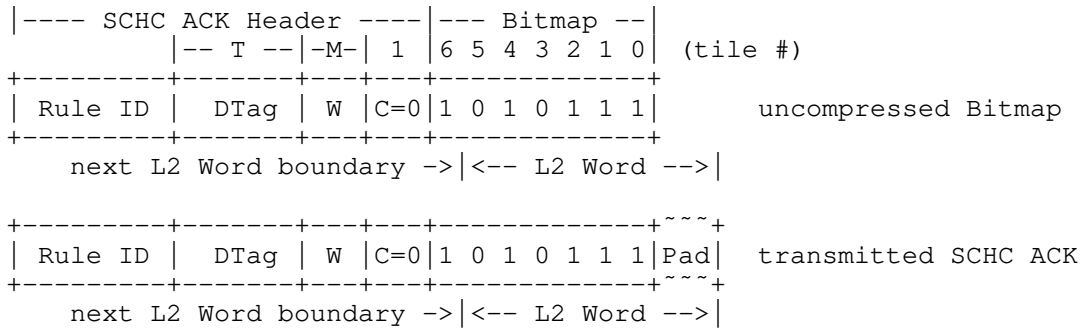


Figure 18: Example of a SCHC ACK message, missing tiles

Figure 19 shows an example of a SCHC ACK with FCN ranging from 6 down to 0, where integrity check has not been performed or has failed and the Bitmap indicates that there is no missing tile in that window.

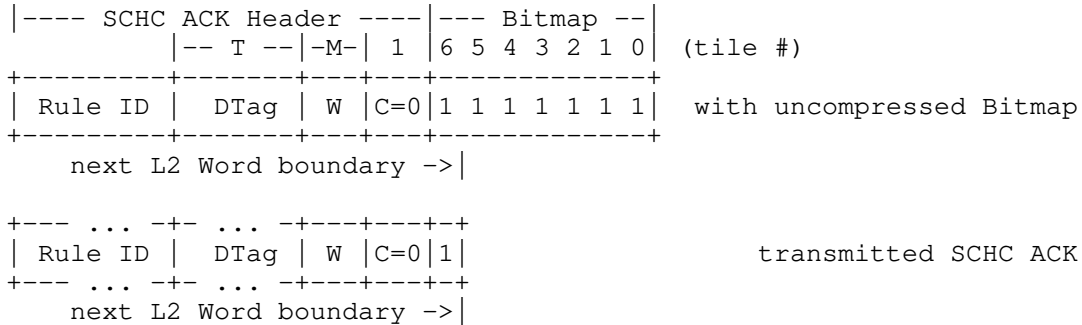


Figure 19: Example of a SCHC ACK message, no missing tile

8.3.3. SCHC ACK REQ format

The SCHC ACK REQ is used by a sender to request a SCHC ACK from the receiver. Its format is shown in Figure 20. The DTag field and the W field are OPTIONAL, their presence is specified by each mode and Profile. The FCN field is all zero.

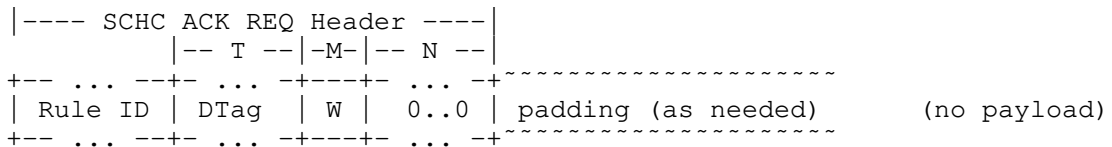


Figure 20: SCHC ACK REQ format

- o the fragment receiver MUST set it to all ones. Other values are RESERVED.
- o if the value is different from all ones, the fragment sender MUST ignore the message.

The SCHC Receiver-Abort has the same header as a SCHC ACK message. The bits that follow the SCHC Receiver-Abort Header MUST be as follows

- o if the Header does not end at an L2 Word boundary, append bits set to 1 as needed to reach the next L2 Word boundary
- o append exactly one more L2 Word with bits all set to ones

Such a bit pattern never occurs in a legitimate SCHC ACK. This is how the fragment sender recognizes a SCHC Receiver-Abort.

The SCHC Receiver-Abort MUST NOT be acknowledged.

8.4. SCHC F/R modes

This specification includes several SCHC F/R modes, which

- o allow for a range of reliability options, such as optional SCHC Fragment retransmission
- o support various LPWAN characteristics, such as links with variable MTU or unidirectional links.

More modes may be defined in the future.

Appendix B provides examples of fragmentation sessions based on the modes described hereafter.

Appendix C provides examples of Finite State Machines implementing the SCHC F/R modes described hereafter.

8.4.1. No-ACK mode

The No-ACK mode has been designed under the assumption that data unit out-of-sequence delivery does not occur between the entity performing fragmentation and the entity performing reassembly. This mode supports LPWAN technologies that have a variable MTU.

In No-ACK mode, there is no communication from the fragment receiver to the fragment sender. The sender transmits all the SCHC Fragments

without expecting any acknowledgement. Therefore, No-ACK does not require bidirectional links: unidirectional links are just fine.

In No-ACK mode, only the All-1 SCHC Fragment is padded as needed. The other SCHC Fragments are intrinsically aligned to L2 Words.

The tile sizes are not required to be uniform. Windows are not used. The Retransmission Timer is not used. The Attempts counter is not used.

Each Profile MUST specify which Rule ID value(s) correspond to SCHC F/R messages operating in this mode.

The W field MUST NOT be present in the SCHC F/R messages. SCHC ACK MUST NOT be sent. SCHC ACK REQ MUST NOT be sent. SCHC Sender-Abort MAY be sent. SCHC Receiver-Abort MUST NOT be sent.

The value of N (size of the FCN field) is RECOMMENDED to be 1.

Each Profile, for each Rule ID value, MUST define

- o the size of the DTag field,
- o the size and algorithm for the RCS field,
- o the expiration time of the Inactivity Timer

Each Profile, for each Rule ID value, MAY define

- o a value of N different from the recommended one,
- o the meaning of values sent in the FCN field, for values different from the All-1 value.

For each active pair of Rule ID and DTag values, the receiver MUST maintain an Inactivity Timer. If the receiver is under-resourced to do this, it MUST silently drop the related messages.

8.4.1.1. Sender behavior

At the beginning of the fragmentation of a new SCHC Packet, the fragment sender MUST select a Rule ID and DTag value pair for this SCHC Packet.

Each SCHC Fragment MUST contain exactly one tile in its Payload. The tile MUST be at least the size of an L2 Word. The sender MUST transmit the SCHC Fragments messages in the order that the tiles appear in the SCHC Packet. Except for the last tile of a SCHC

Packet, each tile MUST be of a size that complements the SCHC Fragment Header so that the SCHC Fragment is a multiple of L2 Words without the need for padding bits. Except for the last one, the SCHC Fragments MUST use the Regular SCHC Fragment format specified in Section 8.3.1.1. The SCHC Fragment that carries the last tile MUST be an All-1 SCHC Fragment, described in Section 8.3.1.2.

The sender MAY transmit a SCHC Sender-Abort.

Figure 37 shows an example of a corresponding state machine.

8.4.1.2. Receiver behavior

Upon receiving each Regular SCHC Fragment,

- o the receiver MUST reset the Inactivity Timer,
- o the receiver assembles the payloads of the SCHC Fragments

On receiving an All-1 SCHC Fragment,

- o the receiver MUST append the All-1 SCHC Fragment Payload and the padding bits to the previously received SCHC Fragment Payloads for this SCHC Packet
- o the receiver MUST perform the integrity check
- o if integrity checking fails, the receiver MUST drop the reassembled SCHC Packet
- o the reassembly operation concludes.

On expiration of the Inactivity Timer, the receiver MUST drop the SCHC Packet being reassembled.

On receiving a SCHC Sender-Abort, the receiver MAY drop the SCHC Packet being reassembled.

Figure 38 shows an example of a corresponding state machine.

8.4.2. ACK-Always mode

The ACK-Always mode has been designed under the following assumptions

- o Data unit out-of-sequence delivery does not occur between the entity performing fragmentation and the entity performing reassembly

- o The L2 MTU value does not change while the fragments of a SCHC Packet are being transmitted.
- o There is a feedback path from the reassembler to the fragmenter. See Appendix F for a discussion on using ACK-Always mode on quasi-bidirectional links.

In ACK-Always mode, windows are used. An acknowledgement, positive or negative, is transmitted by the fragment receiver to the fragment sender at the end of the transmission of each window of SCHC Fragments.

The tiles are not required to be of uniform size. In ACK-Always mode, only the All-1 SCHC Fragment is padded as needed. The other SCHC Fragments are intrinsically aligned to L2 Words.

Briefly, the algorithm is as follows: after a first blind transmission of all the tiles of a window, the fragment sender iterates retransmitting the tiles that are reported missing until the fragment receiver reports that all the tiles belonging to the window have been correctly received, or until too many attempts were made. The fragment sender only advances to the next window of tiles when it has ascertained that all the tiles belonging to the current window have been fully and correctly received. This results in a per-window lock-step behavior between the sender and the receiver.

Each Profile MUST specify which Rule ID value(s) correspond to SCHC F/R messages operating in this mode.

The W field MUST be present and its size M MUST be 1 bit.

Each Profile, for each Rule ID value, MUST define

- o the value of N (size of the FCN field),
- o the value of WINDOW_SIZE, which MUST be strictly less than 2^N ,
- o the size and algorithm for the RCS field,
- o the size of the DTag field,
- o the value of MAX_ACK_REQUESTS,
- o the expiration time of the Retransmission Timer
- o the expiration time of the Inactivity Timer

For each active pair of Rule ID and DTag values, the sender MUST maintain

- o one Attempts counter
- o one Retransmission Timer

For each active pair of Rule ID and DTag values, the receiver MUST maintain

- o one Inactivity Timer
- o one Attempts counter

8.4.2.1. Sender behavior

At the beginning of the fragmentation of a new SCHC Packet, the fragment sender MUST select a Rule ID and DTag value pair for this SCHC Packet.

Each SCHC Fragment MUST contain exactly one tile in its Payload. All tiles with the index 0, as well as the last tile, MUST be at least the size of an L2 Word.

In all SCHC Fragment messages, the W field MUST be filled with the least significant bit of the window number that the sender is currently processing.

For a SCHC Fragment that carries a tile other than the last one of the SCHC Packet,

- o the Fragment MUST be of the Regular type specified in Section 8.3.1.1
- o the FCN field MUST contain the tile index
- o each tile MUST be of a size that complements the SCHC Fragment Header so that the SCHC Fragment is a multiple of L2 Words without the need for padding bits.

The SCHC Fragment that carries the last tile MUST be an All-1 SCHC Fragment, described in Section 8.3.1.2.

The fragment sender MUST start by transmitting the window numbered 0.

All message receptions being discussed in the rest of this section are to be understood as "matching the RuleID and DTag pair being processed", even if not spelled out, for brevity.

The sender starts by a "blind transmission" phase, in which it MUST transmit all the tiles composing the window, in decreasing tile index order.

Then, it enters a "retransmission phase" in which it MUST initialize an Attempts counter to 0, it MUST start a Retransmission Timer and it MUST await a SCHC ACK. Then,

- o upon receiving a SCHC ACK,
 - * if the SCHC ACK indicates that some tiles are missing at the receiver, then the sender MUST transmit all the tiles that have been reported missing, it MUST increment Attempts, it MUST reset the Retransmission Timer and MUST await the next SCHC ACK.
 - * if the current window is not the last one and the SCHC ACK indicates that all tiles were correctly received, the sender MUST stop the Retransmission Timer, it MUST advance to the next fragmentation window and it MUST start a blind transmission phase as described above.
 - * if the current window is the last one and the SCHC ACK indicates that more tiles were received than the sender sent, the fragment sender MUST send a SCHC Sender-Abort, and it MAY exit with an error condition.
 - * if the current window is the last one and the SCHC ACK indicates that all tiles were correctly received yet integrity check was a failure, the fragment sender MUST send a SCHC Sender-Abort, and it MAY exit with an error condition.
 - * if the current window is the last one and the SCHC ACK indicates that integrity checking was successful, the sender exits successfully.
- o on Retransmission Timer expiration,
 - * if Attempts is strictly less than MAX_ACK_REQUESTS, the fragment sender MUST send a SCHC ACK REQ and MUST increment the Attempts counter.
 - * otherwise the fragment sender MUST send a SCHC Sender-Abort, and it MAY exit with an error condition.

At any time,

- o on receiving a SCHC Receiver-Abort, the fragment sender MAY exit with an error condition.
- o on receiving a SCHC ACK that bears a W value different from the W value that it currently uses, the fragment sender MUST silently discard and ignore that SCHC ACK.

Figure 39 shows an example of a corresponding state machine.

8.4.2.2. Receiver behavior

On receiving a SCHC Fragment with a Rule ID and DTag pair not being processed at that time

- o the receiver SHOULD check if the DTag value has not recently been used for that Rule ID value, thereby ensuring that the received SCHC Fragment is not a remnant of a prior fragmented SCHC Packet transmission. The initial value of the Inactivity Timer is the RECOMMENDED lifetime for the DTag value at the receiver. If the SCHC Fragment is determined to be such a remnant, the receiver MAY silently ignore it and discard it.
- o the receiver MUST start a process to assemble a new SCHC Packet with that Rule ID and DTag value pair.
- o the receiver MUST start an Inactivity Timer for that RuleID and DTag pair. It MUST initialize an Attempts counter to 0 for that RuleID and DTag pair. It MUST initialize a window counter to 0. If the receiver is under-resourced to do this, it MUST respond to the sender with a SCHC Receiver Abort.

In the rest of this section, "local W bit" means the least significant bit of the window counter of the receiver.

On reception of any SCHC F/R message for the RuleID and DTag pair being processed, the receiver MUST reset the Inactivity Timer pertaining to that RuleID and DTag pair.

All message receptions being discussed in the rest of this section are to be understood as "matching the RuleID and DTag pair being processed", even if not spelled out, for brevity.

The receiver MUST first initialize an empty Bitmap for the first window, then enter an "acceptance phase", in which

- o on receiving a SCHC Fragment or a SCHC ACK REQ, either one having the W bit different from the local W bit, the receiver MUST silently ignore and discard that message.

- o on receiving a SCHC ACK REQ with the W bit equal to the local W bit, the receiver MUST send a SCHC ACK for this window.
- o on receiving a SCHC Fragment with the W bit equal to the local W bit, the receiver MUST assemble the received tile based on the window counter and on the FCN field in the SCHC Fragment and it MUST update the Bitmap.
 - * if the SCHC Fragment received is an All-0 SCHC Fragment, the current window is determined to be a not-last window, the receiver MUST send a SCHC ACK for this window and it MUST enter the "retransmission phase" for this window.
 - * if the SCHC Fragment received is an All-1 SCHC Fragment, the padding bits of the All-1 SCHC Fragment MUST be assembled after the received tile, the current window is determined to be the last window, the receiver MUST perform the integrity check and it MUST send a SCHC ACK for this window. Then,
 - + If the integrity check indicates that the full SCHC Packet has been correctly reassembled, the receiver MUST enter the "clean-up phase" for this window.
 - + If the integrity check indicates that the full SCHC Packet has not been correctly reassembled, the receiver enters the "retransmission phase" for this window.

In the "retransmission phase":

- o if the window is a not-last window
 - * on receiving a SCHC Fragment that is not All-0 or All-1 and that has a W bit different from the local W bit, the receiver MUST increment its window counter and allocate a fresh Bitmap, it MUST assemble the tile received and update the Bitmap and it MUST enter the "acceptance phase" for that new window.
 - * on receiving a SCHC ACK REQ with a W bit different from the local W bit, the receiver MUST increment its window counter and allocate a fresh Bitmap, it MUST send a SCHC ACK for that new window and it MUST enter the "acceptance phase" for that new window.
 - * on receiving a SCHC All-0 Fragment with a W bit different from the local W bit, the receiver MUST increment its window counter and allocate a fresh Bitmap, it MUST assemble the tile received and update the Bitmap, it MUST send a SCHC ACK for that new

- window and it MUST stay in the "retransmission phase" for that new window.
- * on receiving a SCHC All-1 Fragment with a W bit different from the local W bit, the receiver MUST increment its window counter and allocate a fresh Bitmap, it MUST assemble the tile received, including the padding bits, it MUST update the Bitmap and perform the integrity check, it MUST send a SCHC ACK for the new window, which is determined to be the last window. Then,
 - + If the integrity check indicates that the full SCHC Packet has been correctly reassembled, the receiver MUST enter the "clean-up phase" for that new window.
 - + If the integrity check indicates that the full SCHC Packet has not been correctly reassembled, the receiver enters the "retransmission phase" for that new window.
 - * on receiving a SCHC Fragment with a W bit equal to the local W bit,
 - + if the SCHC Fragment received is an All-1 SCHC Fragment, the receiver MUST silently ignore it and discard it.
 - + otherwise, the receiver MUST assemble the tile received and update the Bitmap. If the Bitmap becomes fully populated with 1's or if the SCHC Fragment is an All-0, the receiver MUST send a SCHC ACK for this window.
 - * on receiving a SCHC ACK REQ with the W bit equal to the local W bit, the receiver MUST send a SCHC ACK for this window.
 - o if the window is the last window
 - * on receiving a SCHC Fragment or a SCHC ACK REQ, either one having a W bit different from the local W bit, the receiver MUST silently ignore and discard that message.
 - * on receiving a SCHC ACK REQ with the W bit equal to the local W bit, the receiver MUST send a SCHC ACK for this window.
 - * on receiving a SCHC Fragment with a W bit equal to the local W bit,
 - + if the SCHC Fragment received is an All-0 SCHC Fragment, the receiver MUST silently ignore it and discard it.

- + otherwise, the receiver MUST update the Bitmap and it MUST assemble the tile received. If the SCHC Fragment received is an All-1 SCHC Fragment, the receiver MUST assemble the padding bits of the All-1 SCHC Fragment after the received tile, it MUST perform the integrity check and
 - if the integrity check indicates that the full SCHC Packet has been correctly reassembled, the receiver MUST send a SCHC ACK and it enters the "clean-up phase".
 - if the integrity check indicates that the full SCHC Packet has not been correctly reassembled,
 - o if the SCHC Fragment received was an All-1 SCHC Fragment, the receiver MUST send a SCHC ACK for this window.

In the "clean-up phase":

- o On receiving an All-1 SCHC Fragment or a SCHC ACK REQ, either one having the W bit equal to the local W bit, the receiver MUST send a SCHC ACK.
- o Any other SCHC Fragment received MUST be silently ignored and discarded.

At any time, on sending a SCHC ACK, the receiver MUST increment the Attempts counter.

At any time, on incrementing its window counter, the receiver MUST reset the Attempts counter.

At any time, on expiration of the Inactivity Timer, on receiving a SCHC Sender-Abort or when Attempts reaches MAX_ACK_REQUESTS, the receiver MUST send a SCHC Receiver-Abort and it MAY exit the receive process for that SCHC Packet.

Figure 40 shows an example of a corresponding state machine.

8.4.3. ACK-on-Error mode

The ACK-on-Error mode supports LPWAN technologies that have variable MTU and out-of-order delivery. It operates with links that provide a feedback path from the reassembler to the fragmenter. See Appendix F for a discussion on using ACK-on-Error mode on quasi-bidirectional links.

In ACK-on-Error mode, windows are used.

All tiles, but the last one and the penultimate one, MUST be of equal size, hereafter called "regular". The size of the last tile MUST be smaller than or equal to the regular tile size. Regarding the penultimate tile, a Profile MUST pick one of the following two options:

- o The penultimate tile size MUST be the regular tile size
- o or the penultimate tile size MUST be either the regular tile size or the regular tile size minus one L2 Word.

A SCHC Fragment message carries one or several contiguous tiles, which may span multiple windows. A SCHC ACK reports on the reception of exactly one window of tiles.

See Figure 23 for an example.

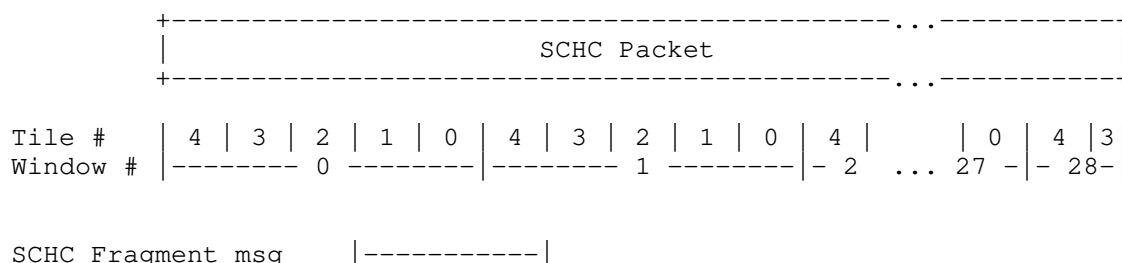


Figure 23: a SCHC Packet fragmented in tiles, ACK-on-Error mode

The W field is wide enough that it unambiguously represents an absolute window number. The fragment receiver sends SCHC ACKs to the fragment sender about windows for which tiles are missing. No SCHC ACK is sent by the fragment receiver for windows that it knows have been fully received.

The fragment sender retransmits SCHC Fragments for tiles that are reported missing. It can advance to next windows even before it has ascertained that all tiles belonging to previous windows have been correctly received, and can still later retransmit SCHC Fragments with tiles belonging to previous windows. Therefore, the sender and the receiver may operate in a decoupled fashion. The fragmented SCHC Packet transmission concludes when

- o integrity checking shows that the fragmented SCHC Packet has been correctly reassembled at the receive end, and this information has been conveyed back to the sender,
- o or too many retransmission attempts were made,

- o or the receiver determines that the transmission of this fragmented SCHC Packet has been inactive for too long.

Each Profile MUST specify which Rule ID value(s) correspond to SCHC F/R messages operating in this mode.

The W field MUST be present in the SCHC F/R messages.

Each Profile, for each Rule ID value, MUST define

- o the tile size (a tile does not need to be multiple of an L2 Word, but it MUST be at least the size of an L2 Word)
- o the value of M (size of the W field),
- o the value of N (size of the FCN field),
- o the value of WINDOW_SIZE, which MUST be strictly less than 2^N ,
- o the size and algorithm for the RCS field,
- o the size of the DTag field,
- o the value of MAX_ACK_REQUESTS,
- o the expiration time of the Retransmission Timer
- o the expiration time of the Inactivity Timer
- o whether the last tile is carried in a Regular SCHC Fragment or an All-1 SCHC Fragment (see Section 8.4.3.1)
- o if the penultimate tile MAY be one L2 Word smaller than the regular tile size. In this case, the regular tile size MUST be at least twice the L2 Word size.

For each active pair of Rule ID and DTag values, the sender MUST maintain

- o one Attempts counter
- o one Retransmission Timer

For each active pair of Rule ID and DTag values, the receiver MUST maintain

- o one Inactivity Timer

- o one Attempts counter

8.4.3.1. Sender behavior

At the beginning of the fragmentation of a new SCHC Packet,

- o the fragment sender MUST select a Rule ID and DTag value pair for this SCHC Packet. A Rule MUST NOT be selected if the values of M and WINDOW_SIZE for that Rule are such that the SCHC Packet cannot be fragmented in $(2^M) * WINDOW_SIZE$ tiles or less.
- o the fragment sender MUST initialize the Attempts counter to 0 for that Rule ID and DTag value pair.

A Regular SCHC Fragment message carries in its payload one or more tiles. If more than one tile is carried in one Regular SCHC Fragment

- o the selected tiles MUST be contiguous in the original SCHC Packet
- o they MUST be placed in the SCHC Fragment Payload adjacent to one another, in the order they appear in the SCHC Packet, from the start of the SCHC Packet toward its end.

Tiles that are not the last one MUST be sent in Regular SCHC Fragments specified in Section 8.3.1.1. The FCN field MUST contain the tile index of the first tile sent in that SCHC Fragment.

In a Regular SCHC Fragment message, the sender MUST fill the W field with the window number of the first tile sent in that SCHC Fragment.

Depending on the Profile, the last tile of a SCHC Packet MUST be sent either

- o in a Regular SCHC Fragment, alone or as part of a multi-tiles Payload
- o alone in an All-1 SCHC Fragment

In an All-1 SCHC Fragment message, the sender MUST fill the W field with the window number of the last tile of the SCHC Packet.

The fragment sender MUST send SCHC Fragments such that, all together, they contain all the tiles of the fragmented SCHC Packet.

The fragment sender MUST send at least one All-1 SCHC Fragment.

The fragment sender MUST listen for SCHC ACK messages after having sent

- o an All-1 SCHC Fragment
- o or a SCHC ACK REQ.

A Profile MAY specify other times at which the fragment sender MUST listen for SCHC ACK messages. For example, this could be after sending a complete window of tiles.

Each time a fragment sender sends an All-1 SCHC Fragment or a SCHC ACK REQ,

- o it MUST increment the Attempts counter
- o it MUST reset the Retransmission Timer

On Retransmission Timer expiration

- o if Attempts is strictly less than MAX_ACK_REQUESTS, the fragment sender MUST send either the All-1 SCHC Fragment or a SCHC ACK REQ with the W field corresponding to the last window,
- o otherwise the fragment sender MUST send a SCHC Sender-Abort and it MAY exit with an error condition.

All message receptions being discussed in the rest of this section are to be understood as "matching the RuleID and DTag pair being processed", even if not spelled out, for brevity.

On receiving a SCHC ACK,

- o if the W field in the SCHC ACK corresponds to the last window of the SCHC Packet,
 - * if the C bit is set, the sender MAY exit successfully
 - * otherwise,
 - + if the Profile mandates that the last tile be sent in an All-1 SCHC Fragment,
 - if the SCHC ACK shows no missing tile at the receiver, the sender
 - o MUST send a SCHC Sender-Abort
 - o MAY exit with an error condition
 - otherwise

- o the fragment sender MUST send SCHC Fragment messages containing all the tiles that are reported missing in the SCHC ACK.
 - o if the last of these SCHC Fragment messages is not an All-1 SCHC Fragment, then the fragment sender MUST in addition send after it a SCHC ACK REQ with the W field corresponding to the last window.
- + otherwise,
- if the SCHC ACK shows no missing tile at the receiver, the sender MUST send the All-1 SCHC Fragment
 - otherwise
 - o the fragment sender MUST send SCHC Fragment messages containing all the tiles that are reported missing in the SCHC ACK.
 - o the fragment sender MUST then send either the All-1 SCHC Fragment or a SCHC ACK REQ with the W field corresponding to the last window.
- o otherwise, the fragment sender
- * MUST send SCHC Fragment messages containing the tiles that are reported missing in the SCHC ACK
 - * then it MAY send a SCHC ACK REQ with the W field corresponding to the last window

See Figure 41 for one among several possible examples of a Finite State Machine implementing a sender behavior obeying this specification.

8.4.3.2. Receiver behavior

On receiving a SCHC Fragment with a Rule ID and DTag pair not being processed at that time

- o the receiver SHOULD check if the DTag value has not recently been used for that Rule ID value, thereby ensuring that the received SCHC Fragment is not a remnant of a prior fragmented SCHC Packet transmission. The initial value of the Inactivity Timer is the RECOMMENDED lifetime for the DTag value at the receiver. If the SCHC Fragment is determined to be such a remnant, the receiver MAY silently ignore it and discard it.

- o the receiver MUST start a process to assemble a new SCHC Packet with that Rule ID and DTag value pair. The receiver MUST start an Inactivity Timer for that Rule ID and DTag value pair. It MUST initialize an Attempts counter to 0 for that Rule ID and DTag value pair. If the receiver is under-resourced to do this, it MUST respond to the sender with a SCHC Receiver Abort.

On reception of any SCHC F/R message for the RuleID and DTag pair being processed, the receiver MUST reset the Inactivity Timer pertaining to that RuleID and DTag pair.

All message receptions being discussed in the rest of this section are to be understood as "matching the RuleID and DTag pair being processed", even if not spelled out, for brevity.

On receiving a SCHC Fragment message, the receiver determines what tiles were received, based on the payload length and on the W and FCN fields of the SCHC Fragment.

- o if the FCN is All-1, if a Payload is present, the full SCHC Fragment Payload MUST be assembled including the padding bits. This is because the size of the last tile is not known by the receiver, therefore padding bits are indistinguishable from the tile data bits, at this stage. They will be removed by the SCHC C/D sublayer. If the size of the SCHC Fragment Payload exceeds or equals the size of one regular tile plus the size of an L2 Word, this SHOULD raise an error flag.
- o otherwise, tiles MUST be assembled based on the a priori known tile size.
 - * If allowed by the Profile, the end of the payload MAY contain the last tile, which may be shorter. Padding bits are indistinguishable from the tile data bits, at this stage.
 - * the payload may contain the penultimate tile that, if allowed by the Profile, MAY be exactly one L2 Word shorter than the regular tile size.
 - * Otherwise, padding bits MUST be discarded. The latter is possible because
 - + the size of the tiles is known a priori,
 - + tiles are larger than an L2 Word
 - + padding bits are always strictly less than an L2 Word

On receiving a SCHC ACK REQ or an All-1 SCHC Fragment,

- o if the receiver knows of any windows with missing tiles for the packet being reassembled, it MUST return a SCHC ACK for the lowest-numbered such window,
- o otherwise,
 - * if it has received at least one tile, it MUST return a SCHC ACK for the highest-numbered window it currently has tiles for
 - * otherwise it MUST return a SCHC ACK for window numbered 0

A Profile MAY specify other times and circumstances at which a receiver sends a SCHC ACK, and which window the SCHC ACK reports about in these circumstances.

Upon sending a SCHC ACK, the receiver MUST increase the Attempts counter.

After receiving an All-1 SCHC Fragment, a receiver MUST check the integrity of the reassembled SCHC Packet at least every time it prepares for sending a SCHC ACK for the last window.

Upon receiving a SCHC Sender-Abort, the receiver MAY exit with an error condition.

Upon expiration of the Inactivity Timer, the receiver MUST send a SCHC Receiver-Abort and it MAY exit with an error condition.

On the Attempts counter exceeding MAX_ACK_REQUESTS, the receiver MUST send a SCHC Receiver-Abort and it MAY exit with an error condition.

Reassembly of the SCHC Packet concludes when

- o a Sender-Abort has been received
- o or the Inactivity Timer has expired
- o or the Attempts counter has exceeded MAX_ACK_REQUESTS
- o or when at least an All-1 SCHC Fragment has been received and integrity checking of the reassembled SCHC Packet is successful.

See Figure 42 for one among several possible examples of a Finite State Machine implementing a receiver behavior obeying this specification, and that is meant to match the sender Finite State Machine of Figure 41.

9. Padding management

SCHC C/D and SCHC F/R operate on bits, not bytes. SCHC itself does not have any alignment prerequisite. The size of SCHC Packets can be any number of bits.

If the layer below SCHC constrains the payload to align to some boundary, called L2 Words (for example, bytes), the SCHC messages MUST be padded. When padding occurs, the number of appended bits MUST be strictly less than the L2 Word size.

If a SCHC Packet is sent unfragmented (see Figure 24), it is padded as needed for transmission.

If a SCHC Packet needs to be fragmented for transmission, it is not padded in itself. Only the SCHC F/R messages are padded as needed for transmission. Some SCHC F/R messages are intrinsically aligned to L2 Words.

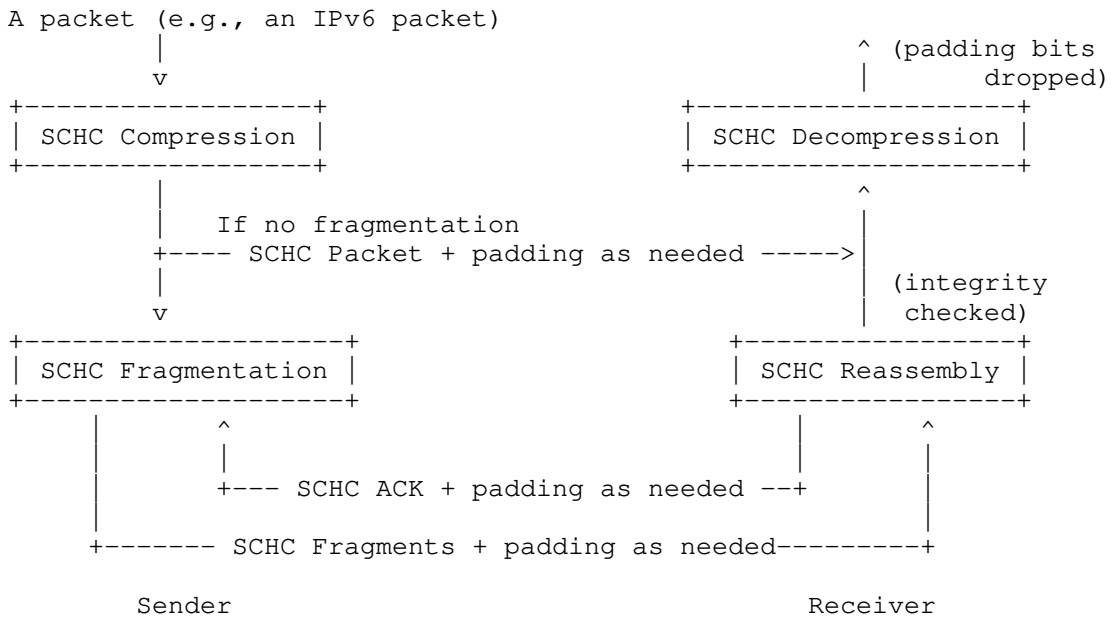


Figure 24: SCHC operations, including padding as needed

Each Profile MUST specify the size of the L2 Word. The L2 Word might actually be a single bit, in which case no padding will take place at all.

A Profile MAY define the value of the padding bits. The RECOMMENDED value is 0.

10. SCHC Compression for IPv6 and UDP headers

This section lists the IPv6 and UDP header fields and describes how they can be compressed. An example of a set of Rules for UDP/IPv6 header compression is provided in Appendix A.

10.1. IPv6 version field

The IPv6 version field is labeled by the protocol parser as being the "version" field of the IPv6 protocol. Therefore, it only exists for IPv6 packets. In the Rule, TV is set to 6, MO to "ignore" and CDA to "not-sent".

10.2. IPv6 Traffic class field

If the DiffServ field does not vary and is known by both sides, the Field Descriptor in the Rule SHOULD contain a TV with this well-known value, an "equal" MO and a "not-sent" CDA.

Otherwise (e.g., ECN bits are to be transmitted), two possibilities can be considered depending on the variability of the value:

- o One possibility is to not compress the field and send the original value. In the Rule, TV is not set to any particular value, MO is set to "ignore" and CDA is set to "value-sent".
- o If some upper bits in the field are constant and known, a better option is to only send the LSBs. In the Rule, TV is set to a value with the stable known upper part, MO is set to MSB(x) and CDA to LSB.

ECN functionality depends on both bits of the ECN field, which are the 2 LSBs of this field, hence sending only a single LSB of this field is NOT RECOMMENDED.

10.3. Flow label field

If the flow label is not set, i.e. its value is zero, the Field Descriptor in the Rule SHOULD contain a TV set to zero, an "equal" MO and a "not-sent" CDA.

If the flow label is set to a pseudo-random value according to [RFC6437], in the Rule, TV is not set to any particular value, MO is set to "ignore" and CDA is set to "value-sent".

If the flow label is set according to some prior agreement, i.e. by a flow state establishment method as allowed by [RFC6437], the Field Descriptor in the Rule SHOULD contain a TV with this agreed-upon value, an "equal" MO and a "not-sent" CDA.

10.4. Payload Length field

This field can be elided for the transmission on the LPWAN network. The SCHC C/D recomputes the original payload length value. In the Field Descriptor, TV is not set, MO is set to "ignore" and CDA is "compute-*".

10.5. Next Header field

If the Next Header field does not vary and is known by both sides, the Field Descriptor in the Rule SHOULD contain a TV with this Next Header value, the MO SHOULD be "equal" and the CDA SHOULD be "not-sent".

Otherwise, TV is not set in the Field Descriptor, MO is set to "ignore" and CDA is set to "value-sent". Alternatively, a matching-list MAY also be used.

10.6. Hop Limit field

The field behavior for this field is different for uplink (Up) and downlink (Dw). In Up, since there is no IP forwarding between the Dev and the SCHC C/D, the value is relatively constant. On the other hand, the Dw value depends on Internet routing and can change more frequently. The Direction Indicator (DI) can be used to distinguish both directions:

- o in the Up, elide the field: the TV in the Field Descriptor is set to the known constant value, the MO is set to "equal" and the CDA is set to "not-sent".
- o in the Dw, the Hop Limit is elided for transmission and forced to 1 at the receiver, by setting TV to 1, MO to "ignore" and CDA to "not-sent". This prevents any further forwarding.

10.7. IPv6 addresses fields

As in 6LoWPAN [RFC4944], IPv6 addresses are split into two 64-bit long fields; one for the prefix and one for the Interface Identifier (IID). These fields SHOULD be compressed. To allow for a single Rule being used for both directions, these values are identified by their role (Dev or App) and not by their position in the header (source or destination).

10.7.1. IPv6 source and destination prefixes

Both ends MUST be configured with the appropriate prefixes. For a specific flow, the source and destination prefixes can be unique and stored in the Context. In that case, the TV for the source and destination prefixes contain the values, the MO is set to "equal" and the CDA is set to "not-sent".

If the Rule is intended to compress packets with different prefix values, match-mapping SHOULD be used. The different prefixes are listed in the TV, the MO is set to "match-mapping" and the CDA is set to "mapping-sent". See Figure 26.

Otherwise, the TV is not set, the MO is set to "ignore" and the CDA is set to "value-sent".

10.7.2. IPv6 source and destination IID

If the Dev or App IID are based on an LPWAN address, then the IID can be reconstructed with information coming from the LPWAN header. In that case, the TV is not set, the MO is set to "ignore" and the CDA is set to "DevIID" or "AppIID". On LPWAN technologies where the frames carry a single identifier (corresponding to the Dev.), AppIID cannot be used.

As described in [RFC8065], it may be undesirable to build the Dev IPv6 IID out of the Dev address. Another static value is used instead. In that case, the TV contains the static value, the MO operator is set to "equal" and the CDA is set to "not-sent".

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".

It may also happen that the IID variability only expresses itself on a few bytes. In that case, the TV is set to the stable part of the IID, the MO is set to "MSB" and the CDA is set to "LSB".

Finally, the IID can be sent in its entirety on the LPWAN. In that case, the TV is not set, the MO is set to "ignore" and the CDA is set to "value-sent".

10.8. IPv6 extension headers

This document does not provide recommendations on how to compress IPv6 extension headers.

10.9. UDP source and destination ports

To allow for a single Rule being used for both directions, the UDP port values are identified by their role (Dev or App) and not by their position in the header (source or destination). The SCHC C/D MUST be aware of the traffic direction (Uplink, Downlink) to select the appropriate field. The following Rules apply for Dev and App port numbers.

If both ends know the port number, it can be elided. The TV contains the port number, the MO is set to "equal" and the CDA is set to "not-sent".

If the port variation is on few bits, the TV contains the stable part of the port number, the MO is set to "MSB" and the CDA is set to "LSB".

If some well-known values are used, the TV can contain the list of these values, the MO is set to "match-mapping" and the CDA is set to "mapping-sent".

Otherwise the port numbers are sent over the LPWAN. The TV is not set, the MO is set to "ignore" and the CDA is set to "value-sent".

10.10. UDP length field

The UDP length can be computed from the received data. The TV is not set, the MO is set to "ignore" and the CDA is set to "compute-*".

10.11. UDP Checksum field

The UDP checksum operation is mandatory with IPv6 for most packets but there are exceptions [RFC8200].

For instance, protocols that use UDP as a tunnel encapsulation may enable zero-checksum mode for a specific port (or set of ports) for sending and/or receiving. [RFC8200] requires any node implementing zero-checksum mode to follow the requirements specified in "Applicability Statement for the Use of IPv6 UDP Datagrams with Zero Checksums" [RFC6936].

6LoWPAN Header Compression [RFC6282] also specifies that a UDP checksum can be elided by the compressor and re-computed by the decompressor when an upper layer guarantees the integrity of the UDP payload and pseudo-header. A specific example of this is when a message integrity check protects the compressed message between the compressor that elides the UDP checksum and the decompressor that

computes it, with a strength that is identical or better to the UDP checksum.

Similarly, 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. In this case, the TV is not set, the MO is set to "ignore" and the CDA is set to "compute-*".

In particular, when SCHC fragmentation is used, a fragmentation RCS of 2 bytes or more provides equal or better protection than the UDP checksum; in that case, if the compressor is collocated with the fragmentation point and the decompressor is collocated with the packet reassembly point, and if the SCHC Packet is fragmented even when it would fit unfragmented in the L2 MTU, then the compressor MAY verify and then elide the UDP checksum. Whether and when the UDP Checksum is elided is to be specified in the Profile.

Since the compression happens before the fragmentation, implementers should understand the risks when dealing with unprotected data below the transport layer and take special care when manipulating that data.

In other cases, the checksum SHOULD be explicitly sent. The TV is not set, the MO is set to "ignore" and the CDA is set to "value-sent".

11. IANA Considerations

This document has no request to IANA.

12. Security considerations

As explained in Section 5, SCHC is expected to be implemented on top of LPWAN technologies, which are expected to implement security measures.

In this section, we analyze the potential security threats that could be introduced into an LPWAN by adding the SCHC functionalities.

12.1. Security considerations for SCHC Compression/Decompression

12.1.1. Forged SCHC Packet

Let's assume that an attacker is able to send a forged SCHC Packet to a SCHC Decompressor.

Let's first consider the case where the Rule ID contained in that forged SCHC Packet does not correspond to a Rule allocated in the

Rule table. An implementation should detect that the Rule ID is invalid and should silently drop the offending SCHC Packet.

Let's now consider that the Rule ID corresponds to a Rule in the table. With the CDAs defined in this document, the reconstructed packet is at most a constant number of bits bigger than the SCHC Packet that was received. This assumes that the compute-* decompression actions produce a bounded number of bits, irrespective of the incoming SCHC Packet. This property is true for IPv6 Length, UDP Length and UDP Checksum, for which the compute-* CDA is recommended by this document.

As a consequence, SCHC Decompression does not amplify attacks, beyond adding a bounded number of bits to the SCHC Packet received. This bound is determined by the Rule stored in the receiving device.

As a general safety measure, a SCHC Decompressor should never reconstruct a packet larger than MAX_PACKET_SIZE (defined in a Profile, with 1500 bytes as generic default).

12.1.2. Compressed packet size as a side channel to guess a secret token

Some packet compression methods are known to be susceptible to attacks, such as BREACH and CRIME. The attack involves injecting arbitrary data into the packet and observing the resulting compressed packet size. The observed size potentially reflects correlation between the arbitrary data and some content that was meant to remain secret, such as a security token, thereby allowing the attacker to get at the secret.

By contrast, SCHC Compression takes place header field by header field, with the SCHC Packet being a mere concatenation of the compression residues of each of the individual field. Any correlation between header fields does not result in a change in the SCHC Packet size compressed under the same Rule.

If SCHC C/D is used to compress packets that include a secret information field, such as a token, the Rule set should be designed so that the size of the compression residue for the field to remain secret is the same irrespective of the value of the secret information. This is achieved by e.g., sending this field in extenso with the "ignore" MO and the "value-sent" CDA. This recommendation is disputable if it is ascertained that the Rule set itself will remain secret.

12.1.3. Decompressed packet different from the original packet

As explained in Section 7.3, using FPs with value 0 in Field Descriptors in a Rule may result in header fields appearing in the decompressed packet in an order different from that in the original packet. Likewise, as stated in Section 7.5.3, using an "ignore" MO together with a "not-sent" CDA will result in the header field taking the TV value, which is likely to be different from the original value.

Depending on the protocol, the order of header fields in the packet may be functionally significant or not.

Furthermore, if the packet is protected by a checksum or a similar integrity protection mechanism, and if the checksum is transmitted instead of being recomputed as part of the decompression, these situations may result in the packet being considered corrupt and dropped.

12.2. Security considerations for SCHC Fragmentation/Reassembly

12.2.1. Buffer reservation attack

Let's assume that an attacker is able to send a forged SCHC Fragment to a SCHC Reassembler.

A node can perform a buffer reservation attack: the receiver will reserve buffer space for the SCHC Packet. If the implementation has only one buffer, other incoming fragmented SCHC Packets will be dropped while the reassembly buffer is occupied during the reassembly timeout. Once that timeout expires, the attacker can repeat the same procedure, and iterate, thus creating a denial of service attack. An implementation may have multiple reassembly buffers. The cost to mount this attack is linear with the number of buffers at the target node. Better, the cost for an attacker can be increased if individual fragments of multiple SCHC Packets can be stored in the reassembly buffer. The finer grained the reassembly buffer (down to the smallest tile size), the higher the cost of the attack. If buffer overload does occur, a smart receiver could selectively discard SCHC Packets being reassembled based on the sender behavior, which may help identify which SCHC Fragments have been sent by the attacker. Another mild counter-measure is for the target to abort the fragmentation/reassembly session as early as it detects a non-identical SCHC Fragment duplicate, anticipating for an eventual corrupt SCHC Packet, so as to save the sender the hassle of sending the rest of the fragments for this SCHC Packet.

12.2.2. Corrupt Fragment attack

Let's assume that an attacker is able to send a forged SCHC Fragment to a SCHC Reassembler. The malicious node is additionally assumed to be able to hear an incoming communication destined to the target node.

It can then send a forged SCHC Fragment that looks like it belongs to a SCHC Packet already being reassembled at the target node. This can cause the SCHC Packet to be considered corrupt and be dropped by the receiver. The amplification happens here by a single spoofed SCHC Fragment rendering a full sequence of legit SCHC Fragments useless. If the target uses ACK-Always or ACK-on-Error mode, such a malicious node can also interfere with the acknowledgement and repetition algorithm of SCHC F/R. A single spoofed ACK, with all bitmap bits set to 0, will trigger the repetition of WINDOW_SIZE tiles. This protocol loop amplification depletes the energy source of the target node and consumes the channel bandwidth. Similarly, a spoofed ACK REQ will trigger the sending of a SCHC ACK, which may be much larger than the ACK REQ if WINDOW_SIZE is large. These consequences should be borne in mind when defining profiles for SCHC over specific LPWAN technologies.

12.2.3. Fragmentation as a way to bypass Network Inspection

Fragmentation is known for potentially allowing to force through a Network Inspection device (e.g., firewall) packets that would be rejected if unfragmented. This involves sending overlapping fragments to rewrite fields whose initial value led the Network Inspection device to allow the flow go through.

SCHC F/R is expected to be used over one LPWAN link, where no Network Inspection device is expected to sit. As described in Section 5.2, even if the SCHC F/R on the Network infrastructure side is located in the Internet, a tunnel is to be established between it and the NGW.

12.2.4. Privacy issues associated with SCHC header fields

SCHC F/R allocates a DTag value to fragments belonging to the same SCHC Packet. Concerns were raised that, if DTag is a wide counter that is incremented in a predictable fashion for each new fragmented SCHC Packet, it might lead to a privacy issue, such as enabling tracking of a device across LPWANs.

However, SCHC F/R is expected to be used over exactly one LPWAN link. As described in Section 5.2, even if the SCHC F/R on the Network infrastructure side is located in the Internet, a tunnel is to be established between it and the NGW. Therefore, assuming the tunnel

provides confidentiality, neither the DTag field nor any other SCHC-introduced field is visible over the Internet.

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Appendix A. Compression Examples

This section gives some scenarios of the compression mechanism for IPv6/UDP. The goal is to illustrate the behavior of SCHC.

The mechanisms defined in this document can be applied to a Dev that embeds some applications running over CoAP. In this example, three flows are considered. The first flow is for the device management based on CoAP using Link Local IPv6 addresses and UDP ports 123 and 124 for Dev and App, respectively. The second flow will be a CoAP

server for measurements done by the Dev (using ports 5683) and Global IPv6 Address prefixes alpha::IID/64 to beta::1/64. The last flow is for legacy applications using different ports numbers, the destination IPv6 address prefix is gamma::1/64.

Figure 25 presents the protocol stack. IPv6 and UDP are represented with dotted lines since these protocols are compressed on the radio link.

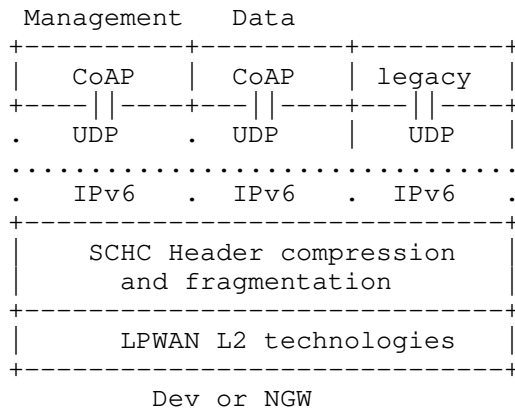


Figure 25: Simplified Protocol Stack for LP-WAN

In some LPWAN technologies, only the Devs have a device ID. When such technologies are used, it is necessary to statically define an IID for the Link Local address for the SCHC C/D.

Rule 0

Special Rule ID used to tag an uncompressed UDP/IPV6 packet.

Rule 1

Field	FL	FP	DI	Value	Match Opera.	Comp Decomp Action	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	255	ignore	not-sent	
IPv6 DevPrefix	64	1	Bi	FE80::/64	equal	not-sent	
IPv6 DevIID	64	1	Bi		ignore	DevIID	
IPv6 AppPrefix	64	1	Bi	FE80::/64	equal	not-sent	

IPv6 AppIID	64	1	Bi	::1	equal	not-sent		
UDP DevPort	16	1	Bi	123	equal	not-sent		
UDP AppPort	16	1	Bi	124	equal	not-sent		
UDP Length	16	1	Bi		ignore	compute-*		
UDP checksum	16	1	Bi		ignore	compute-*		

Rule 2

Field	FL	FP	DI	Value	Match Opera.	Action Action	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	255	ignore	not-sent	
IPv6 DevPrefix	64	1	Bi	[alpha/64, fe80::<64]	match- mapping	mapping-sent	1
IPv6 DevIID	64	1	Bi		ignore	DevIID	
IPv6 AppPrefix	64	1	Bi	[beta/64, alpha/64, fe80::<64]	match- mapping	mapping-sent	2
IPv6 AppIID	64	1	Bi	::1000	equal	not-sent	
UDP DevPort	16	1	Bi	5683	equal	not-sent	
UDP AppPort	16	1	Bi	5683	equal	not-sent	
UDP Length	16	1	Bi		ignore	compute-*	
UDP checksum	16	1	Bi		ignore	compute-*	

Rule 3

Field	FL	FP	DI	Value	Match Opera.	Action Action	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	Up	255	ignore	not-sent	
IPv6 Hop Limit	8	1	Dw		ignore	value-sent	8
IPv6 DevPrefix	64	1	Bi	alpha/64	equal	not-sent	
IPv6 DevIID	64	1	Bi		ignore	DevIID	
IPv6 AppPrefix	64	1	Bi	gamma/64	equal	not-sent	

IPv6 AppIID	64	1	Bi	::1000	equal	not-sent		
UDP DevPort	16	1	Bi	8720	MSB(12)	LSB		4
UDP AppPort	16	1	Bi	8720	MSB(12)	LSB		4
UDP Length	16	1	Bi		ignore	compute-*		
UDP checksum	16	1	Bi		ignore	compute-*		

Figure 26: Context Rules

Figure 26 describes a example of a Rule set.

In this example, 0 was chosen as the special Rule ID that tags packets that cannot be compressed with any compression Rule.

All the fields described in Rules 1-3 are present in the IPv6 and UDP headers. The DevIID-DID value is found in the L2 header.

Rules 2-3 use global addresses. The way the Dev learns the prefix is not in the scope of the document.

Rule 3 compresses each port number to 4 bits.

Appendix B. Fragmentation Examples

This section provides examples for the various fragment reliability modes specified in this document. In the drawings, Bitmaps are shown in their uncompressed form.

Figure 27 illustrates the transmission in No-ACK mode of a SCHC Packet that needs 11 SCHC Fragments. FCN is 1 bit wide.

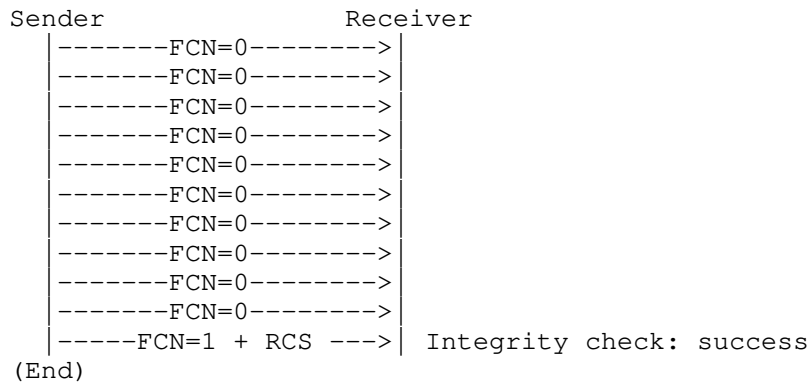


Figure 27: No-ACK mode, 11 SCHC Fragments

In the following examples, N (the size of the FCN field) is 3 bits. The All-1 FCN value is 7.

Figure 28 illustrates the transmission in ACK-on-Error mode of a SCHC Packet fragmented in 11 tiles, with one tile per SCHC Fragment, WINDOW_SIZE=7 and no lost SCHC Fragment.

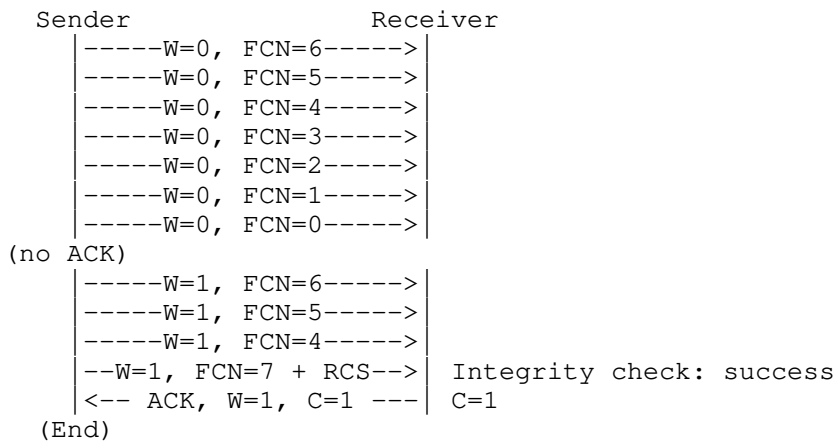


Figure 28: ACK-on-Error mode, 11 tiles, one tile per SCHC Fragment, no lost SCHC Fragment.

Figure 29 illustrates the transmission in ACK-on-Error mode of a SCHC Packet fragmented in 11 tiles, with one tile per SCHC Fragment, WINDOW_SIZE=7 and three lost SCHC Fragments.

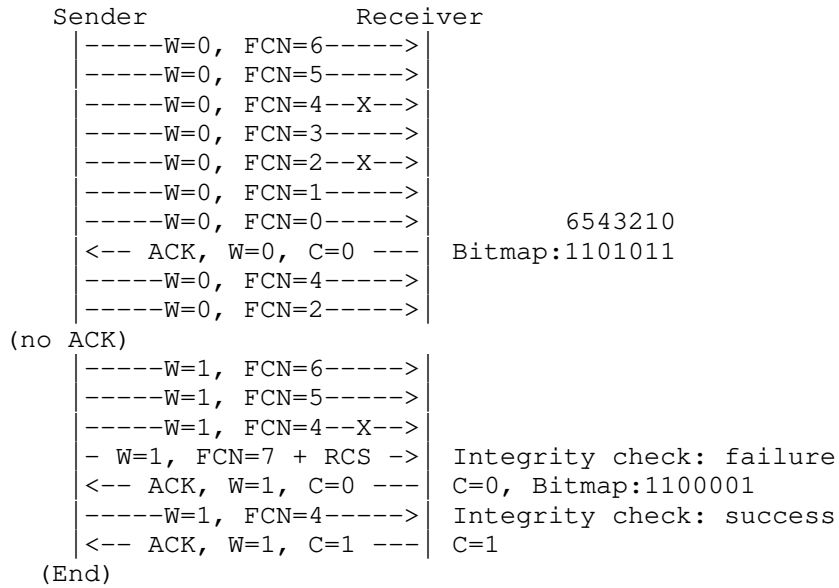


Figure 29: ACK-on-Error mode, 11 tiles, one tile per SCHC Fragment, lost SCHC Fragments.

Figure 30 shows an example of a transmission in ACK-on-Error mode of a SCHC Packet fragmented in 73 tiles, with N=5, WINDOW_SIZE=28, M=2 and 3 lost SCHC Fragments.

Sender	Receiver	
-----W=0, FCN=27----->	4 tiles sent	
-----W=0, FCN=23----->	4 tiles sent	
-----W=0, FCN=19----->	4 tiles sent	
-----W=0, FCN=15--X-->	4 tiles sent	(not received)
-----W=0, FCN=11----->	4 tiles sent	
-----W=0, FCN=7 ----->	4 tiles sent	
-----W=0, FCN=3 ----->	4 tiles sent	
-----W=1, FCN=27----->	4 tiles sent	
-----W=1, FCN=23----->	4 tiles sent	
-----W=1, FCN=19----->	4 tiles sent	
-----W=1, FCN=15----->	4 tiles sent	
-----W=1, FCN=11----->	4 tiles sent	
-----W=1, FCN=7 ----->	4 tiles sent	
-----W=1, FCN=3 --X-->	4 tiles sent	(not received)
-----W=2, FCN=27----->	4 tiles sent	
-----W=2, FCN=23----->	4 tiles sent	
-----W=2, FCN=19----->	1 tile sent	
-----W=2, FCN=18----->	1 tile sent	
-----W=2, FCN=17----->	1 tile sent	
-----W=2, FCN=16----->	1 tile sent	
-----W=2, FCN=15----->	1 tile sent	
-----W=2, FCN=14----->	1 tile sent	
-----W=2, FCN=13--X-->	1 tile sent	(not received)
-----W=2, FCN=12----->	1 tile sent	
---W=2, FCN=31 + RCS->	Integrity check: failure	
<--- ACK, W=0, C=0 ---	C=0, Bitmap:1111111111110000111111111111	
-----W=0, FCN=15----->	1 tile sent	
-----W=0, FCN=14----->	1 tile sent	
-----W=0, FCN=13----->	1 tile sent	
-----W=0, FCN=12----->	1 tile sent	
<--- ACK, W=1, C=0 ---	C=0, Bitmap:11111111111111111111111111110000	
-----W=1, FCN=3 ----->	1 tile sent	
-----W=1, FCN=2 ----->	1 tile sent	
-----W=1, FCN=1 ----->	1 tile sent	
-----W=1, FCN=0 ----->	1 tile sent	
<--- ACK, W=2, C=0 ---	C=0, Bitmap:11111111111111010000000000001	
-----W=2, FCN=13----->	Integrity check: success	
<--- ACK, W=2, C=1 ---	C=1	

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V

(End)

Figure 30: ACK-on-Error mode, variable MTU.

In this example, the L2 MTU becomes reduced just before sending the "W=2, FCN=19" fragment, leaving space for only 1 tile in each forthcoming SCHC Fragment. Before retransmissions, the 73 tiles are carried by a total of 25 SCHC Fragments, the last 9 being of smaller size.

Note: other sequences of events (e.g., regarding when ACKs are sent by the Receiver) are also allowed by this specification. Profiles may restrict this flexibility.

Figure 31 illustrates the transmission in ACK-Always mode of a SCHC Packet fragmented in 11 tiles, with one tile per SCHC Fragment, with N=3, WINDOW_SIZE=7 and no loss.

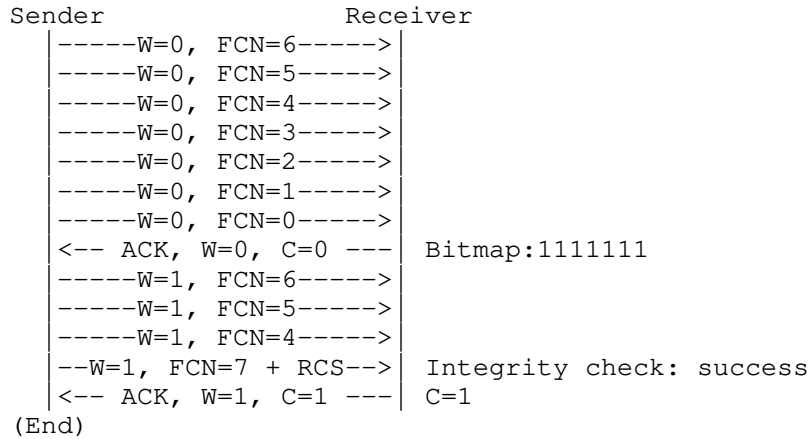


Figure 31: ACK-Always mode, 11 tiles, one tile per SCHC Fragment, no loss.

Figure 32 illustrates the transmission in ACK-Always mode of a SCHC Packet fragmented in 11 tiles, with one tile per SCHC Fragment, N=3, WINDOW_SIZE=7 and three lost SCHC Fragments.

Sender	Receiver
-----W=0, FCN=6----->	
-----W=0, FCN=5----->	
-----W=0, FCN=4--X-->	
-----W=0, FCN=3----->	
-----W=0, FCN=2--X-->	
-----W=0, FCN=1----->	
-----W=0, FCN=0----->	6543210
<-- ACK, W=0, C=0 ---	Bitmap:1101011
-----W=0, FCN=4----->	
-----W=0, FCN=2----->	
<-- ACK, W=0, C=0 ---	Bitmap:1111111
-----W=1, FCN=6----->	
-----W=1, FCN=5----->	
-----W=1, FCN=4--X-->	
--W=1, FCN=7 + RCS-->	Integrity check: failure
<-- ACK, W=1, C=0 ---	C=0, Bitmap:1100001
-----W=1, FCN=4----->	Integrity check: success
<-- ACK, W=1, C=1 ---	C=1

(End)

Figure 32: ACK-Always mode, 11 tiles, one tile per SCHC Fragment, three lost SCHC Fragments.

Figure 33 illustrates the transmission in ACK-Always mode of a SCHC Packet fragmented in 6 tiles, with one tile per SCHC Fragment, N=3, WINDOW_SIZE=7, three lost SCHC Fragments and only one retry needed to recover each lost SCHC Fragment.

Sender	Receiver
-----W=0, FCN=6----->	
-----W=0, FCN=5----->	
-----W=0, FCN=4--X-->	
-----W=0, FCN=3--X-->	
-----W=0, FCN=2--X-->	
--W=0, FCN=7 + RCS-->	Integrity check: failure
<-- ACK, W=0, C=0 ---	C=0, Bitmap:1100001
-----W=0, FCN=4----->	Integrity check: failure
-----W=0, FCN=3----->	Integrity check: failure
-----W=0, FCN=2----->	Integrity check: success
<-- ACK, W=0, C=1 ---	C=1

(End)

Figure 33: ACK-Always mode, 6 tiles, one tile per SCHC Fragment, three lost SCHC Fragments.

Figure 34 illustrates the transmission in ACK-Always mode of a SCHC Packet fragmented in 6 tiles, with one tile per SCHC Fragment, N=3,

WINDOW_SIZE=7, three lost SCHC Fragments, and the second SCHC ACK lost.

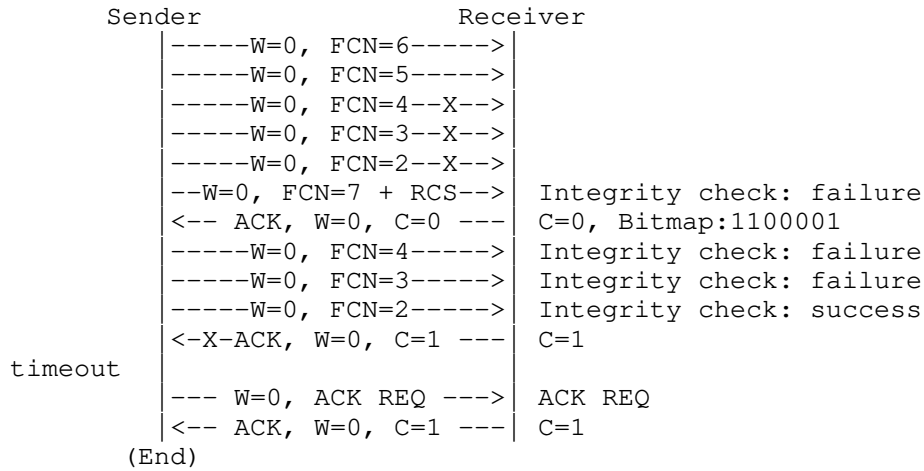


Figure 34: ACK-Always mode, 6 tiles, one tile per SCHC Fragment, SCHC ACK loss.

Figure 35 illustrates the transmission in ACK-Always mode of a SCHC Packet fragmented in 6 tiles, with N=3, WINDOW_SIZE=7, with three lost SCHC Fragments, and one retransmitted SCHC Fragment lost again.

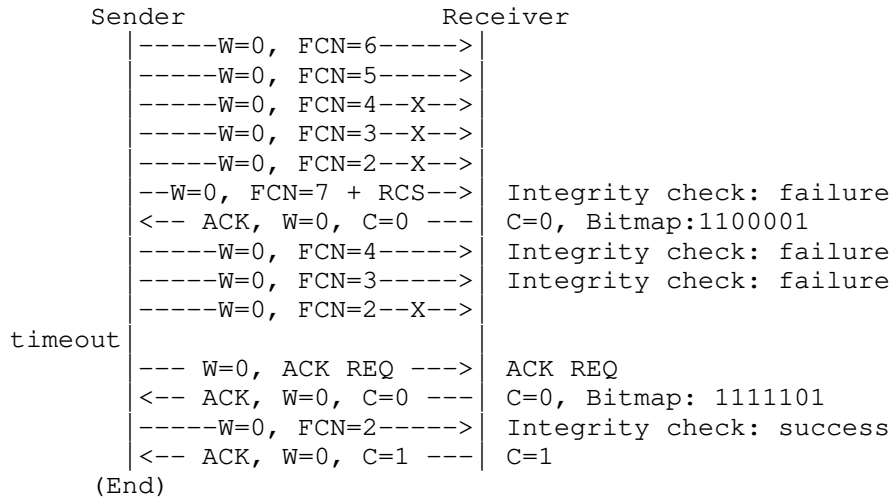


Figure 35: ACK-Always mode, 6 tiles, retransmitted SCHC Fragment lost again.

Figure 36 illustrates the transmission in ACK-Always mode of a SCHC Packet fragmented in 28 tiles, with one tile per SCHC Fragment, N=5, WINDOW_SIZE=24 and two lost SCHC Fragments.

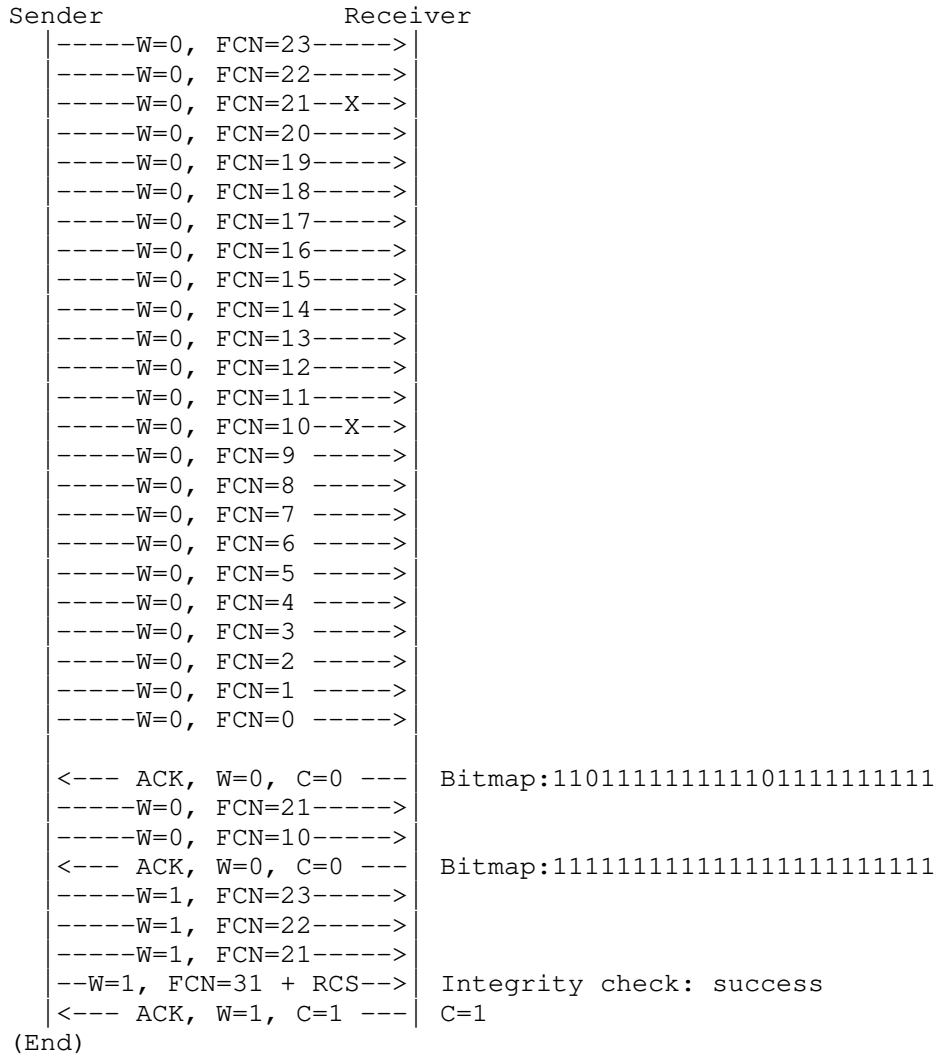


Figure 36: ACK-Always mode, 28 tiles, one tile per SCHC Fragment, lost SCHC Fragments.

Appendix C. Fragmentation State Machines

The fragmentation state machines of the sender and the receiver, one for each of the different reliability modes, are described in the following figures:

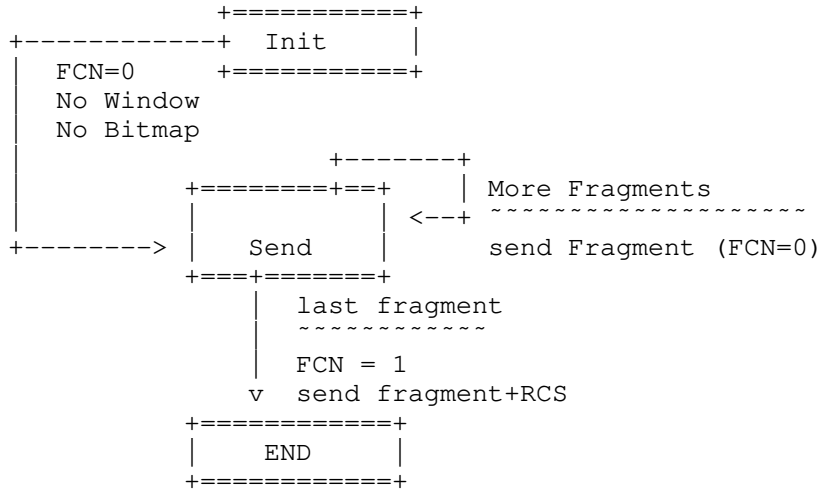


Figure 37: Sender State Machine for the No-ACK Mode

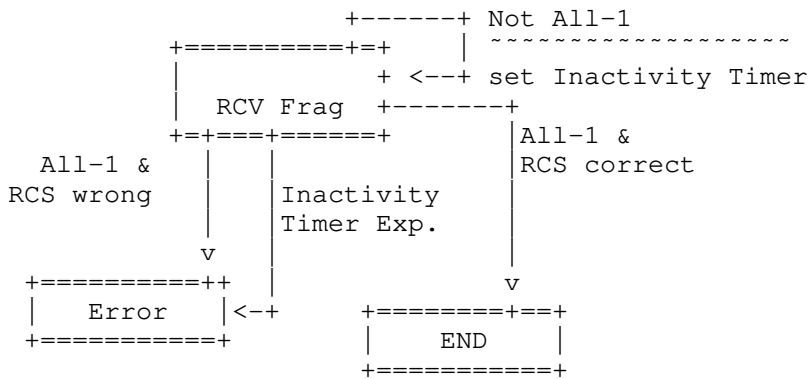
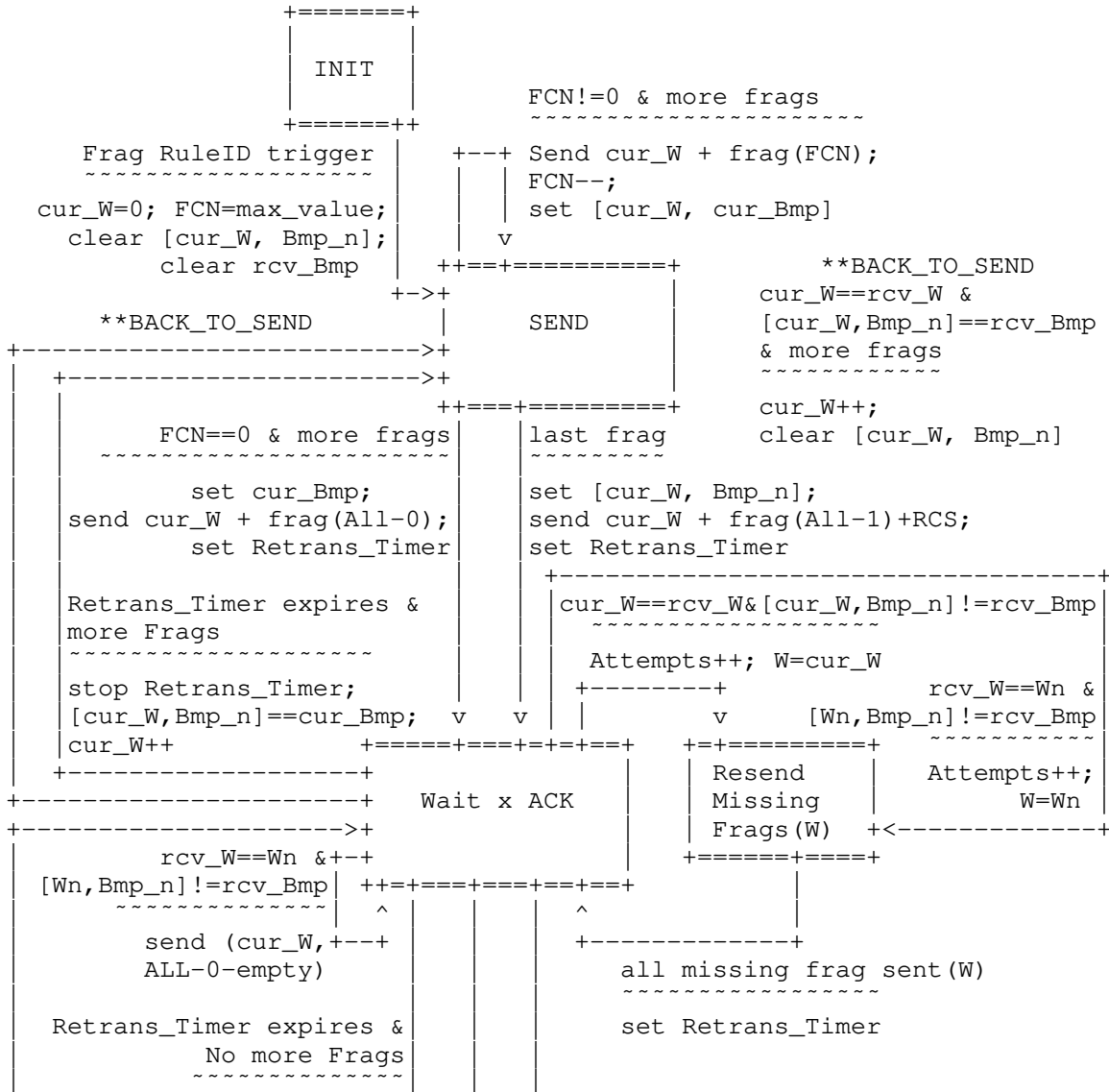


Figure 38: Receiver State Machine for the No-ACK Mode

--->* ABORT

In any state
 on receiving a SCHC ACK REQ
 Send a SCHC ACK for the current window

Figure 40: Receiver State Machine for the ACK-Always Mode



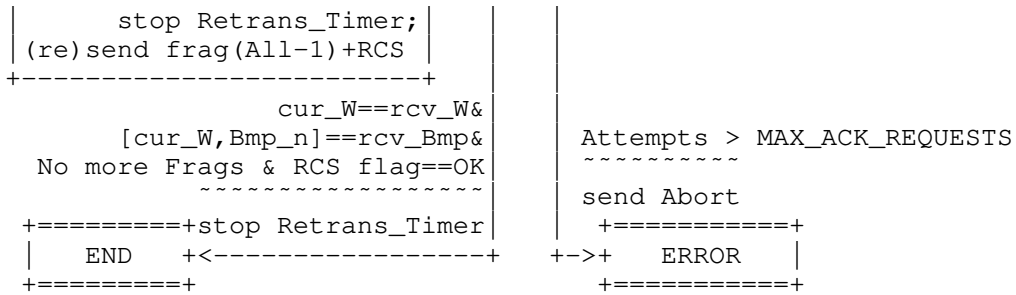
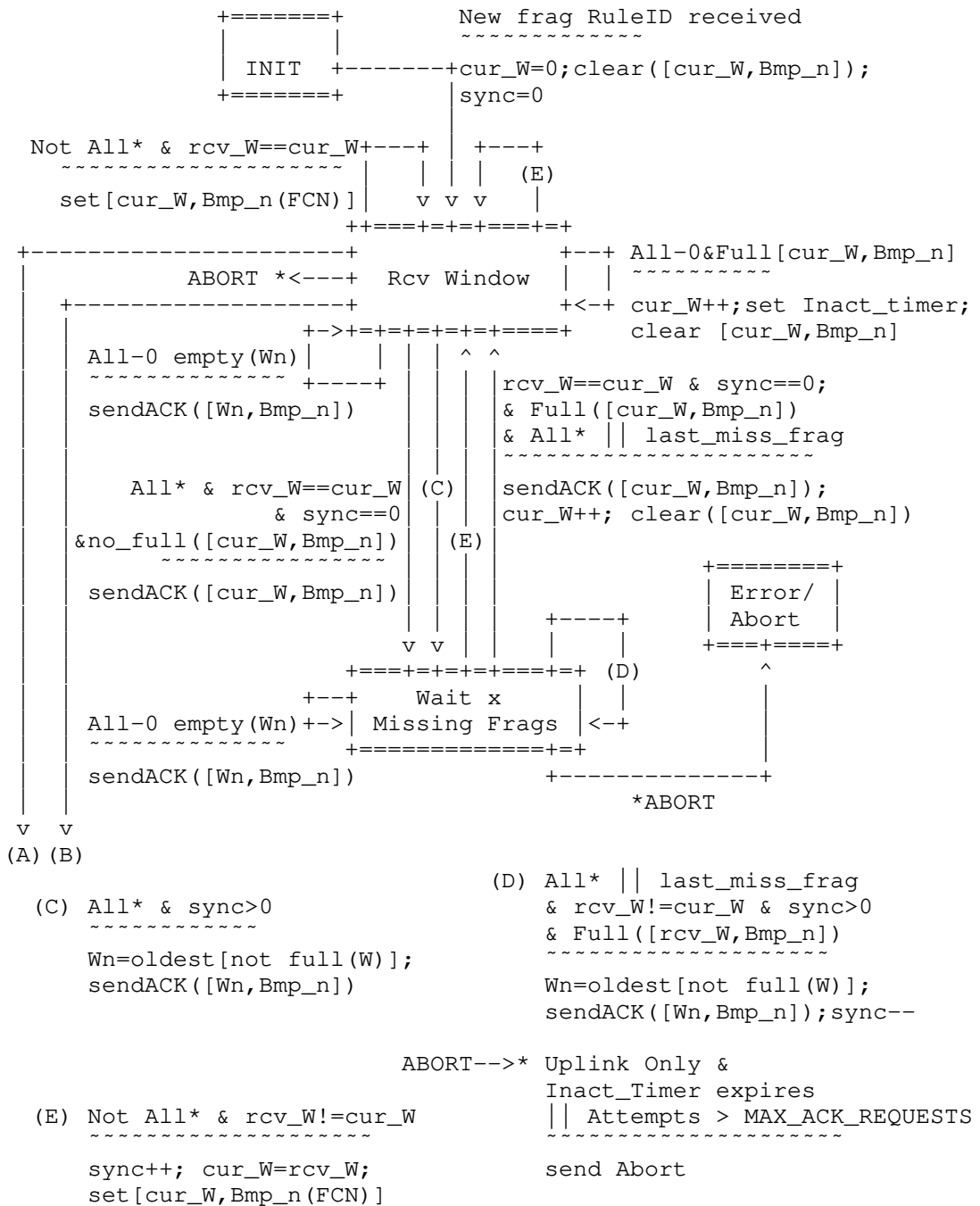


Figure 41: Sender State Machine for the ACK-on-Error Mode

This is an example only. It is not normative. The specification in Section 8.4.3.1 allows for sequences of operations different from the one shown here.



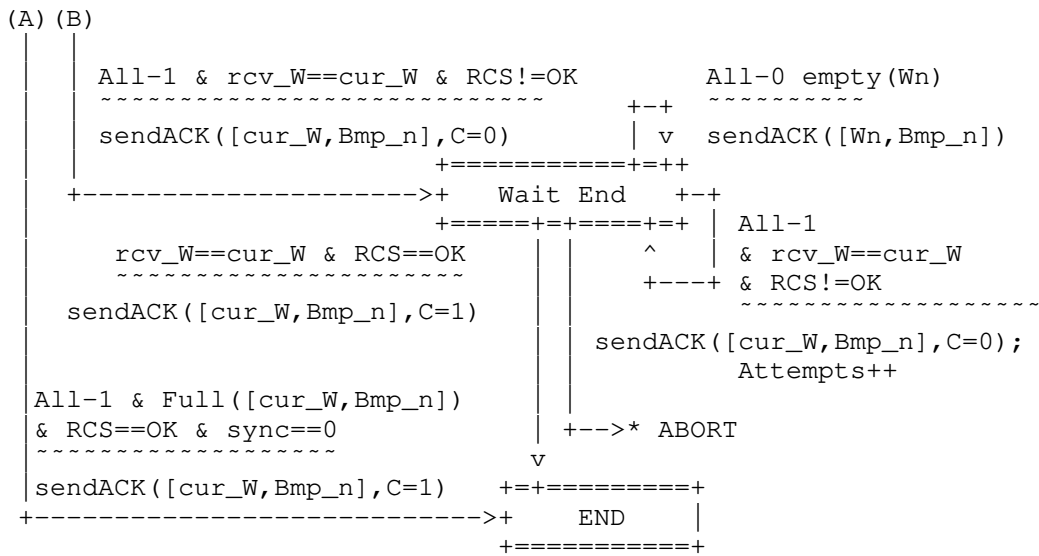


Figure 42: Receiver State Machine for the ACK-on-Error Mode

Appendix D. SCHC Parameters

This section lists the information that needs to be provided in the LPWAN technology-specific documents.

- o Most common uses cases, deployment scenarios
- o Mapping of the SCHC architectural elements onto the LPWAN architecture
- o Assessment of LPWAN integrity checking
- o Various potential channel conditions for the technology and the corresponding recommended use of SCHC C/D and F/R

This section lists the parameters that need to be defined in the Profile.

- o Rule ID numbering scheme, fixed-sized or variable-sized Rule IDs, number of Rules, the way the Rule ID is transmitted
- o maximum packet size that should ever be reconstructed by SCHC Decompression (MAX_PACKET_SIZE). See Section 12.

- o Padding: size of the L2 Word (for most LPWAN technologies, this would be a byte; for some technologies, a bit)
- o Decision to use SCHC fragmentation mechanism or not. If yes, the document must describe:
 - * reliability mode(s) used, in which cases (e.g., based on link channel condition)
 - * Rule ID values assigned to each mode in use
 - * presence and number of bits for DTag (T) for each Rule ID value, lifetime of DTag at the receiver
 - * support for interleaved packet transmission, to what extent
 - * WINDOW_SIZE, for modes that use windows
 - * number of bits for W (M) for each Rule ID value, for modes that use windows
 - * number of bits for FCN (N) for each Rule ID value
 - * what makes an All-0 SCHC Fragment and a SCHC ACK REQ distinguishable (see Section 8.3.1.1).
 - * what makes an All-1 SCHC Fragment and a SCHC Sender-Abort distinguishable (see Section 8.3.1.2).
 - * size of RCS and algorithm for its computation, for each Rule ID, if different from the default CRC32. Byte fill-up with zeroes or other mechanism, to be specified.
 - * Retransmission Timer duration for each Rule ID value, if applicable to the SCHC F/R mode
 - * Inactivity Timer duration for each Rule ID value, if applicable to the SCHC F/R mode
 - * MAX_ACK_REQUESTS value for each Rule ID value, if applicable to the SCHC F/R mode
- o if L2 Word is wider than a bit and SCHC fragmentation is used, value of the padding bits (0 or 1). This is needed because the padding bits of the last fragment are included in the RCS computation.

A Profile may define a delay to be added after each SCHC message transmission for compliance with local regulations or other constraints imposed by the applications.

- o In some LPWAN technologies, as part of energy-saving techniques, downlink transmission is only possible immediately after an uplink transmission. In order to avoid potentially high delay in the downlink transmission of a fragmented SCHC Packet, the SCHC Fragment receiver may perform an uplink transmission as soon as possible after reception of a SCHC Fragment that is not the last one. Such uplink transmission may be triggered by the L2 (e.g., an L2 ACK sent in response to a SCHC Fragment encapsulated in a L2 PDU that requires an L2 ACK) or it may be triggered from an upper layer. See Appendix F.
- o the following parameters need to be addressed in documents other than this one but not necessarily in the LPWAN technology-specific documents:
 - * The way the Contexts are provisioned
 - * The way the Rules are generated

Appendix E. Supporting multiple window sizes for fragmentation

For ACK-Always or ACK-on-Error, implementers may opt to support a single window size or multiple window sizes. The latter, when feasible, may provide performance optimizations. For example, a large window size should be used for packets that need to be split into a large number of tiles. However, when the number of tiles required to carry a packet is low, a smaller window size, and thus a shorter Bitmap, may be sufficient to provide reception status on all tiles. If multiple window sizes are supported, the Rule ID signals the window size in use for a specific packet transmission.

Appendix F. ACK-Always and ACK-on-Error on quasi-bidirectional links

The ACK-Always and ACK-on-Error modes of SCHC F/R are bidirectional protocols: they require a feedback path from the reassembler to the fragmenter.

Some LPWAN technologies provide quasi-bidirectional connectivity, whereby a downlink transmission from the Network Infrastructure can only take place right after an uplink transmission by the Dev.

When using SCHC F/R to send fragmented SCHC Packets downlink over these quasi-bidirectional links, the following situation may arise: if an uplink SCHC ACK is lost, the SCHC ACK REQ message by the sender

could be stuck indefinitely in the downlink queue at the Network Infrastructure, waiting for a transmission opportunity.

There are many ways by which this deadlock can be avoided. The Dev application might be sending recurring uplink messages such as keep-alive, or the Dev application stack might be sending other recurring uplink messages as part of its operation. However, these are out of the control of this generic SCHC specification.

In order to cope with quasi-bidirectional links, a SCHC-over-foo specification may want to amend the SCHC F/R specification to add a timer-based retransmission of the SCHC ACK. Below is an example of the suggested behavior for ACK-Always mode. Because it is an example, [RFC2119] language is deliberately not used here.

For downlink transmission of a fragmented SCHC Packet in ACK-Always mode, the SCHC Fragment receiver may support timer-based SCHC ACK retransmission. In this mechanism, the SCHC Fragment receiver initializes and starts a timer (the UplinkACK Timer) after the transmission of a SCHC ACK, except when the SCHC ACK is sent in response to the last SCHC Fragment of a packet (All-1 fragment). In the latter case, the SCHC Fragment receiver does not start a timer after transmission of the SCHC ACK.

If, after transmission of a SCHC ACK that is not an All-1 fragment, and before expiration of the corresponding UplinkACK timer, the SCHC Fragment receiver receives a SCHC Fragment that belongs to the current window (e.g., a missing SCHC Fragment from the current window) or to the next window, the UplinkACK timer for the SCHC ACK is stopped. However, if the UplinkACK timer expires, the SCHC ACK is resent and the UplinkACK timer is reinitialized and restarted.

The default initial value for the UplinkACK Timer, as well as the maximum number of retries for a specific SCHC ACK, denoted `MAX_ACK_REQUESTS`, is to be defined in a Profile. The initial value of the UplinkACK timer is expected to be greater than that of the Retransmission timer, in order to make sure that a (buffered) SCHC Fragment to be retransmitted finds an opportunity for that transmission. One exception to this recommendation is the special case of the All-1 SCHC Fragment transmission.

When the SCHC Fragment sender transmits the All-1 SCHC Fragment, it starts its Retransmission Timer with a large timeout value (e.g., several times that of the initial UplinkACK Timer). If a SCHC ACK is received before expiration of this timer, the SCHC Fragment sender retransmits any lost SCHC Fragments as reported by the SCHC ACK, or if the SCHC ACK confirms successful reception of all SCHC Fragments of the last window, the transmission of the fragmented SCHC Packet is

considered complete. If the timer expires, and no SCHC ACK has been received since the start of the timer, the SCHC Fragment sender assumes that the All-1 SCHC Fragment has been successfully received (and possibly, the last SCHC ACK has been lost: this mechanism assumes that the Retransmission Timer for the All-1 SCHC Fragment is long enough to allow several SCHC ACK retries if the All-1 SCHC Fragment has not been received by the SCHC Fragment receiver, and it also assumes that it is unlikely that several ACKs become all lost).

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LPWAN Overview
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Abstract

Low Power Wide Area Networks (LPWAN) are wireless technologies with characteristics such as large coverage areas, low bandwidth, possibly very small packet and application layer data sizes and long battery life operation. This memo is an informational overview of the set of LPWAN technologies being considered in the IETF and of the gaps that exist between the needs of those technologies and the goal of running IP in LPWANs.

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1. Introduction

This document provides background material and an overview of the technologies being considered in the IETF's Low Power Wide-Area Networking (LPWAN) working group. We also provide a gap analysis between the needs of these technologies and currently available IETF specifications.

Most technologies in this space aim for similar goals of supporting large numbers of very low-cost, low-throughput devices with very-low power consumption, so that even battery-powered devices can be deployed for years. LPWAN devices also tend to be constrained in their use of bandwidth, for example with limited frequencies being allowed to be used within limited duty-cycles (usually expressed as a percentage of time per-hour that the device is allowed to transmit.) And as the name implies, coverage of large areas is also a common goal. So, by and large, the different technologies aim for deployment in very similar circumstances.

What mainly distinguishes LPWANs from other constrained networks is that in LPWANs the balancing act related to power consumption/battery life, cost and bandwidth tends to prioritise doing better with respect to power and cost and we are more willing to live with extremely low bandwidth and constrained duty-cycles when making the various trade-offs required, in order to get the multiple-kilometre radio links implied by the "wide area" aspect of the LPWAN term.

Existing pilot deployments have shown huge potential and created much industrial interest in these technologies. As of today, essentially no LPWAN end-devices (other than for Wi-SUN) have IP capabilities. Connecting LPWANs to the Internet would provide significant benefits to these networks in terms of interoperability, application deployment, and management, among others. The goal of the IETF LPWAN working group is to, where necessary, adapt IETF-defined protocols, addressing schemes and naming to this particular constrained environment.

This document is largely the work of the people listed in Section 7.

2. LPWAN Technologies

This section provides an overview of the set of LPWAN technologies that are being considered in the LPWAN working group. The text for each was mainly contributed by proponents of each technology.

Note that this text is not intended to be normative in any sense, but simply to help the reader in finding the relevant layer 2 specifications and in understanding how those integrate with IETF-defined technologies. Similarly, there is no attempt here to set out the pros and cons of the relevant technologies.

Note that some of the technology-specific drafts referenced below may have been updated since publication of this document.

2.1. LoRaWAN

2.1.1. Provenance and Documents

LoRaWAN is an ISM-based wireless technology for long-range low-power low-data-rate applications developed by the LoRa Alliance, a membership consortium. <https://www.lora-alliance.org/> This draft is based on version 1.0.2 [LoRaSpec] of the LoRa specification. That specification is publicly available and has already seen several deployments across the globe.

2.1.2. Characteristics

LoRaWAN aims to support end-devices operating on a single battery for an extended period of time (e.g., 10 years or more), extended coverage through 155 dB maximum coupling loss, and reliable and efficient file download (as needed for remote software/firmware upgrade).

LoRaWAN networks are typically organized in a star-of-stars topology in which gateways relay messages between end-devices and a central "network server" in the backend. Gateways are connected to the network server via IP links while end-devices use single-hop LoRaWAN communication that can be received at one or more gateways. Communication is generally bi-directional; uplink communication from end-devices to the network server is favored in terms of overall bandwidth availability.

Figure 1 shows the entities involved in a LoRaWAN network.

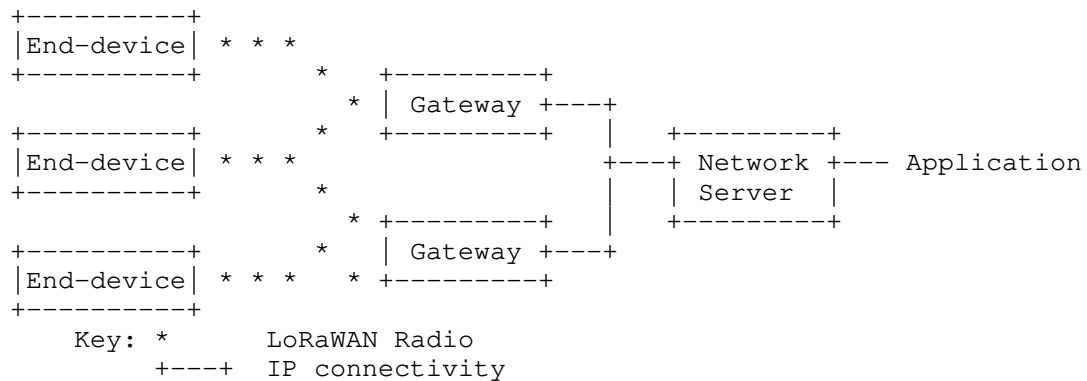


Figure 1: LoRaWAN architecture

- o End-device: a LoRa client device, sometimes called a mote. Communicates with gateways.
- o Gateway: a radio on the infrastructure-side, sometimes called a concentrator or base-station. Communicates with end-devices and, via IP, with a network server.
- o Network Server: The Network Server (NS) terminates the LoRaWAN MAC layer for the end-devices connected to the network. It is the center of the star topology.
- o Join Server: The Join Server (JS) is a server on the Internet side of an NS that processes join requests from an end-devices.
- o Uplink message: refers to communications from an end-device to a network server or application via one or more gateways.
- o Downlink message: refers to communications from a network server or application via one gateway to a single end-device or a group of end-devices (considering multicasting).
- o Application: refers to application layer code both on the end-device and running "behind" the network server. For LoRaWAN, there will generally only be one application running on most end-devices. Interfaces between the network server and application are not further described here.

In LoRaWAN networks, end-device transmissions may be received at multiple gateways, so during nominal operation a network server may see multiple instances of the same uplink message from an end-device.

The LoRaWAN network infrastructure manages the data rate and RF output power for each end-device individually by means of an adaptive data rate (ADR) scheme. End-devices may transmit on any channel allowed by local regulation at any time.

LoRaWAN radios make use of industrial, scientific and medical (ISM) bands, for example, 433MHz and 868MHz within the European Union and 915MHz in the Americas.

The end-device changes channel in a pseudo-random fashion for every transmission to help make the system more robust to interference and/or to conform to local regulations.

Figure 2 below shows that after a transmission slot a Class A device turns on its receiver for two short receive windows that are offset from the end of the transmission window. End-devices can only transmit a subsequent uplink frame after the end of the associated receive windows. When a device joins a LoRaWAN network, there are similar timeouts on parts of that process.

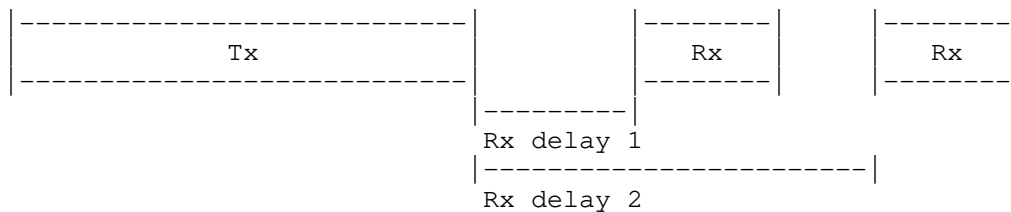


Figure 2: LoRaWAN Class A transmission and reception window

Given the different regional requirements the detailed specification for the LoRaWAN physical layer (taking up more than 30 pages of the specification) is not reproduced here. Instead and mainly to illustrate the kinds of issue encountered, in Table 1 we present some of the default settings for one ISM band (without fully explaining those here) and in Table 2 we describe maxima and minima for some parameters of interest to those defining ways to use IETF protocols over the LoRaWAN MAC layer.

Parameters	Default Value
Rx delay 1	1 s
Rx delay 2	2 s (must be RECEIVE_DELAY1 + 1s)
join delay 1	5 s
join delay 2	6 s
868MHz Default channels	3 (868.1,868.2,868.3), data rate: 0.3-50kbps

Table 1: Default settings for EU 868MHz band

Parameter/Notes	Min	Max
Duty Cycle: some but not all ISM bands impose a limit in terms of how often an end-device can transmit. In some cases LoRaWAN is more restrictive in an attempt to avoid congestion.	1%	no-limit
EU 868MHz band data rate/frame-size	250 bits/s : 59 octets	50000 bits/s : 250 octets
US 915MHz band data rate/frame-size	980 bits/s : 19 octets	21900 bits/s : 250 octets

Table 2: Minima and Maxima for various LoRaWAN Parameters

Note that in the case of the smallest frame size (19 octets), 8 octets are required for LoRa MAC layer headers leaving only 11 octets for payload (including MAC layer options). However, those settings do not apply for the join procedure - end-devices are required to use a channel and data rate that can send the 23-byte Join-request message for the join procedure.

Uplink and downlink higher layer data is carried in a MACPayload. There is a concept of "ports" (an optional 8-bit value) to handle

different applications on an end-device. Port zero is reserved for LoRaWAN specific messaging, such as the configuration of the end device's network parameters (available channels, data rates, ADR parameters, RX1/2 delay, etc.).

In addition to carrying higher layer PDUs there are Join-Request and Join-Response (aka Join-Accept) messages for handling network access. And so-called "MAC commands" (see below) up to 15 bytes long can be piggybacked in an options field ("FOpts").

There are a number of MAC commands for link and device status checking, ADR and duty-cycle negotiation, managing the RX windows and radio channel settings. For example, the link check response message allows the network server (in response to a request from an end-device) to inform an end-device about the signal attenuation seen most recently at a gateway, and to also tell the end-device how many gateways received the corresponding link request MAC command.

Some MAC commands are initiated by the network server. For example, one command allows the network server to ask an end-device to reduce its duty-cycle to only use a proportion of the maximum allowed in a region. Another allows the network server to query the end-device's power status with the response from the end-device specifying whether it has an external power source or is battery powered (in which case a relative battery level is also sent to the network server).

In order to operate nominally on a LoRaWAN network, a device needs a 32-bit device address, that is assigned when the device "joins" the network (see below for the join procedure) or that is pre-provisioned into the device. In case of roaming devices, the device address is assigned based on the 24-bit network identifier (NetID) that is allocated to the network by the LoRa Alliance. Non-roaming devices can be assigned device addresses by the network without relying on a LoRa Alliance-assigned NetID.

End-devices are assumed to work with one or a quite limited number of applications, identified by a 64-bit AppEUI, which is assumed to be a registered IEEE EUI64 value. In addition, a device needs to have two symmetric session keys, one for protecting network artifacts (port=0), the NwkSKey, and another for protecting application layer traffic, the AppSKey. Both keys are used for 128-bit AES cryptographic operations. So, one option is for an end-device to have all of the above, plus channel information, somehow (pre-)provisioned, in which case the end-device can simply start transmitting. This is achievable in many cases via out-of-band means given the nature of LoRaWAN networks. Table 3 summarizes these values.

Value	Description
DevAddr	DevAddr (32-bits) = device-specific network address generated from the NetID
AppEUI	IEEE EUI64 corresponding to the join server for an application
NwksKey	128-bit network session key used with AES-CMAC
AppSKey	128-bit application session key used with AES-CTR
AppKey	128-bit application session key used with AES-ECB

Table 3: Values required for nominal operation

As an alternative, end-devices can use the LoRaWAN join procedure with a join server behind the NS in order to setup some of these values and dynamically gain access to the network. To use the join procedure, an end-device must still know the AppEUI, and in addition, a different (long-term) symmetric key that is bound to the AppEUI - this is the application key (AppKey), and is distinct from the application session key (AppSKey). The AppKey is required to be specific to the device, that is, each end-device should have a different AppKey value. And finally, the end-device also needs a long-term identifier for itself, syntactically also an EUI-64, and known as the device EUI or DevEUI. Table 4 summarizes these values.

Value	Description
DevEUI	IEEE EUI64 naming the device
AppEUI	IEEE EUI64 naming the application
AppKey	128-bit long term application key for use with AES

Table 4: Values required for join procedure

The join procedure involves a special exchange where the end-device asserts the AppEUI and DevEUI (integrity protected with the long-term AppKey, but not encrypted) in a Join-request uplink message. This is then routed to the network server which interacts with an entity that knows that AppKey to verify the Join-request. All going well, a Join-accept downlink message is returned from the network server to

the end-device that specifies the 24-bit NetID, 32-bit DevAddr and channel information and from which the AppSKey and NwkSKey can be derived based on knowledge of the AppKey. This provides the end-device with all the values listed in Table 3.

All payloads are encrypted and have data integrity. MAC commands, when sent as a payload (port zero), are therefore protected. MAC commands piggy-backed as frame options ("FOpts") are however sent in clear. Any MAC commands sent as frame options and not only as payload, are visible to a passive attacker but are not malleable for an active attacker due to the use of the Message Integrity Check (MIC) described below.

For LoRaWAN version 1.0.x, the NwkSKey session key is used to provide data integrity between the end-device and the network server. The AppSKey is used to provide data confidentiality between the end-device and network server, or to the application "behind" the network server, depending on the implementation of the network.

All MAC layer messages have an outer 32-bit MIC calculated using AES-CMAC calculated over the ciphertext payload and other headers and using the NwkSKey. Payloads are encrypted using AES-128, with a counter-mode derived from IEEE 802.15.4 using the AppSKey. Gateways are not expected to be provided with the AppSKey or NwkSKey, all of the infrastructure-side cryptography happens in (or "behind") the network server. When session keys are derived from the AppKey as a result of the join procedure the Join-accept message payload is specially handled.

The long-term AppKey is directly used to protect the Join-accept message content, but the function used is not an AES-encrypt operation, but rather an AES-decrypt operation. The justification is that this means that the end-device only needs to implement the AES-encrypt operation. (The counter mode variant used for payload decryption means the end-device doesn't need an AES-decrypt primitive.)

The Join-accept plaintext is always less than 16 bytes long, so electronic code book (ECB) mode is used for protecting Join-accept messages. The Join-accept contains an AppNonce (a 24 bit value) that is recovered on the end-device along with the other Join-accept content (e.g. DevAddr) using the AES-encrypt operation. Once the Join-accept payload is available to the end-device the session keys are derived from the AppKey, AppNonce and other values, again using an ECB mode AES-encrypt operation, with the plaintext input being a maximum of 16 octets.

2.2. Narrowband IoT (NB-IoT)

2.2.1. Provenance and Documents

Narrowband Internet of Things (NB-IoT) is developed and standardized by 3GPP. The standardization of NB-IoT was finalized with 3GPP Release 13 in June 2016, and further enhancements for NB-IoT are specified in 3GPP Release 14 in 2017, for example in the form of multicast support. Further features and improvements will be developed in the following releases, but NB-IoT has been ready to be deployed since 2016, and is rather simple to deploy especially in the existing LTE networks with a software upgrade in the operator's base stations. For more information of what has been specified for NB-IoT, 3GPP specification 36.300 [TGPP36300] provides an overview and overall description of the E-UTRAN radio interface protocol architecture, while specifications 36.321 [TGPP36321], 36.322 [TGPP36322], 36.323 [TGPP36323] and 36.331 [TGPP36331] give more detailed description of MAC, Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP) and Radio Resource Control (RRC) protocol layers, respectively. Note that the description below assumes familiarity with numerous 3GPP terms.

For a general overview of NB-IoT, see [nbiot-ov].

2.2.2. Characteristics

Specific targets for NB-IoT include: Less than US\$5 module cost, extended coverage of 164 dB maximum coupling loss, battery life of over 10 years, ~55000 devices per cell and uplink reporting latency of less than 10 seconds.

NB-IoT supports Half Duplex FDD operation mode with 60 kbps peak rate in uplink and 30 kbps peak rate in downlink, and a maximum transmission unit (MTU) size of 1600 bytes limited by PDCP layer (see Figure 4 for the protocol structure), which is the highest layer in the user plane, as explained later. Any packet size up to the said MTU size can be passed to the NB-IoT stack from higher layers, segmentation of the packet is performed in the RLC layer, which can segment the data to transmission blocks with size as small as 16 bits. As the name suggests, NB-IoT uses narrowbands with bandwidth of 180 kHz in both downlink and uplink. The multiple access scheme used in the downlink is OFDMA with 15 kHz sub-carrier spacing. In uplink, SC-FDMA single tone with either 15kHz or 3.75 kHz tone spacing is used, or optionally multi-tone SC-FDMA can be used with 15 kHz tone spacing.

NB-IoT can be deployed in three ways. In-band deployment means that the narrowband is deployed inside the LTE band and radio resources

are flexibly shared between NB-IoT and normal LTE carrier. In Guard-band deployment the narrowband uses the unused resource blocks between two adjacent LTE carriers. Standalone deployment is also supported, where the narrowband can be located alone in dedicated spectrum, which makes it possible for example to reframe a GSM carrier at 850/900 MHz for NB-IoT. All three deployment modes are used in licensed frequency bands. The maximum transmission power is either 20 or 23 dBm for uplink transmissions, while for downlink transmission the eNodeB may use higher transmission power, up to 46 dBm depending on the deployment.

A maximum coupling loss (MCL) target for NB-IoT coverage enhancements defined by 3GPP is 164 dB. With this MCL, the performance of NB-IoT in downlink varies between 200 bps and 2-3 kbps, depending on the deployment mode. Stand-alone operation may achieve the highest data rates, up to few kbps, while in-band and guard-band operations may reach several hundreds of bps. NB-IoT may even operate with MCL higher than 170 dB with very low bit rates.

For signaling optimization, two options are introduced in addition to legacy LTE RRC connection setup; mandatory Data-over-NAS (Control Plane optimization, solution 2 in [TGPP23720]) and optional RRC Suspend/Resume (User Plane optimization, solution 18 in [TGPP23720]). In the control plane optimization the data is sent over Non-Access Stratum, directly to/from Mobility Management Entity (MME) (see Figure 3 for the network architecture) in the core network to the User Equipment (UE) without interaction from the base station. This means there are no Access Stratum security or header compression provided by the PDCP layer in the eNodeB, as the Access Stratum is bypassed, and only limited RRC procedures. RoHC based header compression may still optionally be provided and terminated in MME.

The RRC Suspend/Resume procedures reduce the signaling overhead required for UE state transition from RRC Idle to RRC Connected mode compared to legacy LTE operation in order to have quicker user plane transaction with the network and return to RRC Idle mode faster.

In order to prolong device battery life, both power-saving mode (PSM) and extended DRX (eDRX) are available to NB-IoT. With eDRX the RRC Connected mode DRX cycle is up to 10.24 seconds and in RRC Idle the eDRX cycle can be up to 3 hours. In PSM the device is in a deep sleep state and only wakes up for uplink reporting, after which there is a window, configured by the network, during which the device receiver is open for downlink connectivity, or for periodical "keep-alive" signaling (PSM uses periodic TAU signaling with additional reception window for downlink reachability).

Since NB-IoT operates in licensed spectrum, it has no channel access restrictions allowing up to a 100% duty-cycle.

3GPP access security is specified in [TGPP33203].

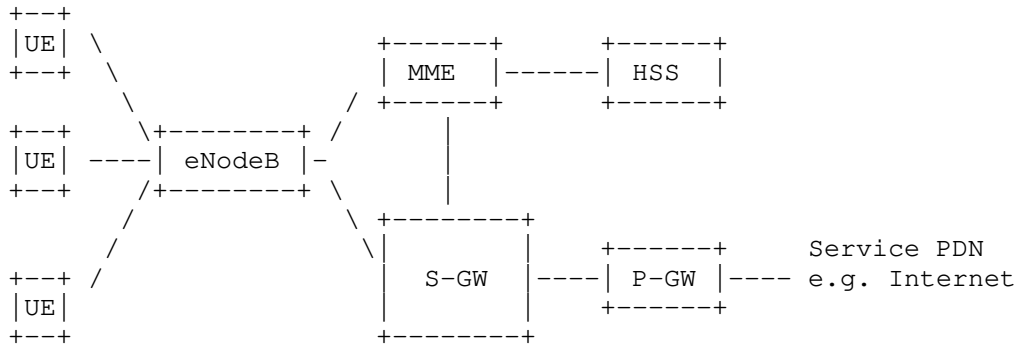


Figure 3: 3GPP network architecture

Figure 3 shows the 3GPP network architecture, which applies to NB-IoT. Mobility Management Entity (MME) is responsible for handling the mobility of the UE. MME tasks include tracking and paging UEs, session management, choosing the Serving gateway for the UE during initial attachment and authenticating the user. At MME, the Non-Access Stratum (NAS) signaling from the UE is terminated.

Serving Gateway (S-GW) routes and forwards the user data packets through the access network and acts as a mobility anchor for UEs during handover between base stations known as eNodeBs and also during handovers between NB-IoT and other 3GPP technologies.

Packet Data Network Gateway (P-GW) works as an interface between 3GPP network and external networks.

The Home Subscriber Server (HSS) contains user-related and subscription-related information. It is a database, which performs mobility management, session establishment support, user authentication and access authorization.

E-UTRAN consists of components of a single type, eNodeB. eNodeB is a base station, which controls the UEs in one or several cells.

The 3GPP radio protocol architecture is illustrated in Figure 4.

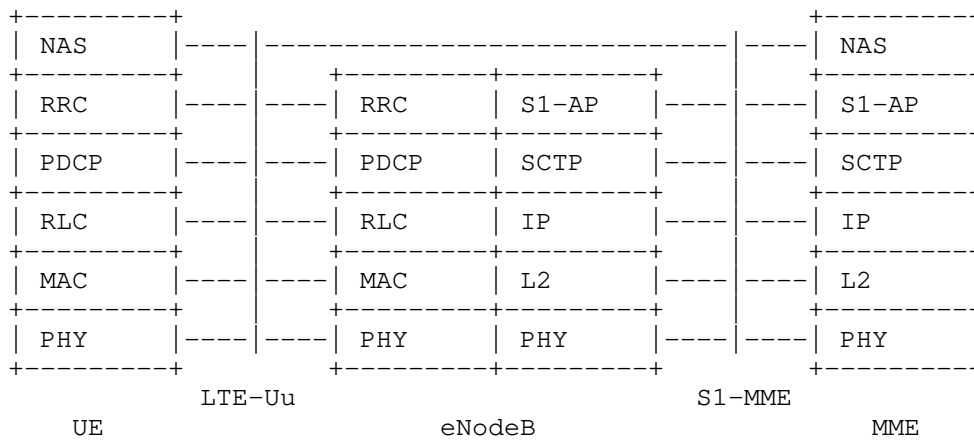


Figure 4: 3GPP radio protocol architecture for control plane

Control plane protocol stack

The radio protocol architecture of NB-IoT (and LTE) is separated into control plane and user plane. The control plane consists of protocols which control the radio access bearers and the connection between the UE and the network. The highest layer of control plane is called Non-Access Stratum (NAS), which conveys the radio signaling between the UE and the Evolved Packet Core (EPC), passing transparently through the radio network. NAS responsible for authentication, security control, mobility management and bearer management.

Access Stratum (AS) is the functional layer below NAS, and in the control plane it consists of Radio Resource Control protocol (RRC) [TGPP36331], which handles connection establishment and release functions, broadcast of system information, radio bearer establishment, reconfiguration and release. RRC configures the user and control planes according to the network status. There exists two RRC states, RRC_Idle or RRC_Connected, and RRC entity controls the switching between these states. In RRC_Idle, the network knows that the UE is present in the network and the UE can be reached in case of incoming call/downlink data. In this state, the UE monitors paging, performs cell measurements and cell selection and acquires system information. Also the UE can receive broadcast and multicast data, but it is not expected to transmit or receive unicast data. In RRC_Connected the UE has a connection to the eNodeB, the network knows the UE location on the cell level and the UE may receive and transmit unicast data. An RRC connection is established when the UE is expected to be active in the network, to transmit or receive data. The RRC connection is released, switching back to RRC_Idle, when

there is no more traffic in order to preserve UE battery life and radio resources. However, a new feature was introduced for NB-IoT, as mentioned earlier, which allows data to be transmitted from the MME directly to the UE transparently to the eNodeB, thus bypassing AS functions.

Packet Data Convergence Protocol's (PDCP) [TGPP36323] main services in control plane are transfer of control plane data, ciphering and integrity protection.

Radio Link Control protocol (RLC) [TGPP36322] performs transfer of upper layer PDUs and optionally error correction with Automatic Repeat reQuest (ARQ), concatenation, segmentation, and reassembly of RLC SDUs, in-sequence delivery of upper layer PDUs, duplicate detection, RLC SDU discard, RLC-re-establishment and protocol error detection and recovery.

Medium Access Control protocol (MAC) [TGPP36321] provides mapping between logical channels and transport channels, multiplexing of MAC SDUs, scheduling information reporting, error correction with HARQ, priority handling and transport format selection.

Physical layer [TGPP36201] provides data transport services to higher layers. These include error detection and indication to higher layers, FEC encoding, HARQ soft-combining, rate matching and mapping of the transport channels onto physical channels, power weighting and modulation of physical channels, frequency and time synchronization and radio characteristics measurements.

User plane is responsible for transferring the user data through the Access Stratum. It interfaces with IP and the highest layer of user plane is PDCP, which in user plane performs header compression using Robust Header Compression (RoHC), transfer of user plane data between eNodeB and UE, ciphering and integrity protection. Similar to control plane, lower layers in user plane include RLC, MAC and physical layer performing the same tasks as in control plane.

2.3. SIGFOX

2.3.1. Provenance and Documents

The SIGFOX LPWAN is in line with the terminology and specifications being defined by ETSI [etsi_unb]. As of today, SIGFOX's network has been fully deployed in 12 countries, with ongoing deployments on 26 other countries, giving in total a geography of 2 million square kilometers, containing 512 million people.

2.3.2. Characteristics

SIGFOX LPWAN autonomous battery-operated devices send only a few bytes per day, week or month, in principle allowing them to remain on a single battery for up to 10-15 years. Hence, the system is designed as to allow devices to last several years, sometimes even buried underground.

Since the radio protocol is connection-less and optimized for uplink communications, the capacity of a SIGFOX base station depends on the number of messages generated by devices, and not on the actual number of devices. Likewise, the battery life of devices depends on the number of messages generated by the device. Depending on the use case, devices can vary from sending less than one message per device per day, to dozens of messages per device per day.

The coverage of the cell depends on the link budget and on the type of deployment (urban, rural, etc.). The radio interface is compliant with the following regulations:

Spectrum allocation in the USA [fcc_ref]

Spectrum allocation in Europe [etsi_ref]

Spectrum allocation in Japan [arib_ref]

The SIGFOX radio interface is also compliant with the local regulations of the following countries: Australia, Brazil, Canada, Kenya, Lebanon, Mauritius, Mexico, New Zealand, Oman, Peru, Singapore, South Africa, South Korea, and Thailand.

The radio interface is based on Ultra Narrow Band (UNB) communications, which allow an increased transmission range by spending a limited amount of energy at the device. Moreover, UNB allows a large number of devices to coexist in a given cell without significantly increasing the spectrum interference.

Both uplink and downlink are supported, although the system is optimized for uplink communications. Due to spectrum optimizations, different uplink and downlink frames and time synchronization methods are needed.

The main radio characteristics of the UNB uplink transmission are:

- o Channelization mask: 100 Hz / 600 Hz (depending on the region)
- o Uplink baud rate: 100 baud / 600 baud (depending on the region)

- o Modulation scheme: DBPSK
- o Uplink transmission power: compliant with local regulation
- o Link budget: 155 dB (or better)
- o Central frequency accuracy: not relevant, provided there is no significant frequency drift within an uplink packet transmission

For example, in Europe the UNB uplink frequency band is limited to 868.00 to 868.60 MHz, with a maximum output power of 25 mW and a duty cycle of 1%.

The format of the uplink frame is the following:

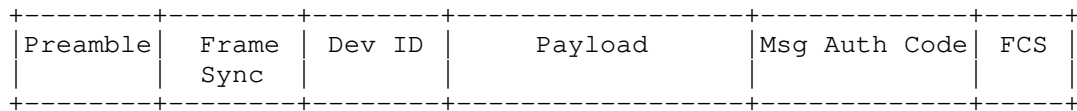


Figure 5: Uplink Frame Format

The uplink frame is composed of the following fields:

- o Preamble: 19 bits
- o Frame sync and header: 29 bits
- o Device ID: 32 bits
- o Payload: 0-96 bits
- o Authentication: 16-40 bits
- o Frame check sequence: 16 bits (CRC)

The main radio characteristics of the UNB downlink transmission are:

- o Channelization mask: 1.5 kHz
- o Downlink baud rate: 600 baud
- o Modulation scheme: GFSK
- o Downlink transmission power: 500 mW / 4W (depending on the region)
- o Link budget: 153 dB (or better)

- o Central frequency accuracy: the center frequency of downlink transmission is set by the network according to the corresponding uplink transmission

For example, in Europe the UNB downlink frequency band is limited to 869.40 to 869.65 MHz, with a maximum output power of 500 mW with 10% duty cycle.

The format of the downlink frame is the following:

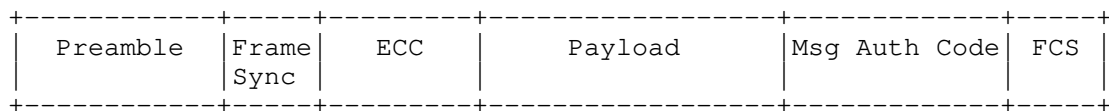


Figure 6: Downlink Frame Format

The downlink frame is composed of the following fields:

- o Preamble: 91 bits
- o Frame sync and header: 13 bits
- o Error Correcting Code (ECC): 32 bits
- o Payload: 0-64 bits
- o Authentication: 16 bits
- o Frame check sequence: 8 bits (CRC)

The radio interface is optimized for uplink transmissions, which are asynchronous. Downlink communications are achieved by devices querying the network for available data.

A device willing to receive downlink messages opens a fixed window for reception after sending an uplink transmission. The delay and duration of this window have fixed values. The network transmits the downlink message for a given device during the reception window, and the network also selects the base station (BS) for transmitting the corresponding downlink message.

Uplink and downlink transmissions are unbalanced due to the regulatory constraints on ISM bands. Under the strictest regulations, the system can allow a maximum of 140 uplink messages and 4 downlink messages per device per day. These restrictions can

be slightly relaxed depending on system conditions and the specific regulatory domain of operation.

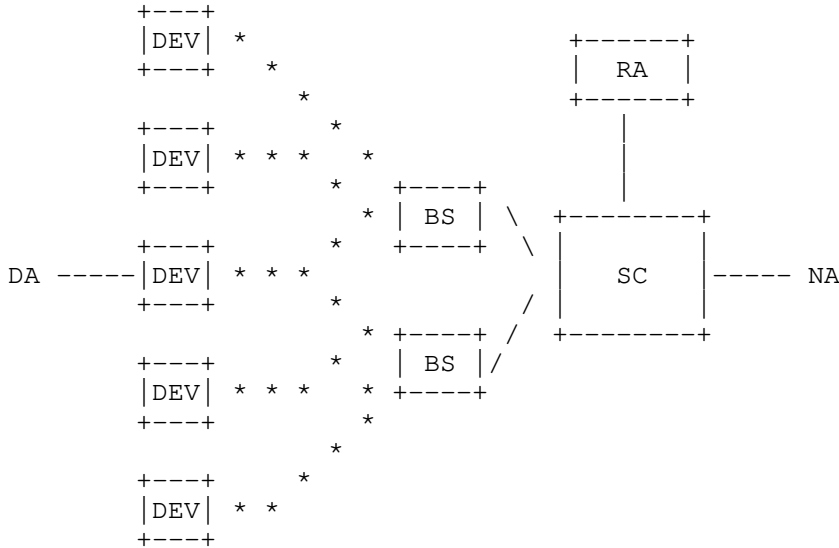


Figure 7: SIGFOX network architecture

Figure 7 depicts the different elements of the SIGFOX network architecture.

SIGFOX has a "one-contract one-network" model allowing devices to connect in any country, without any need or notion of either roaming or handover.

The architecture consists of a single cloud-based core network, which allows global connectivity with minimal impact on the end device and radio access network. The core network elements are the Service Center (SC) and the Registration Authority (RA). The SC is in charge of the data connectivity between the Base Station (BS) and the Internet, as well as the control and management of the BSs and End Points. The RA is in charge of the End Point network access authorization.

The radio access network is comprised of several BSs connected directly to the SC. Each BS performs complex L1/L2 functions, leaving some L2 and L3 functionalities to the SC.

The Devices (DEVs) or End Points (EPs) are the objects that communicate application data between local device applications (DAs) and network applications (NAs).

Devices (or EPs) can be static or nomadic, as they associate with the SC and they do not attach to any specific BS. Hence, they can communicate with the SC through one or multiple BSs.

Due to constraints in the complexity of the Device, it is assumed that Devices host only one or very few device applications, which most of the time communicate each to a single network application at a time.

The radio protocol authenticates and ensures the integrity of each message. This is achieved by using a unique device ID and an AES-128 based message authentication code, ensuring that the message has been generated and sent by the device with the ID claimed in the message. Application data can be encrypted at the application level or not, depending on the criticality of the use case, to provide a balance between cost and effort vs. risk. AES-128 in counter mode is used for encryption. Cryptographic keys are independent for each device. These keys are associated with the device ID and separate integrity and confidentiality keys are pre-provisioned. A confidentiality key is only provisioned if confidentiality is to be used. At the time of writing the algorithms and keying details for this are not published.

2.4. Wi-SUN Alliance Field Area Network (FAN)

Text here is via personal communication from Bob Heile (bheile@ieee.org) and was authored by Bob and Sum Chin Sean. Duffy (paduffy@cisco.com) also provided additional comments/input on this section.

2.4.1. Provenance and Documents

The Wi-SUN Alliance <<https://www.wi-sun.org/>> is an industry alliance for smart city, smart grid, smart utility, and a broad set of general IoT applications. The Wi-SUN Alliance Field Area Network (FAN) profile is open standards based (primarily on IETF and IEEE802 standards) and was developed to address applications like smart municipality/city infrastructure monitoring and management, electric vehicle (EV) infrastructure, advanced metering infrastructure (AMI), distribution automation (DA), supervisory control and data acquisition (SCADA) protection/management, distributed generation monitoring and management, and many more IoT applications. Additionally, the Alliance has created a certification program to promote global multi-vendor interoperability.

The FAN profile is specified within ANSI/TIA as an extension of work previously done on Smart Utility Networks. [ANSI-4957-000]. Updates to those specifications intended to be published in 2017 will contain details of the FAN profile. A current snapshot of the work to

produce that profile is presented in [wisun-pressie1]
[wisun-pressie2] .

2.4.2. Characteristics

The FAN profile is an IPv6 wireless mesh network with support for enterprise level security. The frequency hopping wireless mesh topology aims to offer superior network robustness, reliability due to high redundancy, good scalability due to the flexible mesh configuration and good resilience to interference. Very low power modes are in development permitting long term battery operation of network nodes.

The following list contains some overall characteristics of Wi-SUN that are relevant to LPWAN applications.

- o Coverage: The range of Wi-SUN FAN is typically 2 -- 3 km in line of sight, matching the needs of neighborhood area networks, campus area networks, or corporate area networks. The range can also be extended via multi-hop networking.
- o High bandwidth, low link latency: Wi-SUN supports relatively high bandwidth, i.e. up to 300 kbps [FANTPS], enables remote update and upgrade of devices so that they can handle new applications, extending their working life. Wi-SUN supports LPWAN IoT applications that require on-demand control by providing low link latency (0.02s) and bi-directional communication.
- o Low power consumption: FAN devices draw less than 2 uA when resting and only 8 mA when listening. Such devices can maintain a long lifetime even if they are frequently listening. For instance, suppose the device transmits data for 10 ms once every 10 s; theoretically, a battery of 1000 mAh can last more than 10 years.
- o Scalability: Tens of millions Wi-SUN FAN devices have been deployed in urban, suburban and rural environments, including deployments with more than 1 million devices.

A FAN contains one or more networks. Within a network, nodes assume one of three operational roles. First, each network contains a Border Router providing Wide Area Network (WAN) connectivity to the network. The Border Router maintains source routing tables for all nodes within its network, provides node authentication and key management services, and disseminates network-wide information such as broadcast schedules. Secondly, Router nodes, which provide upward and downward packet forwarding (within a network). A Router also provides services for relaying security and address management

protocols. Lastly, Leaf nodes provide minimum capabilities: discovering and joining a network, send/receive IPv6 packets, etc. A low power network may contain a mesh topology with Routers at the edges that construct a star topology with Leaf nodes.

The FAN profile is based on various open standards developed by the IETF (including [RFC0768], [RFC2460], [RFC4443] and [RFC6282]), IEEE802 (including [IEEE-802-15-4] and [IEEE-802-15-9]) and ANSI/TIA [ANSI-4957-210] for low power and lossy networks.

The FAN profile specification provides an application-independent IPv6-based transport service. There are two possible methods for establishing the IPv6 packet routing: Routing Protocol for Low-Power and Lossy Networks (RPL) at the Network layer is mandatory, and Multi-Hop Delivery Service (MHDS) is optional at the Data Link layer. Table 5 provides an overview of the FAN network stack.

The Transport service is based on User Datagram Protocol (UDP) defined in RFC768 or Transmission Control Protocol (TCP) defined in RFC793.

The Network service is provided by IPv6 as defined in RFC2460 with 6LoWPAN adaptation as defined in RFC4944 and RFC6282. ICMPv6, as defined in RFC4443, is used for the control plane during information exchange.

The Data Link service provides both control/management of the Physical layer and data transfer/management services to the Network layer. These services are divided into Media Access Control (MAC) and Logical Link Control (LLC) sub-layers. The LLC sub-layer provides a protocol dispatch service which supports 6LoWPAN and an optional MAC sub-layer mesh service. The MAC sub-layer is constructed using data structures defined in IEEE802.15.4-2015. Multiple modes of frequency hopping are defined. The entire MAC payload is encapsulated in an IEEE802.15.9 Information Element to enable LLC protocol dispatch between upper layer 6LoWPAN processing, MAC sublayer mesh processing, etc. These areas will be expanded once IEEE802.15.12 is completed.

The PHY service is derived from a sub-set of the SUN FSK specification in IEEE802.15.4-2015. The 2-FSK modulation schemes, with channel spacing range from 200 to 600 kHz, are defined to provide data rates from 50 to 300 kbps, with Forward Error Coding (FEC) as an optional feature. Towards enabling ultra-low-power applications, the PHY layer design is also extendable to low energy and critical infrastructure monitoring networks.

Layer	Description
IPv6 protocol suite	TCP/UDP 6LoWPAN Adaptation + Header Compression DHCPv6 for IP address management. Routing using RPL. ICMPv6. Unicast and Multicast forwarding.
MAC based on IEEE 802.15.4e + IE extensions	Frequency hopping Discovery and Join Protocol Dispatch (IEEE 802.15.9) Several Frame Exchange patterns Optional Mesh Under routing (ANSI 4957.210).
PHY based on 802.15.4g	Various data rates and regions
Security	802.1X/EAP-TLS/PKI Authentication. TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8 required for EAP-TLS. 802.11i Group Key Management Frame security is implemented as AES-CCM* as specified in IEEE 802.15.4 Optional ETSI-TS-102-887-2 Node 2 Node Key Management

Table 5: Wi-SUN Stack Overview

The FAN security supports Data Link layer network access control, mutual authentication, and establishment of a secure pairwise link

between a FAN node and its Border Router, which is implemented with an adaptation of IEEE802.1X and EAP-TLS as described in [RFC5216] using secure device identity as described in IEEE802.1AR. Certificate formats are based upon [RFC5280]. A secure group link between a Border Router and a set of FAN nodes is established using an adaptation of the IEEE802.11 Four-Way Handshake. A set of 4 group keys are maintained within the network, one of which is the current transmit key. Secure node to node links are supported between one-hop FAN neighbors using an adaptation of ETSI-TS-102-887-2. FAN nodes implement Frame Security as specified in IEEE802.15.4-2015.

3. Generic Terminology

LPWAN technologies, such as those discussed above, have similar architectures but different terminology. We can identify different types of entities in a typical LPWAN network:

- o End-Devices are the devices or the "things" (e.g. sensors, actuators, etc.); they are named differently in each technology (End Device, User Equipment or End Point). There can be a high density of end devices per radio gateway.
- o The Radio Gateway, which is the end point of the constrained link. It is known as: Gateway, Evolved Node B or Base station.
- o The Network Gateway or Router is the interconnection node between the Radio Gateway and the Internet. It is known as: Network Server, Serving GW or Service Center.
- o LPWAN-AAA Server, which controls the user authentication, the applications. It is known as: Join-Server, Home Subscriber Server or Registration Authority. (We use the term LPWAN-AAA server because we're not assuming that this entity speaks RADIUS or Diameter as many/most AAA servers do, but equally we don't want to rule that out, as the functionality will be similar.
- o At last we have the Application Server, known also as Packet Data Node Gateway or Network Application.

Function/ Technology	LORAWAN	NB-IOT	SIGFOX	Wi-SUN	IETF
Sensor, Actuator, device, object	End Device	User Equipment	End Point	Leaf Node	Device (Dev)
Transceiver Antenna	Gateway	Evolved Node B	Base Station	Router Node	RADIO Gateway
Server	Network Server	PDN GW/ SCEF	Service Center	Border Router	Network Gateway (NGW)
Security Server	Join Server	Home Subscriber Server	Registration Authority	Authent. Server	LPWAN- AAA SERVER
Application	Application Server	Application Server	Network Application	Appli- cation	Application (App)

Figure 8: LPWAN Architecture Terminology

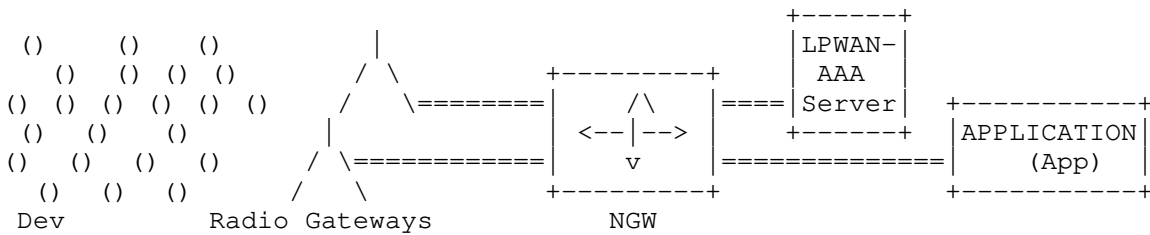


Figure 9: LPWAN Architecture

In addition to the names of entities, LPWANs are also subject to possibly regional frequency band regulations. Those may include restrictions on the duty-cycle, for example requiring that hosts only transmit for a certain percentage of each hour.

4. Gap Analysis

This section considers some of the gaps between current LPWAN technologies and the goals of the LPWAN working group. Many of the generic considerations described in [RFC7452] will also apply in LPWANs, as end-devices can also be considered as a subclass of (so-

called) "smart objects." In addition, LPWAN device implementers will also need to consider the issues relating to firmware updates described in [RFC8240].

4.1. Naive application of IPv6

IPv6 [RFC8200] has been designed to allocate addresses to all the nodes connected to the Internet. Nevertheless, the header overhead of at least 40 bytes introduced by the protocol is incompatible with LPWAN constraints. If IPv6 with no further optimization were used, several LPWAN frames could be needed just to carry the IP header. Another problem arises from IPv6 MTU requirements, which require the layer below to support at least 1280 byte packets [RFC2460].

IPv6 has a configuration protocol - neighbor discovery protocol, (NDP) [RFC4861]). For a node to learn network parameters NDP generates regular traffic with a relatively large message size that does not fit LPWAN constraints.

In some LPWAN technologies, layer two multicast is not supported. In that case, if the network topology is a star, the solution and considerations of section 3.2.5 of [RFC7668] may be applied.

Other key protocols such as DHCPv6 [RFC3315], IPsec [RFC4301] and TLS [RFC5246] have similarly problematic properties in this context. Each of those require relatively frequent round-trips between the host and some other host on the network. In the case of cryptographic protocols such as IPsec and TLS, in addition to the round-trips required for secure session establishment, cryptographic operations can require padding and addition of authenticators that are problematic when considering LPWAN lower layers. Note that mains powered Wi-SUN mesh router nodes will typically be more resource capable than the other LPWAN techs discussed. This can enable use of more "chatty" protocols for some aspects of Wi-SUN.

4.2. 6LoWPAN

Several technologies that exhibit significant constraints in various dimensions have exploited the 6LoWPAN suite of specifications [RFC4944], [RFC6282], [RFC6775] to support IPv6 [I-D.hong-6lo-use-cases]. However, the constraints of LPWANs, often more extreme than those typical of technologies that have (re)used 6LoWPAN, constitute a challenge for the 6LoWPAN suite in order to enable IPv6 over LPWAN. LPWANs are characterized by device constraints (in terms of processing capacity, memory, and energy availability), and specially, link constraints, such as:

- o tiny layer two payload size (from ~10 to ~100 bytes),

- o very low bit rate (from ~10 bit/s to ~100 kbit/s), and
- o in some specific technologies, further message rate constraints (e.g. between ~0.1 message/minute and ~1 message/minute) due to regional regulations that limit the duty cycle.

4.2.1. Header Compression

6LoWPAN header compression reduces IPv6 (and UDP) header overhead by eliding header fields when they can be derived from the link layer, and by assuming that some of the header fields will frequently carry expected values. 6LoWPAN provides both stateless and stateful header compression. In the latter, all nodes of a 6LoWPAN are assumed to share compression context. In the best case, the IPv6 header for link-local communication can be reduced to only 2 bytes. For global communication, the IPv6 header may be compressed down to 3 bytes in the most extreme case. However, in more practical situations, the smallest IPv6 header size may be 11 bytes (one address prefix compressed) or 19 bytes (both source and destination prefixes compressed). These headers are large considering the link layer payload size of LPWAN technologies, and in some cases are even bigger than the LPWAN PDUs. 6LoWPAN has been initially designed for IEEE 802.15.4 networks with a frame size up to 127 bytes and a throughput of up to 250 kb/s, which may or may not be duty-cycled.

4.2.2. Address Autoconfiguration

Traditionally, Interface Identifiers (IIDs) have been derived from link layer identifiers [RFC4944]. This allows optimizations such as header compression. Nevertheless, recent guidance has given advice on the fact that, due to privacy concerns, 6LoWPAN devices should not be configured to embed their link layer addresses in the IID by default. [RFC8065] provides guidance on better methods for generating IIDs.

4.2.3. Fragmentation

As stated above, IPv6 requires the layer below to support an MTU of 1280 bytes [RFC2460]. Therefore, given the low maximum payload size of LPWAN technologies, fragmentation is needed.

If a layer of an LPWAN technology supports fragmentation, proper analysis has to be carried out to decide whether the fragmentation functionality provided by the lower layer or fragmentation at the adaptation layer should be used. Otherwise, fragmentation functionality shall be used at the adaptation layer.

6LoWPAN defined a fragmentation mechanism and a fragmentation header to support the transmission of IPv6 packets over IEEE 802.15.4 networks [RFC4944]. While the 6LoWPAN fragmentation header is appropriate for IEEE 802.15.4-2003 (which has a frame payload size of 81-102 bytes), it is not suitable for several LPWAN technologies, many of which have a maximum payload size that is one order of magnitude below that of IEEE 802.15.4-2003. The overhead of the 6LoWPAN fragmentation header is high, considering the reduced payload size of LPWAN technologies and the limited energy availability of the devices using such technologies. Furthermore, its datagram offset field is expressed in increments of eight octets. In some LPWAN technologies, the 6LoWPAN fragmentation header plus eight octets from the original datagram exceeds the available space in the layer two payload. In addition, the MTU in the LPWAN networks could be variable which implies a variable fragmentation solution.

4.2.4. Neighbor Discovery

6LoWPAN Neighbor Discovery [RFC6775] defined optimizations to IPv6 Neighbor Discovery [RFC4861], in order to adapt functionality of the latter for networks of devices using IEEE 802.15.4 or similar technologies. The optimizations comprise host-initiated interactions to allow for sleeping hosts, replacement of multicast-based address resolution for hosts by an address registration mechanism, multihop extensions for prefix distribution and duplicate address detection (note that these are not needed in a star topology network), and support for 6LoWPAN header compression.

6LoWPAN Neighbor Discovery may be used in not so severely constrained LPWAN networks. The relative overhead incurred will depend on the LPWAN technology used (and on its configuration, if appropriate). In certain LPWAN setups (with a maximum payload size above ~60 bytes, and duty-cycle-free or equivalent operation), an RS/RA/NS/NA exchange may be completed in a few seconds, without incurring packet fragmentation.

In other LPWANs (with a maximum payload size of ~10 bytes, and a message rate of ~0.1 message/minute), the same exchange may take hours or even days, leading to severe fragmentation and consuming a significant amount of the available network resources. 6LoWPAN Neighbor Discovery behavior may be tuned through the use of appropriate values for the default Router Lifetime, the Valid Lifetime in the PIOs, and the Valid Lifetime in the 6LoWPAN Context Option (6CO), as well as the address Registration Lifetime. However, for the latter LPWANs mentioned above, 6LoWPAN Neighbor Discovery is not suitable.

4.3. 6lo

The 6lo WG has been reusing and adapting 6LoWPAN to enable IPv6 support over link layer technologies such as Bluetooth Low Energy (BTLE), ITU-T G.9959, DECT-ULE, MS/TP-RS485, NFC IEEE 802.11ah. (See <<https://tools.ietf.org/wg/6lo>> for details.) These technologies are similar in several aspects to IEEE 802.15.4, which was the original 6LoWPAN target technology.

6lo has mostly used the subset of 6LoWPAN techniques best suited for each lower layer technology, and has provided additional optimizations for technologies where the star topology is used, such as BTLE or DECT-ULE.

The main constraint in these networks comes from the nature of the devices (constrained devices), whereas in LPWANs it is the network itself that imposes the most stringent constraints.

4.4. 6tisch

The 6tisch solution is dedicated to mesh networks that operate using 802.15.4e MAC with a deterministic slotted channel. The time slot channel (TSCH) can help to reduce collisions and to enable a better balance over the channels. It improves the battery life by avoiding the idle listening time for the return channel.

A key element of 6tisch is the use of synchronization to enable determinism. TSCH and 6TiSCH may provide a standard scheduling function. The LPWAN networks probably will not support synchronization like the one used in 6tisch.

4.5. RoHC

Robust header compression (RoHC) is a header compression mechanism [RFC3095] developed for multimedia flows in a point to point channel. RoHC uses 3 levels of compression, each level having its own header format. In the first level, RoHC sends 52 bytes of header, in the second level the header could be from 34 to 15 bytes and in the third level header size could be from 7 to 2 bytes. The level of compression is managed by a sequence number, which varies in size from 2 bytes to 4 bits in the minimal compression. SN compression is done with an algorithm called W-LSB (Window- Least Significant Bits). This window has a 4-bit size representing 15 packets, so every 15 packets RoHC needs to slide the window in order to receive the correct sequence number, and sliding the window implies a reduction of the level of compression. When packets are lost or errored, the decompressor loses context and drops packets until a bigger header is sent with more complete information. To estimate the performance of

RoHC, an average header size is used. This average depends on the transmission conditions, but most of the time is between 3 and 4 bytes.

RoHC has not been adapted specifically to the constrained hosts and networks of LPWANs: it does not take into account energy limitations nor the transmission rate, and RoHC context is synchronised during transmission, which does not allow better compression.

4.6. ROLL

Most technologies considered by the lpwan WG are based on a star topology, which eliminates the need for routing at that layer. Future work may address additional use-cases that may require adaptation of existing routing protocols or the definition of new ones. As of the time of writing, work similar to that done in the ROLL WG and other routing protocols are out of scope of the LPWAN WG.

4.7. CoAP

CoAP [RFC7252] provides a RESTful framework for applications intended to run on constrained IP networks. It may be necessary to adapt CoAP or related protocols to take into account for the extreme duty cycles and the potentially extremely limited throughput of LPWANs.

For example, some of the timers in CoAP may need to be redefined. Taking into account CoAP acknowledgments may allow the reduction of L2 acknowledgments. On the other hand, the current work in progress in the CoRE WG where the COMI/CoOL network management interface which, uses Structured Identifiers (SID) to reduce payload size over CoAP may prove to be a good solution for the LPWAN technologies. The overhead is reduced by adding a dictionary which matches a URI to a small identifier and a compact mapping of the YANG model into the CBOR binary representation.

4.8. Mobility

LPWAN nodes can be mobile. However, LPWAN mobility is different from the one specified for Mobile IP. LPWAN implies sporadic traffic and will rarely be used for high-frequency, real-time communications. The applications do not generate a flow, they need to save energy and most of the time the node will be down.

In addition, LPWAN mobility may mostly apply to groups of devices, that represent a network in which case mobility is more a concern for the gateway than the devices. NEMO [RFC3963] Mobility or other mobile gateway solutions (such as a gateway with an LTE uplink) may be used in the case where some end-devices belonging to the same

network gateway move from one point to another such that they are not aware of being mobile.

4.9. DNS and LPWAN

The Domain Name System (DNS) [RFC1035], enables applications to name things with a globally resolvable name. Many protocols use the DNS to identify hosts, for example applications using CoAP.

The DNS query/answer protocol as a pre-cursor to other communication within the time-to-live (TTL) of a DNS answer is clearly problematic in an LPWAN, say where only one round-trip per hour can be used, and with a TTL that is less than 3600. It is currently unclear whether and how DNS-like functionality might be provided in LPWANs.

5. Security Considerations

Most LPWAN technologies integrate some authentication or encryption mechanisms that were defined outside the IETF. The working group may need to do work to integrate these mechanisms to unify management. A standardized Authentication, Accounting, and Authorization (AAA) infrastructure [RFC2904] may offer a scalable solution for some of the security and management issues for LPWANs. AAA offers centralized management that may be of use in LPWANs, for example [I-D.garcia-dime-diameter-lorawan] and [I-D.garcia-radext-radius-lorawan] suggest possible security processes for a LoRaWAN network. Similar mechanisms may be useful to explore for other LPWAN technologies.

Some applications using LPWANs may raise few or no privacy considerations. For example, temperature sensors in a large office building may not raise privacy issues. However, the same sensors, if deployed in a home environment and especially if triggered due to human presence, can raise significant privacy issues - if an end-device emits (an encrypted) packet every time someone enters a room in a home, then that traffic is privacy sensitive. And the more that the existence of that traffic is visible to network entities, the more privacy sensitivities arise. At this point, it is not clear whether there are workable mitigations for problems like this - in a more typical network, one would consider defining padding mechanisms and allowing for cover traffic. In some LPWANs, those mechanisms may not be feasible. Nonetheless, the privacy challenges do exist and can be real and so some solutions will be needed. Note that many aspects of solutions in this space may not be visible in IETF specifications, but can be e.g. implementation or deployment specific.

Another challenge for LPWANs will be how to handle key management and associated protocols. In a more traditional network (e.g. the web), servers can "staple" Online Certificate Status Protocol (OCSP) responses in order to allow browsers to check revocation status for presented certificates. [RFC6961] While the stapling approach is likely something that would help in an LPWAN, as it avoids an RTT, certificates and OCSP responses are bulky items and will prove challenging to handle in LPWANs with bounded bandwidth.

6. IANA Considerations

There are no IANA considerations related to this memo.

7. Contributors

[[RFC editor: Please fix names below for I18N.]]

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- o Text for Section 2.2 was provided by Antti Ratilainen in [I-D.ratilainen-lpwan-nb-iot].
- o Text for Section 2.3 was provided by Juan Carlos Zuniga and Benoit Ponsard in [I-D.zuniga-lpwan-sigfox-system-description].
- o Text for Section 2.4 was provided via personal communication from Bob Heile (bheile@ieee.org) and was authored by Bob and Sum Chin Sean. There is no Internet draft for that at present.
- o Text for Section 4 was provided by Ana Minabiru, Carles Gomez, Laurent Toutain, Josep Paradells and Jon Crowcroft in [I-D.minaburo-lpwan-gap-analysis]. Additional text from that draft is also used elsewhere above.

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Appendix A. Changes

[[RFC editor: Please remove this before publication]]

A.1. From -00 to -01

- o WG have stated they want this to be an RFC.
- o WG clearly want to keep the RF details.
- o Various changes made to remove/resolve a number of editorial notes from -00 (in some cases as per suggestions from Ana Minaburo)
- o Merged PR's: #1...
- o Rejected PR's: #2 (change was made to .txt not .xml but was replicated manually by editor)
- o Github repo is at: <https://github.com/sftcd/lpwan-ov>

A.2. From -01 to -02

- o WG seem to agree with editor suggestions in slides 13-24 of the presentation on this topic given at IETF98 (See: <https://www.ietf.org/proceedings/98/slides/slides-98-lpwan-aggregated-slides-07.pdf>)
- o Got new text wrt Wi-SUN via email from Paul Duffy and merged that in
- o Reflected list discussion wrt terminology and "end-device"
- o Merged PR's: #3...

A.3. From -02 to -03

- o Editorial changes and typo fixes thanks to Fred Baker running something called Grammerly and sending me it's report.
- o Merged PR's: #4, #6, #7...
- o Editor did an editing pass on the lot.

A.4. From -03 to -04

- o Picked up a PR that had been wrongly applied that expands UE
- o Editorial changes wrt LoRa suggested by Alper
- o Editorial changes wrt SIGFOX provided by Juan-Carlos

A.5. From -04 to -05

- o Handled Russ Housley's WGLC review.
- o Handled Alper Yegin's WGLC review.

A.6. From -05 to -06

- o More Alper comments:-)
- o Added some more detail about sigfox security.
- o Added Wi-SUN changes from Charlie Perkins

A.7. From -06 to -07

Yet more Alper comments:-)
Comments from Behcet Sarikaya

A.8. From -07 to -08

various typos

Last call and directorate comments from Abdussalam Baryun (AB) and Andy Malis

20180118 IESG ballot comments from Warren: nits handled, two possible bits of text still needed.

Some more AB comments handled. Still need to check over 7452 and 8240 to see if issues from those need to be discussed here.

Corrected "no IP capabilities - Wi-SUN devices do v6 (thanks Paul Duffy:-)

Mirja's AD ballot comments handled.

Added a sentence in intro trying to say what's "special" about LPWAN compared to other constrained networks. (As suggested by Warren.)

Added text @ start of gap analysis referring to RFCs 7252 and 8240, as suggested by a few folks (AB, Warren, Mirja)

Added nbiot-ov reference for those who'd like a more polished presentation of NB-IoT

A.9. From -08 to -09

Changes due to IoT-DIR review from Samita Chakrabarti: fixed error on max rate between tables 1 and 2; s/eNb/eNodeB/; fixed references to hong-6lo-use-cases; added RFC8065 reference

A.10. From -09 to -10

Added Charlie Perkins as contributor - was supposed to have been done ages ago - editor forgot;-)

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LPWAN Static Context Header Compression (SCHC) for ICMPv6
draft-lagos-lpwan-icmpv6-static-context-hc-01

Abstract

This document provides the implementation of the LPWAN static context header compression (SCHC) for the Internet Control Message Protocol version 6 (ICMPv6) on networks with star topology. SCHC is a header compression technique which uses RoHC concepts and the flexibility of 6LoWPAN to avoid fields that are known by all network devices and compress the remaining header fields. The ICMPv6 messages considered in this draft are Echo Request, Echo Reply and Neighbor Discovery.

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 RFC 2119 [RFC2119].

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1. TEMPORARY EDITORIAL NOTES

This document is an Internet Draft, so it is work-in-progress by nature. It contains the following work-in-progress elements:

- o "TODO" statements are elements which have not yet been written by the authors for some reason (lack of time, ongoing discussions with no clear consensus, etc). The statement does indicate that the text will be written at some time.
- o "TEMPORARY" appendices are there to capture current ongoing discussions, or the changelog of the document. These appendices will be removed in the final text.
- o "IANA_" identifiers are placeholders for numbers assigned by IANA. These placeholders are to be replaced by the actual values they represent after their assignment by IANA.

- o The string "REMARK" is put before a remark (questions, suggestion, etc) from an author, editor or contributor. These are on-going discussions at the time of writing, NOT part of the final text.
- o This section will be removed in the final text.

2. Introduction

LPWANs are networks where low power consumption, high delay and extremely small packets characterize the traffic. The nodes are typically connected in a star topology, with a central gateway that connects the network to the Internet. Most IP-based networks require ICMP services to enable network configuration and testing, such as neighbor node detection and round trip time calculation. Because ICMPv6 has redundant information in header fields, SCHC can be deployed efficiently, especially for LPWA devices that are constrained by a small available bandwidth and power limitations.

This document describes ICMPv6 message compression using SCHC compression defined on [I-D.toutain-lpwan-ipv6-static-context-hc] to reduce to the minimum the required LPWAN packet size.

3. LoRa networks using ICMPv6 message

High coverage and low power communication technologies - LoRa networks - allow the construction of data capture systems with the goal of covering a large area with a low bandwidth. This technology is characterized by the transmission of short packets and their direct sequence spread spectrum - DSSS.

To maintain communications between the nodes and the outer is necessary the implementation of a neighbor discovery protocol. The internet layer will be composed by the ICMPv6 protocol.

The use of SCHC in LoRa messages is fundamental in the ICMPv6 communication. This is because the IPv6 header consist in 40 Bytes and the ICMPv6 header in the worst esenario can be reach lenght over the 36 Bytes. For a LoRa esenario the field checksum of a ICMPv6 message will be avoided how is shown in the next chapters. This is because LoRa message posses CRC so it is not necesassary to send it.

The fields link layer and target address (only link local) in a ICMPv6 message are going be sendes ones as they will be saved in the memory of the LoRa Gateway. For more details see Section 9

4. SCHC compression over Echo Request - Echo Reply

Echo Request and Echo Reply are composed by the same fields:

- o Type: Message type. In case it is Echo Request the value will be 0x80. If it is Echo Reply will be 0x81.
- o Code: Always 0.
- o Checksum: This field is composed by 2 Bytes where the values are calculated as defined on RFC 4443 [RFC4443].
- o Identifier: It is the ID of the package.
- o Sequence: It is the sequence number of the transmitted packet.

For a SCHC compression it is necessary to identify which fields stay static to build the context.

The fields Code and checksum can be elided because Code is always zero and Checksum can be calculated after the decompression of the packet. In the case of Type, this field can be represented in the SCHC rule. The Identifier and Sequence fields will be sent after the SCHC rule.

Field	FP	DI	Match Opera.	Comp Decomp Action	Sent [bits]
Type	1	Bi	equal	not sent	
Code	1	Bi	equal	not sent	
Checksum	1	Bi	ignore	compute-checksum	
Identifier	1	Bi	equal	sent	[16]
Sequence	1	Bi	ignore	sent	[16]

5. Router Solicitation SCHC compression

The Router Solicitation packet header is composed by:

- o Type: Type of message. Value: 0x85.
- o Code: Always 0.
- o Checksum: This field is composed by 2 Bytes where the values are calculated as defined on RFC 4443 [RFC4443]
- o Reserved: These 4 bytes have a 0 value.
- o Option: This field corresponds to the MAC address.

The most significant field is the MAC address of the network host. As mentioned on RFC 4861 [RFC4861], Router Solicitation should have a Link-Local Source Address and a Router Multicast Address which can be integrated after the packet decompression.

Field	FP	DI	Match Opera.	Comp Decomp Action	Sent [bits]
Type	1	Bi	equal	not sent	
Code	1	Bi	equal	not sent	
Checksum	1	Bi	ignore	compute-checksum	
Reserved	1	Bi	equal	not sent	
Option - type	1	Bi	equal	not sent	
Option - length	1	Bi	ignore	compute-length	
Option - link-layer	1	Bi	ignore	sent	[48]

6. Router Advertisement SCHC compression

The Router Advertisement packet header is composed by:

- o Type: Type of message. Value: 0x86.
- o Code: Always 0.
- o Checksum: This field is composed by 2 Bytes where they values are caculated as it is explained on RFC 4443 [RFC4443].
- o Current Hop Limit: Because this is a star topology, the value MUST be set to 255.
- o Autoconfig Flags: Depending on the router configuration, it will advertise if DHCP is allowed or not.
- o Router Lifetime: This field indicates the time that the Router keeps the condition of default device.
- o Reachable Time: Indicates to the host how much time a neighbour is considered reachable.
- o Retransmission Timer: Indicates the delay that the host should have before transmission.
- o Options: This field contains the MAC Address, MTU and the IPv6 Prefix of the network.

The SCHC compression for Router Advertisement is designed to send the MAC address of the packet. Like the Echo message, the Type field can be represented in the SCHC rule.

The Current Hop Limit, Autoconfig Flags, Lifetime Router, Reachable Time, and Retransmission Timer fields can be deleted if the host knows these values. The MTU of this packet can be elided and the IPv6 prefix helps the SCHC compression of the global address, omitting the first 8 bytes of the address.

Field	FP	DI	Match Opera.	Comp Decomp Action	Sent [bits]
Type	1	Bi	equal	not sent	
Code	1	Bi	equal	not sent	
Checksum	1	Bi	ignore	compute-checksum	
Current Hop Limit	1	Bi	ignore	not sent	
Autoconfig Flags	1	Bi	ignore	not sent	
Router Lifetime	1	Bi	ignore	not sent	
Reachable Time	1	Bi	ignore	not sent	
Retransmission Timer	1	Bi	ignore	not sent	
Option - type	1	Bi	equal	not sent	
Option - length	1	Bi	ignore	compute-length	
Option - link- layer	1	Bi	ignore	sent	[48]
Option - type	1	Bi	equal	not sent	
Option - length	1	Bi	ignore	not sent	
Option -	1	Bi	equal	not sent	

reserved							
Option - MTU	1	Bi	ignore	not sent			
Option - type	1	Bi	equal	not sent			
Option - length	1	Bi	equal	not sent			
Option - Flag	1	Bi	ignore	not sent			
Option - Valid lifetime	1	Bi	ignore	not sent			
Option - Preferred lifetime	1	Bi	ignore	not sent			
Option - reserved	1	Bi	equal	not sent			
Option - prefix	1	Bi	ignore	not sent			

7. SCHC compression over Neighbor Solicitation

The Neighbor Solicitation packet header is composed by:

- o Type: Type of message. Value: 0x87.
- o Code: Always 0.
- o Checksum: This field is composed by 2 Bytes where the values are calculated as it is specified on RFC 4443 [RFC4443].
- o Target Address: It contains the address to be resolved.
- o Options: This field contains the MAC Address from the host.

For SCHC compression over Neighbor Solicitation, the MAC address and the Target Address are the minimal fields for the transmission. If the Target address has a Link-Local value, the last 8 Bytes of the address are sent, otherwise, the full 16 Bytes are sent. The type field can be represented in the SCHC rule.

Field	FP	DI	Match Opera.	Comp Decomp Action	Sent [bits]
Type	1	Bi	equal	not sent	
Code	1	Bi	equal	not sent	
Checksum	1	Bi	ignore	compute-checksum	
Target Address	1	Bi	match- mapping	sent	link-local [64] global [128]
Option - type	1	Bi	equal	not sent	
Option - length	1	Bi	ignore	compute-length	
Option - link-layer	1	Bi	ignore	sent	[48]

8. SCHC compression over Neighbor Advertisement

A Neighbor Advertisement is composed by:

- o Type: Type of message. Value: 0x88.
- o Code: Is always 0.
- o Checksum: This field is composed by 2 Bytes where the values are caculated as it is specified on RFC 4443 [RFC4443].
- o Flags: Describes first if the device sending the packet is a router or a node, second if the packet is sent because it is a neighbor search response and third, if the receiver has to rewrite the host information.
- o Target Address: If it is a reply of a Neighbor Solicitation request, it contains the same Target address, otherwise it will contain the address to be resolved.
- o Options: If the packet source is a Multicast Neighbor Solicitation reply, the MAC is sent, otherwise it is elided.

For the compression of SCHC in Neighbor Advertisement, the MAC address is sent if it is a Multicast neighborhood request response. If the Target address has a Link-Local value, the last 8 Bytes of the address will be sent, otherwise, the full 16 Bytes will be

transmitted. If the Flags field is known by the host, it can be deleted. The Type field can be represented in the SCHC rule.

Field	FP	DI	Match Opera.	Comp Decomp Action	Sent [bits]
Type	1	Bi	equal	not sent	
Code	1	Bi	equal	not sent	
Checksum	1	Bi	ignore	compute-checksum	
Flags	1	Bi	equal	not sent	
Target Address	1	Bi	match-mapping	sent	link-local [64] global [128]
Option - type	1	Bi	equal	not sent	
Option - length	1	Bi	ignore	not sent	
Option - link-layer	1	Bi	ignore	not sent	

9. LoRa Gateway tables

(TODO)

10. Acknowledgments

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11.4. LPWAN Static Context Header Compression (SCHC) and fragmentation for IPv6 and UDP

[I-D.toutain-lpwan-ipv6-static-context-hc] Minaburo, A. and L. Toutain, "LPWAN Static Context Header Compression (SCHC) for IPv6 and UDP", draft-toutain-lpwan-ipv6-static-context-hc-00 (work in progress), September 2016.

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LPWAN Static Context Header Compression (SCHC) over NB-IoT
draft-minaburo-lpwan-nbiot-hc-02

Abstract

The Static Context Header Compression (SCHC) specification describes a header compression and fragmentation functionalities for LPWAN (Low Power Wide Area Networks) technologies. SCHC was designed to be adapted over any of the LPWAN technologies.

This document describes the use of SCHC over the NB-IoT wireless access, and provides elements for an efficient parameterization.

Status of This Memo

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1. Introduction

The Static Context Header Compression (SCHC) [I-D.ietf-lpwan-ipv6-static-context-hc] defines a header compression scheme and fragmentation functionality, both specially tailored for Low Power Wide Area Networks (LPWAN) networks defined in [RFC8376].

Header compression is needed to efficiently bring Internet connectivity to the node within an NB-IoT network. SCHC uses a static context to performs header compression with specific parameters that need to be adapted into the NB-IoT wireless access. This document assumes functionality for NB-IoT of 3GPP release 15 otherwise other versions functionality is explicitly mentioned in the text.

This document describes the use of SCHC and its parameterizing over the NB-IoT wireless access.

2. Terminology

This document will follow the terms defined in [I-D.ietf-lpwan-ipv6-static-context-hc], in [RFC8376], and the [TGPP23720].

- o CIoT. Cellular IoT
- o C-SGN. CIoT Serving Gateway Node
- o UE. User Equipment
- o eNB. Node B. Base Station that controls the UE
- o EPC. Evolved Packet Connectivity. Core network of 3GPP LTE systems.
- o EUTRAN. Evolved Universal Terrestrial Radio Access Network. Radio network from LTE based systems.
- o MME. Mobility Management Entity. Handle mobility of the UE
- o NB-IoT. Narrow Band IoT. Referring to 3GPP LPWAN technology based in LTE architecture but with additional optimization for IoT and using a Narrow Band spectrum frequency.
- o SGW. Serving Gateway. Routes and forwards the user data packets through the access network

- o HSS. Home Subscriber Server. It is a database that performs mobility management
- o PGW. Packet Data Node Gateway. An interface between the internal with the external network
- o PDU. Protocol Data Unit. Data packets including headers that are transmitted between entities through a protocol.
- o SDU. Service Data Unit. Data packets (PDUs) from higher layers protocols used by lower layer protocols as a payload of their own PDUs that has not yet been encapsulated.
- o IWK-SCEF. InterWorking Service Capabilities Exposure Function. Used in roaming scenarios and serves for interconnection with the SCEF of the Home PLMN and is located in the Visited PLMN
- o SCEF. Service Capability Exposure Function. EPC node for exposure of 3GPP network service capabilities to 3rd party applications.

3. Architecture

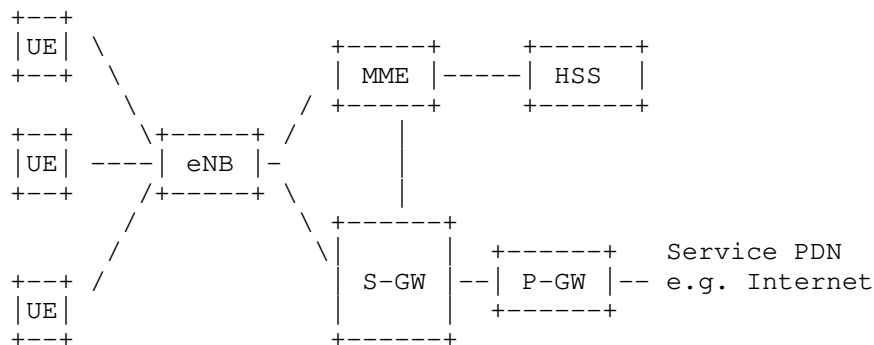


Figure 1: 3GPP network architecture

The architecture for 3GPP LTE network has been reused for NB-IoT with some optimizations and simplifications known as Cellular IoT (CIoT). Considering the typical use cases for CIoT devices here are described some of the additions to the LTE architecture specific for CIoT. C-SGN(CIoT Serving Gateway Node) is a deployment option co-locating EPS entities in the control plane and user plane paths (for example, MME + SGW + P-GW) and the external interfaces of the entities supported. The C-SGN also supports at least some of the following CIoT EPS Optimizations:

- o Control Plane CIoT EPS Optimization for small data transmission.
- o User Plane CIoT EPS Optimization for small data transmission.
- o Necessary security procedures for efficient small data transmission.
- o SMS without combined attach for NB-IoT only UEs.
- o Paging optimizations for coverage enhancements.
- o Support for non-IP data transmission via SGi tunneling and/or SCEF.
- o Support for Attach without PDN (Packet Data Network) connectivity.

Another node introduced in the CIoT architecture is the SCEF (Service Capability Exposure Function) that provide means to securely expose service and network capabilities to entities external to the network operator. The northbound APIS are defined by OMA and OneM2M. The main functions of a SCEF are:

- o Non-IP Data Delivery (NIDD) established through the SCEF.
- o Monitoring and exposure of event related to UE reachability, loss of connectivity, location reporting, roaming status, communication failure and change of IMEI-IMSI association.

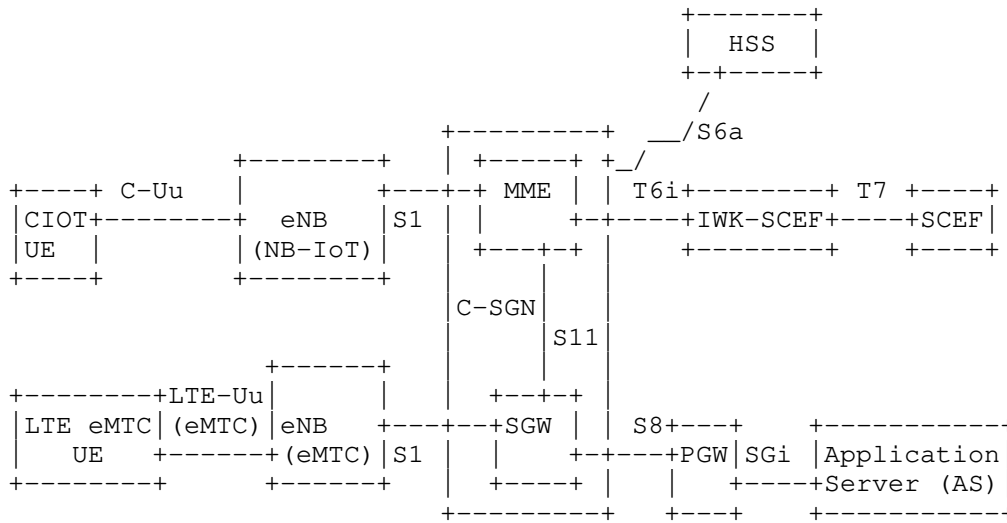


Figure 2: 3GPP optimized CIOT network architecture

4. Data Transmission

3GPP networks deal not only with data transmitted end-to-end but also with in-band signaling that is used between the nodes and functions to configure, control and monitor the system functions and behaviors. The control data is handled using a Control Plane which has a specific set of protocols, handling processes and entities. In contrast, the end-to-end or user data utilize a User Plane with characteristics of its own separated from the Control Plane. The handling and setup of the Control Plane and User Plane spans over the whole 3GPP network and it has particular implications in the radio network (i.e., EUTRAN) and in the packet core (ex., EPC).

For the CIOT cases, additionally to transmissions of data over User Plane, 3GPP has specified optimizations for small data transmissions, allowing to transport user data (IP, Non-IP) within signaling on the access network (Data transmission over Control Plane or Data Over NAS).

The maximum recommended MTU size is 1358 Bytes. The radio network protocols limit the packet sizes to be transmitted over the air including radio protocol overhead to 1600 Octets. But the value is reduced further to avoid fragmentation in the backbone of the network due to the payload encryption size (multiple of 16) and handling of the additional core transport overhead.

NB-IoT and in general the cellular technologies interfaces and functions are standardized by 3GPP. Therefore the introduction of SCHC entities to UE, eNB and C-SGN does need to be specified in the NB-IoT standard. This implies that standard specified SCHC support would not be backwards compatible. A terminal or a network supporting a version of the standard without support of SCHC or without capability implementation (in case of not being standardized as mandatory capability) is not able to utilize the compression services with this approach.

SCHC could be deployed differently depending on where the header compression and the fragmentation are applied. The SCHC functionalities could be applied to the packets about to be transmitted over the air, or to the whole end-to-end link. To accomplish the first, it is required to place SCHC compression and decompression entities in the eNB and in the UE for transmissions over the User Plane. Additionally, to handle the case of the transmissions over Control Plane or Data Over NAS, the network SCHC entity has to be placed in the C-SGN as well. For these two cases, the functions are to be standardized by 3GPP.

Another possibility is to apply SCHC functionalities to the end-to-end connection or at least up to the operator network edge. In that case, the SCHC entities would be placed in the application layer of the terminal in one end, and either in the application servers or in a broker function in the edge of the operator network in the other end. For the radio network, the packets are transmitted as non-IP traffic, which can be currently served utilizing IP tunneling or SCEF services. Since this option does not necessarily require 3GPP standardization, it is possible to also benefit legacy devices with SCHC by utilizing the non-IP transmission features of the operator network.

Accordingly, there are four different scenarios where SCHC can be used in the NB-IoT architecture. IP header compression on the data transmission over User Plane, IP header compression on the optimized transmissions over Control Plane (i.e., DoNAS), non-IP transmissions of SCHC packets by IP tunneling, and non-IP transmissions of SCHC packets by SCEF forwarding. The following sections describe each of them in more detail. The first two scenarios refer to transmissions using the 3GPP IP transmission capabilities and the last two refers to transmission using the Non-IP capabilities.

5. IP based Data Transmission

5.1. SCHC over User Plane transmissions

Deploying SCHC only over the radio link would require to place it as part of the User Plane data transmission. The User Plane utilizes the protocol stack of the Access Stratum (AS) for data transfer. AS (Access Stratum) is the functional layer responsible for transporting data over wireless connection and managing radio resources. The user plane AS has support for features such as reliability, segmentation and concatenation. The transmissions of the AS make use of link adaptation, meaning that the transport format utilized for the transmissions are optimized according to the radio conditions, the number of bits to transmit and the power and interference constrains. That means that the number of bits transmitted over the air depends of the Modulation and Coding Schemes (MCS) selected. The transmissions in the physical layer happens at network synchronized intervals of times called TTI (Transmission Time Interval). The transmission of a Transport Block (TB) is completed during, at least, one TTI. Each Transport Block has a different MCS and number of bits available to transmit. The Transport Blocks characteristics are defined by the MAC technical specification [TGPP36321]. The Access Stratum for User Plane is comprised by Packet Data Convergence Protocol (PDCP) [TGPP36323], Radio Link Protocol (RLC) [TGPP36322], Medium Access Control protocol (MAC) [TGPP36321] and the Physical Layer [TGPP36201]. More details of this protocols are given in the Appendix.

5.1.1. SCHC Entities Placing

The current architecture provides support for header compression in PDCP utilizing RoHC [RFC5795]. Therefore SCHC entities can be deployed in similar fashion without need for major changes in the 3GPP specifications.

In this scenario, RLC takes care of the handling of fragmentation (if transparent mode is not configured) when packets exceeds the transport block size at the time of transmission. Therefore SCHC fragmentation is not needed and should not be used to avoid additional protocol overhead. It is not common to configure RLC in Transparent Mode for IP based user plane data. But given the case in the future, SCHC fragmentation may be used. In that case, a SCHC tile would match the minimum transport block size minus the PDCP and MAC headers.

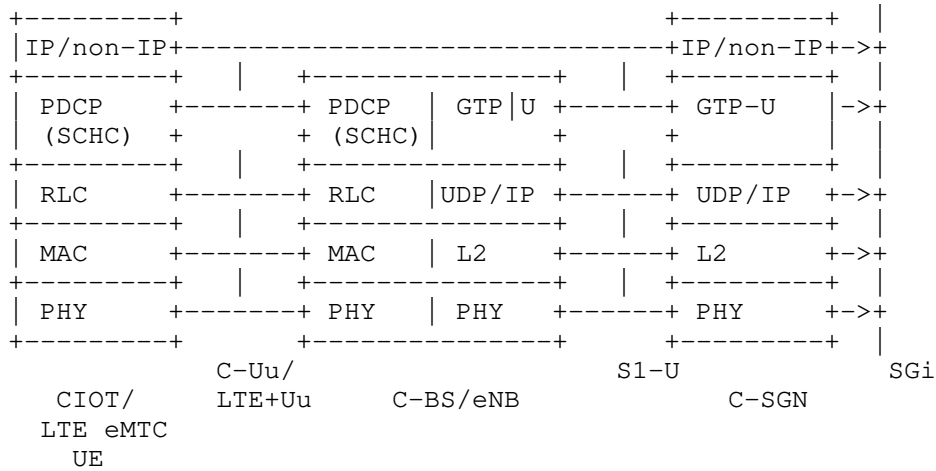


Figure 3: SCHC entities placement in the 3GPP CIoT radio protocol architecture for data over user plane

5.2. Data Over Control Plane

The Non-Access Stratum (NAS), conveys mainly control signaling between the UE and the cellular network [TGPP24301]. NAS is transported on top of the Access Stratum (AS) already mentioned in the previous section.

NAS has been adapted to provide support for user plane data transmissions to reduce the overhead when transmitting infrequent small quantities of data. This is known as Data over NAS (DoNAS) or Control Plane CIoT EPS optimization. In DoNAS the UE makes use of the pre-established NAS security and piggyback uplink small data into the initial NAS uplink message, and uses an additional NAS message to receive downlink small data response.

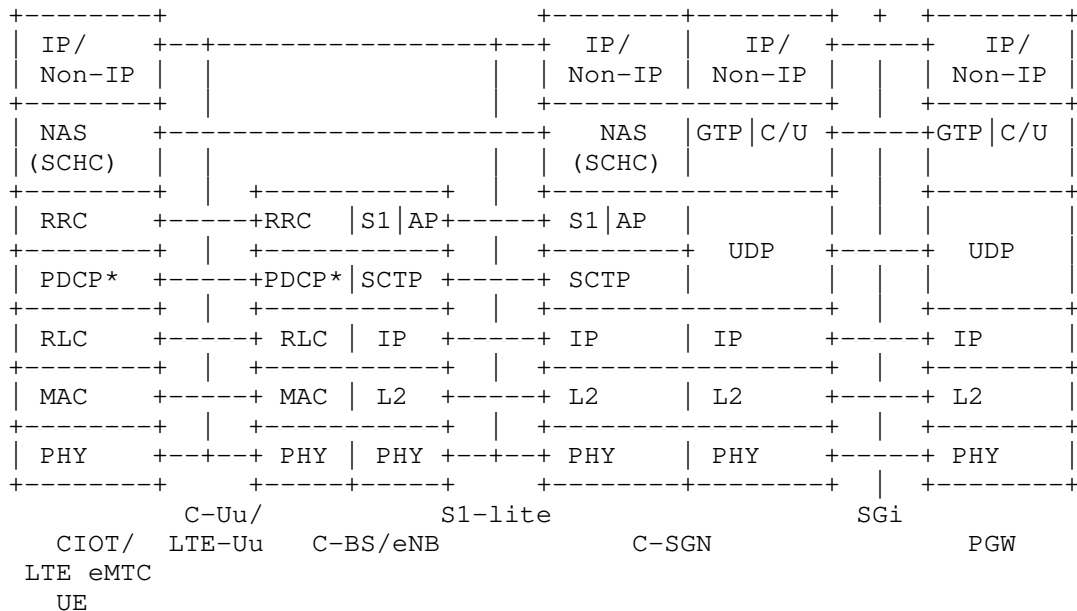
The data encryption from the network side is performed by the C-SGN in a NAS PDU. Depending on the data type signaled indication (IP or non-IP data), the network allocates an IP address or just establish a direct forwarding path. DoNAS (Data over NAS) is regulated under rate control upon previous agreement, meaning that a maximum number of bits per unit of time is agreed per device subscription beforehand and configured in the device.

The use of DoNAS is typically expected when a terminal in a power saving state requires to do a short transmission and receive an acknowledgment or short feedback from the network. Depending on the size of buffered data to transmit, the UE might be instructed to

deploy the connected mode transmissions instead, limiting and controlling the DoNAS transmissions to predefined thresholds and a good resource optimization balance for the terminal and the network. The support for mobility of DoNAS is present but produces additional overhead. Additional details of DoNAS are given in the Appendix.

5.2.1. SCHC Entities Placing

In this scenario SCHC can be applied in the NAS protocol layer instead of PDCP. The same principles than for user plane transmissions applies here as well. The main difference is the physical placing of the SCHC entities in the network side as the C-SGN (placed in the core network) is the terminating node for NAS instead of the eNB.



*PDCP is bypassed until AS security is activated [TGPP36300].

Figure 4

5.3. Parameters for Static Context Header Compression (SCHC)

5.3.1. SCHC Context initialization

RRC (Radio Resource Control) protocol is the main tool used to configure the operation parameters of the AS transmissions for 3GPP technologies. RoHC operation is configured with this protocol and it is to expect that SCHC will be configured and the static context distributed in similar fashion for these scenarios.

5.3.2. SCHC Rules

The number of rules in a context are defined by the network operator in these scenarios. For this, the operator must be aware of the type of IP traffic that the device will carry out. This means that the operator might provision sets of rules compatible with the use case of the device. For devices acting as gateways of other devices several rules that match the diversity of devices and protocols used by the devices associated to the gateway. Meanwhile than simpler devices (for example an electricity meter) may have a predetermined set of protocols and parameters fixed. Additionally, the deployment of IPV4 addresses in addition to IPV6 may force to provision separate rules to deal with each of the cases.

5.3.3. Rule ID

For these transmission scenarios in NB-IoT, a reasonable assumption of 9 bytes of radio protocol overhead can be expected. PDCP 5 bytes due to header and integrity protection, and 4 bytes of RLC and MAC. The minimum physical Transport Block (TB) that can withhold this overhead value according to 3GPP Release 15 specifications are: 88, 104, 120 and 144 bits. If it is wished to optimize the number of transmissions of a very small application packet so that in some cases can be transmitted using only one physical layer transmission, then the SCHC overhead should not exceed the available number of bits of the smallest utile physical TB available. The packets handled by 3GPP networks are byte-aligned, and therefore the minimum payload possible (including padding) is 8 bits. Therefore in order to utilize the smallest TB the maximum SCHC is 8 bits. This must include the Compression Residue in addition to the Rule ID. In the other hand, it is possible that more complex NB-IoT devices (such as a capillarity gateway) might require additional bits to handle the variety and multiple parameters the of higher layer protocols deployed. In that sense, the operator may want to have flexibility on the number and type of rules supported by each device independently, and consequently a configurable value is preferred for these scenarios. The configuration may be set as part of the operation profile agreed together with the context distribution. The Rule Id field size may range for example from 2 bits resulting in 4 rules to a 8 bits value that would yield up to 256 rules which can be

used together with the operators and seems quite a reasonable maximum limit even for a device acting as a NAT. More bits could be configured, but it should take in account the byte-alignment of the expected Compression Residue too. In the minimum TB size case, 2 bits size of Rule Id leave only 6 bits available for Compression Residue.

5.3.4. SCHC MAX_PACKET_SIZE

The Access Stratum can handle the fragmentation of SCHC packets if needed including reliability. Hence the packet size is limited by the MTU possible to be handled by the AS radio protocols that corresponds to 1600 bytes for 3GPP Release 15.

5.3.5. Fragmentation

For these scenarios the SCHC fragmentation functions are recommend to be disabled. The RLC layer of NB-IoT can segment packets in suitable units that fit the selected transport blocks for transmissions of the physical layer. The selection of the blocks is done according to the input of the link adaptation function in the MAC layer and the quantity of data in the buffer. The link adaptation layer may produce different results at each Time Transmission Interval (TTI) resulting in varying physical transport blocks that depends of the network load, interference and number of bits to be transmitted and QoS. Even if setting a value that allows the construction of data units following SCHC tiles principle, the protocol overhead may be greater or equal than allowing the AS radio protocols to take care of the fragmentation natively.

5.3.5.1. Fragmentation in Transparent Mode

If RLC is configured to operate in Transparent Mode, there could be a case to activate a fragmentation function together with a light reliability function such as the ACK-Always mode. In practice, it is very rare to transmit user plane data using this configuration and it is mainly targeting control plane transmissions. In those cases the reliability is normally ensured by MAC based mechanisms, such as repetitions or automatic retransmissions, and additional reliability might only generate protocol overhead.

In future operations, it could be devised the utilization of SCHC to reduce radio network protocols overhead and support the reliability of the transmissions, and targeting small data with the fewer possible transmissions. This could be realized by using fixed or limited set of transport blocks compatible with the tiling SCHC fragmentation handling.

6. Non-IP based Data Transmission

The Non-IP Data Delivery (NIDD) services of 3GPP enable the possibility of transmitting SCHC packets compressed by the application layer. The packets can be delivered by means of IP-tunnels to the 3GPP network or using SCEF functions (i.e., API calls). In both cases the packet IP is not understood by the 3GPP network since it is already compressed and the network does not has information of the context used for compression. Therefore the network will treat the packet as a Non-IP traffic and deliver it to the UE without any other stack element, directly under the L2.

6.1. SCHC Entities Placing

In the two scenarios using NIDD, SCHC entities are located almost in top of the stack. In the terminal, it may be implemented by a application utilizing the NB-IoT connectivity services. In the network side, the SCHC entities are located in the Application Server (AS). The IP tunneling scenario requires that the Application Server sends the compressed packet over an IP connection that is terminated by the 3GPP core network. If instead the SCEF services are used, then it is possible to utilize a API call to transfer the SCHC packets between the core network and the AS, also an IP tunnel could be established by the AS, if negotiated with the SCEF.

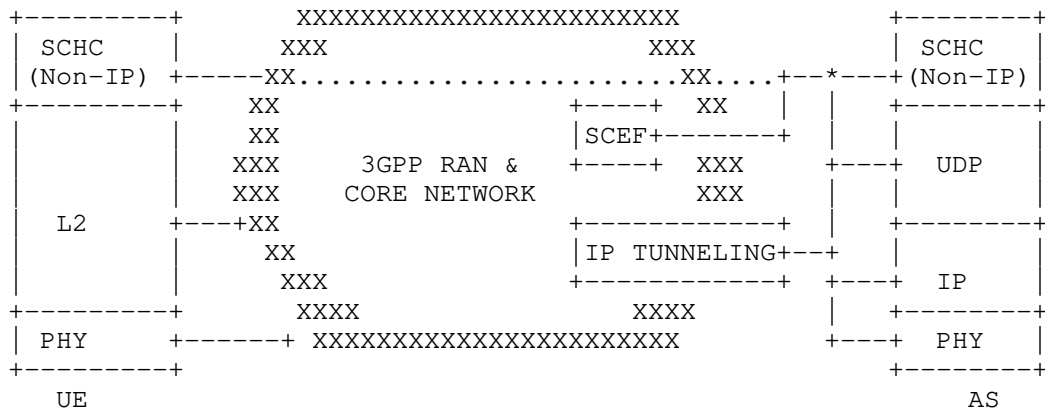


Figure 5: SCHC entities placed when using Non-IP Delivery (NIDD) 3GPP Services

6.2. Parameters for Static Context Header Compression

6.2.1. SCHC Context initialization

The static context is handled in the application layer level, consequently the contexts are required to be distributed according to the applications own capabilities, perhaps utilizing IP data transmissions up to context initialization. Also the same IP tunneling or SCEF services used later for the SCHC packets transport may be used by the applications in both ends to deliver the static contexts to be used.

6.2.2. SCHC Rules

Even when the transmissions content are not visible for the 3GPP network, the same limitations than for IP based data transmissions applies in these scenarios in terms of aiming to use the minimum number of transmission and minimize the protocol overhead.

6.2.3. Rule ID

Similarly to the case of IP transmissions, the Rule ID size can be dynamically set prior the context delivery. For example negotiated between the applications when choosing a profile according to the type of traffic and type of application deployed. Same considerations related to the transport block size and performance mentioned for the IP type of traffic has to be follow when choosing a size value for the Rule ID field.

6.2.4. SCHC MAX_PACKET_SIZE

In these scenarios the maximum recommended MTU size that applies is 1358 Bytes, since the SCHC packets (and fragments) are traversing the whole 3GPP network infrastructure (core and radio), and not only the radio as the IP transmissions case.

6.3. Fragmentation

In principle the fragmentation function should be activated for packets greater than 1358 Bytes. Since the 3GPP reliability functions take great deal care of it, for simple point to point connections may be enough a NO-ACK mode. Nevertheless additional considerations for more complex cases are mentioned in the next subsection to be taken in account.

6.3.1. Fragmentation modes

Depending of the QoS that has been assigned to the packets, it is possible that packets are lost before they arrive to 3GPP radio network transmission, for example in between the links of a capillarity gateway, or due to buffer overflow handling in a backhaul connection. In consequence, it is possible to secure additional reliability on the packets transmitted with a small trade-off on additional transmissions to signal the packets arrival indication end-to-end if no transport protocol takes care of retransmission. To achieve this, the packets fragmentation is activated with the ACK-on-Error mode enabled. In some cases, it is even desirable to keep track of all the SCHC packets delivered, in that case, the fragmentation function could be active for all packets transmitted by the applications (SCHC MAX_PACKET_SIZE == 1 Byte) and the ACK-on-Error mode.

6.3.2. Fragmentation Parameters (TBD)

- o Rule ID
- o DTag
- o FCN
- o W (number of bits)
- o WINDOW_SIZE
- o Retransmission Timer
- o Inactivity Timer
- o MAX_ACK_Retries
- o MAX_ATTEMPS
- o MIC (size and algorithm)

7. Padding

NB-IoT and 3GPP wireless access, in general, assumes byte aligned payload. Therefore the L2 word for NB-IoT MUST be considered 8 bits and the treatment of padding should use this value accordingly.

8. Security considerations

3GPP access security is specified in (TGPP33203).

9. 3GPP References

- o [TGPP23720] 3GPP, "TR 23.720 v13.0.0 - Study on architecture enhancements for Cellular Internet of Things", 2016.
- o [TGPP33203] 3GPP, "TS 33.203 v13.1.0 - 3G security; Access security for IP-based services", 2016.
- o [TGPP36321] 3GPP, "TS 36.321 v13.2.0 - Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification", 2016
- o [TGPP36323] 3GPP, "TS 36.323 v13.2.0 - Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification", 2016.
- o [TGPP36331] 3GPP, "TS 36.331 v13.2.0 - Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification", 2016.
- o [TGPP36300] 3GPP, "TS 36.300 v15.1.0 - Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2", 2018
- o [TGPP24301] 3GPP "TS 24.301 v15.2.0 - Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3", 2018

10. Appendix

10.1. NB-IoT User Plane protocol architecture

10.1.1. Packet Data Convergence Protocol (PDCP)

Each of the Radio Bearers (RB) are associated with one PDCP entity. And a PDCP entity is associated with one or two RLC entities depending of the unidirectional or bi-directional characteristics of the RB and RLC mode used. A PDCP entity is associated either control plane or user plane which independent configuration and functions. The maximum supported size for NB-IoT of a PDCP SDU is 1600 octets. The main services and functions of the PDCP sublayer for NB-IoT for the user plane include:

- o Header compression and decompression by means of ROHC (Robust Header Compression)
- o Transfer of user and control data to higher and lower layers
- o Duplicate detection of lower layer SDUs when re-establishing connection (when RLC with Acknowledge Mode in use for User Plane only)
- o Ciphering and deciphering
- o Timer-based SDU discard in uplink

10.1.2. Radio Link Protocol (RLC)

RLC is a layer-2 protocol that operates between the UE and the base station (eNB). It supports the packet delivery from higher layers to MAC creating packets that are transmitted over the air optimizing the Transport Block utilization. RLC flow of data packets is unidirectional and it is composed of a transmitter located in the transmission device and a receiver located in the destination device. Therefore to configure bi-directional flows, two set of entities, one in each direction (downlink and uplink) must be configured and they are effectively peered to each other. The peering allows the transmission of control packets (ex., status reports) between entities. RLC can be configured for data transfer in one of the following modes:

- o Transparent Mode (TM). In this mode RLC do not segment or concatenate SDUs from higher layers and do not include any header to the payload. When acting as a transmitter, RLC receives SDUs from upper layers and transmit directly to its flow RLC receiver via lower layers. Similarly, an TM RLC receiver would only deliver without additional processing the packets to higher layers upon reception.
- o Unacknowledged Mode (UM). This mode provides support for segmentation and concatenation of payload. The size of the RLC packet depends of the indication given at a particular transmission opportunity by the lower layer (MAC) and are octets aligned. The packet delivery to the receiver do not include support for reliability and the lost of a segment from a packet means a whole packet loss. Also in case of lower layer retransmissions there is no support for re-segmentation in case of change of the radio conditions triggering the selection of a smaller transport block. Additionally it provides PDU duplication detection and discard, reordering of out of sequence and loss detection.

- o Acknowledged Mode (AM). Additional to the same functions supported from UM, this mode also adds a moving windows based reliability service on top of the lower layer services. It also provides support for re-segmentation and it requires bidirectional communication to exchange acknowledgment reports called RLC Status Report and trigger retransmissions is needed. Protocol error detection is also supported by this mode. The mode uses depends of the operator configuration for the type of data to be transmitted. For example, data transmissions supporting mobility or requiring high reliability would be most likely configured using AM, meanwhile streaming and real time data would be map to a UM configuration.

10.1.3. Medium Access Control (MAC)

MAC provides a mapping between the higher layers abstraction called Logical Channels comprised by the previously described protocols to the Physical layer channels (transport channels). Additionally, MAC may multiplex packets from different Logical Channels and prioritize what to fit into one Transport Block if there is data and space available to maximize the efficiency of data transmission. MAC also provides error correction and reliability support by means of HARQ, transport format selection and scheduling information reporting from the terminal to the network. MAC also adds the necessary padding and piggyback control elements when possible additional to the higher layers data.

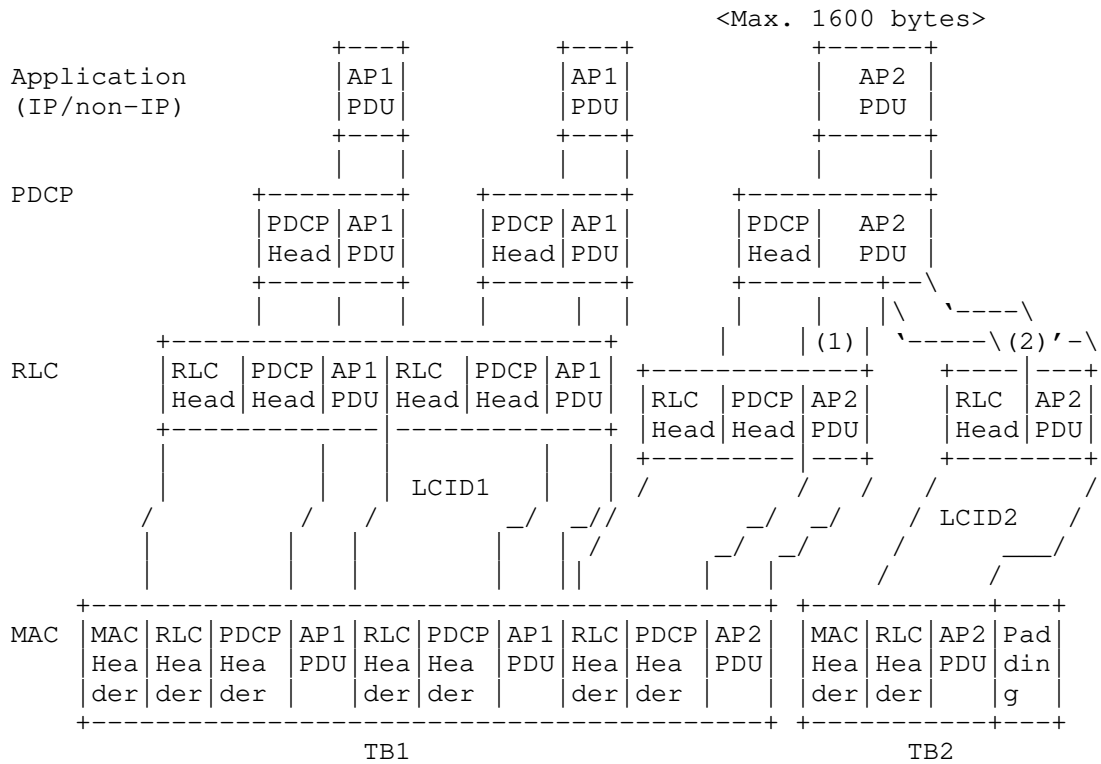


Figure 6: Example of User Plane packet encapsulation for two transport blocks

10.2. NB-IoT Data over NAS (DoNAS)

The AS protocol stack used by DoNAS is somehow special. Since the security associations are not established yet in the radio network, to reduce the protocol overhead, PDCP (Packet Data Convergence Protocol) is bypassed until AS security is activated. RLC (Radio Link Control protocol) is configured by default in AM mode, but depending of the features supported by the network and the terminal it may be configured in other modes by the network operator. For example, the transparent mode does not add any header or does not process the payload in any way reducing the overhead, but the MTU would be limited by the transport block used to transmit the data which is couple of thousand of bits maximum. If UM (only Release 15 compatible terminals) is used, the RLC mechanisms of reliability is disabled and only the reliability provided by the MAC layer by Hybrid Automatic Repeat reQuest (HARQ) is available. In this case, the protocol overhead might be smaller than for the AM case because the

lack of status reporting but with the same support for segmentation up to 16000 Bytes. NAS packet are encapsulated within a RRC (Radio Resource Control) [TGPP36331] message.

Depending of the data type indication signaled (IP or non-IP data), the network allocates an IP address or just establish a direct forwarding path. DoNAS is regulated under rate control upon previous agreement, meaning that a maximum number of bits per unit of time is agreed per device subscription beforehand and configured in the device. The use of DoNAS is typically expected when a terminal in a power saving state requires to do a short transmission and receive an acknowledgment or short feedback from the network. Depending of the size of buffered data to transmit, the UE might be instructed to deploy the connected mode transmissions instead, limiting and controlling the DoNAS transmissions to predefined thresholds and a good resource optimization balance for the terminal and the network. The support for mobility of DoNAS is present but produces additional overhead.

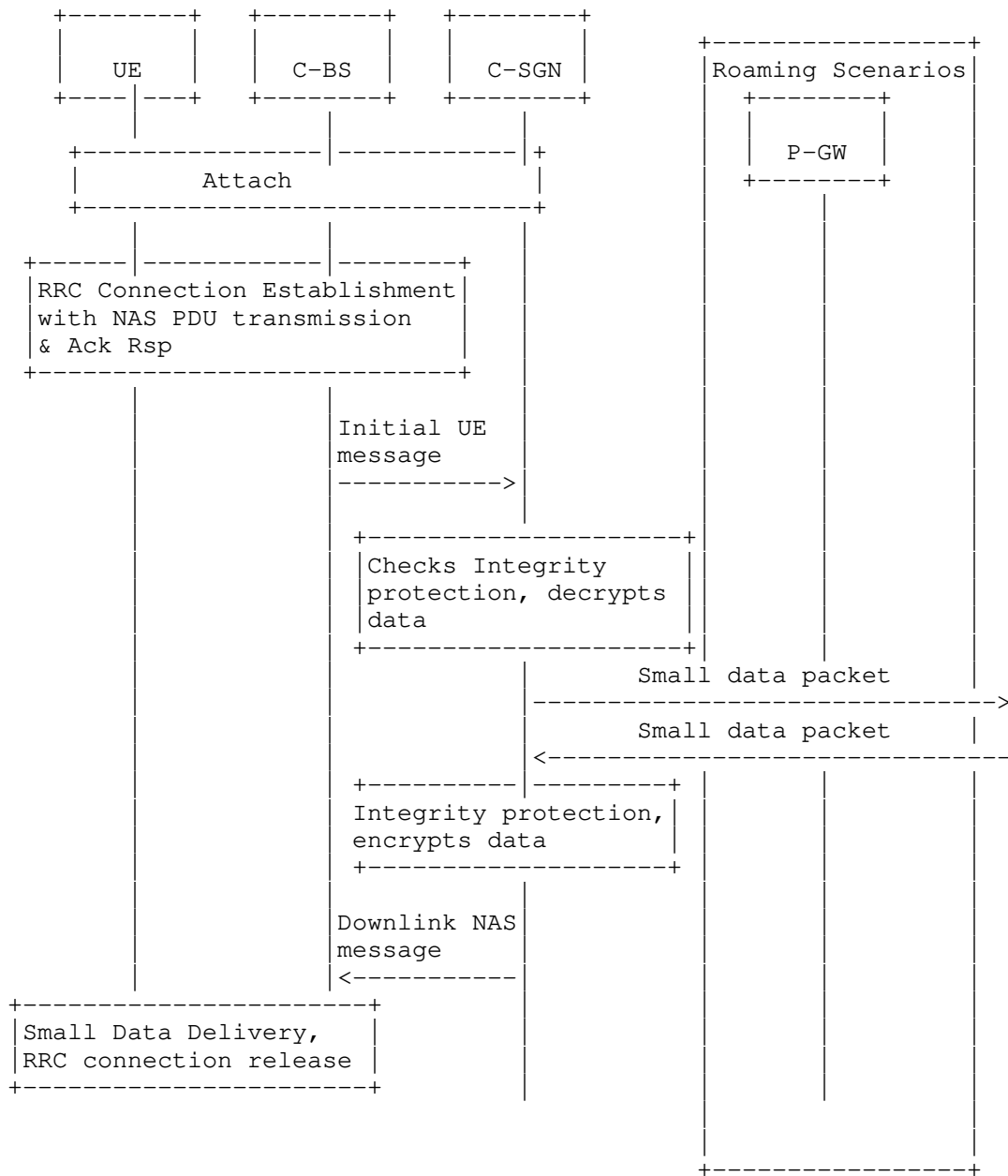


Figure 7: DoNAS transmission sequence from an Uplink initiated access

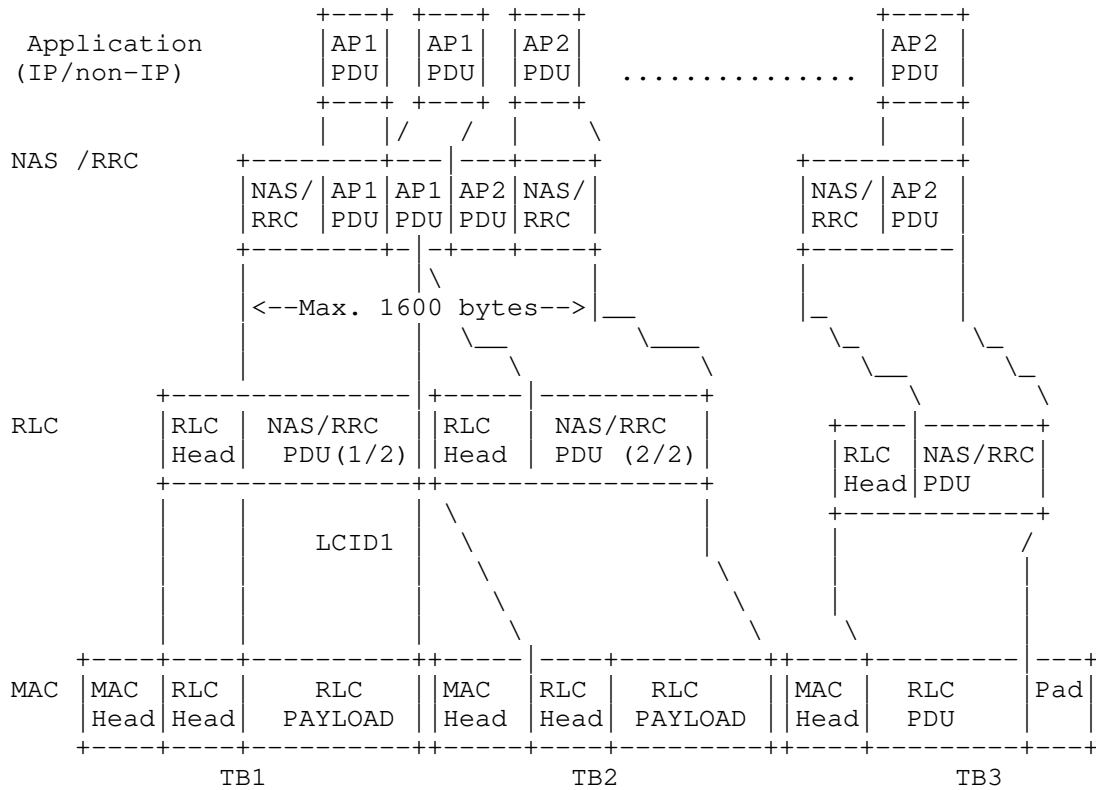


Figure 8: Example of User Plane packet encapsulation for Data over NAS

11. Informative References

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Static Context Header Compression (SCHC) over LoRaWAN
draft-petrov-lpwan-ipv6-schc-over-lorawan-03

Abstract

The Static Context Header Compression (SCHC) specification describes generic header compression and fragmentation techniques for LPWAN (Low Power Wide Area Networks) technologies. SCHC is a generic mechanism designed for great flexibility, so that it can be adapted for any of the LPWAN technologies.

This document provides the adaptation of SCHC for use in LoRaWAN networks, and provides elements such as efficient parameterization and modes of operation.

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1. Introduction

The Static Context Header Compression (SCHC) specification [I-D.ietf-lpwan-ipv6-static-context-hc] describes generic header compression and fragmentation techniques that can be used on all LPWAN (Low Power Wide Area Networks) technologies defined in [I-D.ietf-lpwan-overview]. Even though those technologies share a

great number of common features like start-oriented topologies, network architecture, devices with mostly quite predictable communications, etc; they do have some slight differences in respect of payload sizes, reactivity, etc.

SCHC gives a generic framework that enables those devices to communicate with other Internet networks. However, for efficient performance, some parameters and modes of operation need to be set appropriately for each of the LPWAN technologies.

This document describes the efficient parameters and modes of operation when SCHC is used over LoRaWAN networks.

2. Terminology

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

This section defines the terminology and acronyms used in this document. For all other definitions, please look up the SCHC specification [I-D.ietf-lpwan-ipv6-static-context-hc].

- o DevEUI: an IEEE EUI-64 identifier used to identify the device during the procedure while joining the network (Join Procedure)
- o DevAddr: a 32-bit non-unique identifier assigned to a device statically or dynamically after a Join Procedure (depending on the activation mode)
- o TBD: all significant LoRaWAN-related terms.

3. Static Context Header Compression Overview

This section contains a short overview of Static Context Header Compression (SCHC). For a detailed description, refer to the full specification [I-D.ietf-lpwan-ipv6-static-context-hc].

Static Context Header Compression (SCHC) avoids context synchronization, which is the most bandwidth-consuming operation in other header compression mechanisms such as RoHC [RFC5795]. Based on the fact that the nature of data flows is highly predictable in LPWAN networks, some static contexts may be stored on the Device (Dev). The contexts must be stored in both ends, and it can either be learned by a provisioning protocol or by out of band means or it can be pre-provisioned, etc. The way the context is learned on both sides is out of the scope of this document.

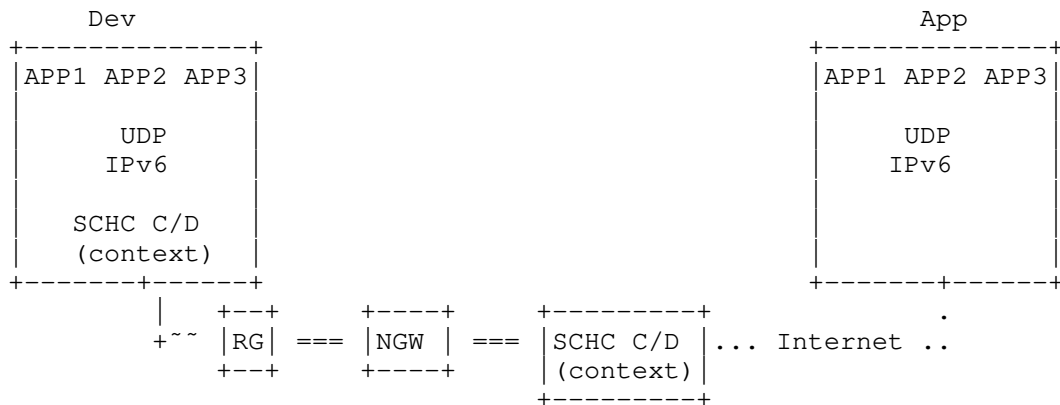


Figure 1: Architecture

Figure 1 represents the architecture for compression/decompression, it is based on [I-D.ietf-lpwan-overview] terminology. The Device is sending applications flows using IPv6 or IPv6/UDP protocols. These flows are compressed by an Static Context Header Compression Compressor/Decompressor (SCHC C/D) to reduce headers size. Resulting information is sent on a layer two (L2) frame to a LPWAN Radio Network (RG) which forwards the frame to a Network Gateway (NGW). The NGW sends the data to a SCHC C/D for decompression which shares the same rules with the Dev. The SCHC C/D can be located on the Network Gateway (NGW) or in another place as long as a tunnel is established between the NGW and the SCHC C/D. The SCHC C/D in both sides must share the same set of Rules. After decompression, the packet can be sent on the Internet to one or several LPWAN Application Servers (App).

The SCHC C/D process is bidirectional, so the same principles can be applied in the other direction.

In a LoRaWAN network, the RG is called a Gateway, the NGW is Network Server, and the SCHC C/D can be embedded in different places, for example in the Network Server and/or the Application Server.

Next steps for this section: detailed overview of the LoRaWAN architecture and its mapping to the SCHC architecture.

4. LoRaWAN Architecture

An overview of LoRaWAN [lora-alliance-spec] protocol and architecture is described in [I-D.ietf-lpwan-overview]. Mapping between the LPWAN architecture entities as described in

[I-D.ietf-lpwan-ipv6-static-context-hc] and the ones in [lora-alliance-spec] is as follows:

- o Devices (Dev) are the end-devices or hosts (e.g. sensors, actuators, etc.). There can be a very high density of devices per radio gateway. This entity maps to the LoRaWAN End-device.
- o The Radio Gateway (RGW), which is the end point of the constrained link. This entity maps to the LoRaWAN Gateway.
- o The Network Gateway (NGW) is the interconnection node between the Radio Gateway and the Internet. This entity maps to the LoRaWAN Network Server.
- o LPWAN-AAA Server, which controls the user authentication and the applications. This entity maps to the LoRaWAN Join Server.
- o Application Server (App). The same terminology is used in LoRaWAN.

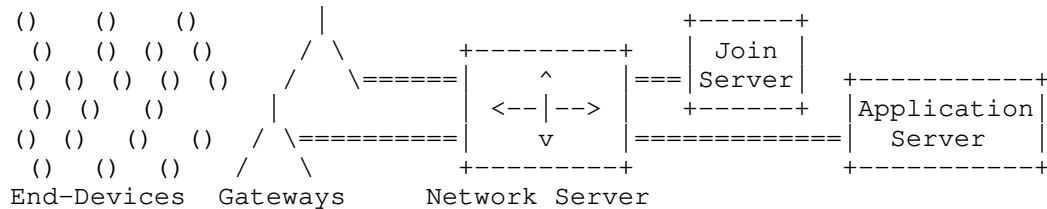


Figure 2: LPWAN Architecture

SCHC C/D (Compressor/Decompressor) and SCHC Fragmentation are performed on the LoRaWAN End-device and the Application Server. While the point-to-point link between the End-device and the Application Server constitutes single IP hop, the ultimate end-point of the IP communication may be an Internet node beyond the Application Server. In other words, the LoRaWAN Application Server acts as the first hop IP router for the End-device. Note that the Application Server and Network Server may be co-located, which effectively turns the Network/Application Server into the first hop IP router.

4.1. Device classes (A, B, C) and interactions

The LoRaWAN MAC layer supports 3 classes of devices named A,B and C. All devices implement the classA, some devices implement classA+B or class A+C. ClassB and classC are mutually exclusive.

- o ***ClassA***: The classA is the simplest class of devices. The device is allowed to transmit at any time, randomly selecting a communication channel. The network may reply with a downlink in one of the 2 receive windows immediately following the uplinks. Therefore, the network cannot initiate a downlink, it has to wait for the next uplink from the device to get a downlink opportunity. The classA is the lowest power device class.
- o ***ClassB***: classB devices implement all the functionalities of classA devices, but also schedule periodic listen windows. Therefore, as opposed the classA devices, classB devices can receive downlink that are initiated by the network and not following an uplink. There is a trade-off between the periodicity of those scheduled classB listen windows and the power consumption of the device. The lower the downlink latency, the higher the power consumption.
- o ***ClassC***: classC devices implement all the functionalities of classA devices, but keep their receiver open whenever they are not transmitting. ClassC devices can receive downlinks at any time at the expense of a higher power consumption. Battery powered devices can only operate in classC for a limited amount of time (for example for a firmware upgrade over the air). Most of the classC devices are main powered (for example Smart Plugs).

4.2. Device addressing

LoRaWAN devices use a 32bits network address (devAddr) to communicate with the network over the air. However that address might be reused several time on the same network at the same time for different devices. Devices using the same devAddr are distinguish by the network server based on the cryptographic signature appended to every single LoRaWAN MAC frame, as all devices use different security keys. To communicate with the SCHC gateway the network server MUST identify the devices by a unique 64bits device ID called the devEUI. Unlike devAddr, devEUI is guaranteed to be unique for every single device across all networks. The devEUI is assigned to the device during the manufacturing process by the device's manufacturer. The devEUI is built like an Ethernet MAC address by concatenating the manufacturer's IEEE 24bits OUI field with a 40bits serial number. The network server translates the devAddr into a devEUI in the uplink direction and reciprocally on the downlink direction.

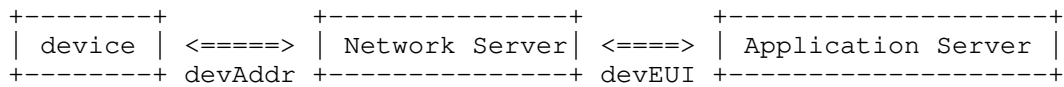


Figure 3: LoRaWAN addresses

4.3. General Message Types

- o Confirmed messages:
- o Unconfirmed messages:

4.4. LoRaWAN MAC Frames

- o JoinRequest
- o JoinAccept
- o Data

5. SCHC over LoRaWAN

5.1. Rule ID management

The LoRaWAN MAC layers features a port field in all frames. This port field (FPort) is 8bit long and the values from 1 to 220 can be used. SCHC over LoRaWAN uses 2 contiguous FPort value to separate the uplink SCHC traffic from the downlink and avoid any confusion. Those FPorts are called FPortUp and FPortDwn. Those FPorts can use arbitrary values inside the allowed Fport range but must be shared by the end-device and SCHC gateway.

SCHC over LoRAWAN SHOULD support encoding RuleID on 3 bits, there are therefore 8 possible RuleIds on both uplink and downlink direction.

The RuleID 0 is reserved for fragmentation in both directions. The 7 remaining RuleIDs are available for IPV6 header compression. Uplink (on FPortUp) and downlink (on FportDwn) RuleIDs are independent. The same RuleID may have different meanings on the uplink and downlink paths.

The only uplink messages using the FportDwn port are the fragmentation SCHC ACKs messages of a downlink fragmentation session. Similarly, the only downlink messages using the FportUp port are the fragmentation SCHC ACKs messages of an uplink fragmentation session

5.2. IID computation

TBD (To discuss with the SCHC authors).

5.3. No compression packets are sent using Rule ID 7.

5.4. Fragmentation

The L2 word size used by LoRaWAN is 1 octet (8 bits). The SCHC fragmentation over LoRaWAN exclusively uses the ACK-always mode. A LoRaWAN device cannot support simultaneous interleaved fragmentation sessions in the same direction (uplink or downlink). This means that only a single fragmented IPV6 datagram may be transmitted and/or received by the device at a given moment. The fragmentation parameters are different for uplink and downlink fragmentation sessions and are successively described in the next sections.

5.4.1. Uplink fragmentation: From device to gateway

In that case the device is the fragmentation transmitter, and the SCHC gateway the fragmentation receiver.

- o SCHC fragmentation reliability mode : "ACK_ALWAYS"
- o Window size: 8, the FCN field is encoded on 3 bits
- o DTag : 1bit. this field is used to clearly separate two consecutive fragmentation sessions. A LoRaWAN device cannot interleave several fragmented SCHC datagrams.
- o MIC calculation algorithm: CRC32 using 0xEDB88320 (i.e. the reverse representation of the polynomial used e.g. in the Ethernet standard [RFC3385])
- o Retransmission Timer and inactivity Timer: LoRaWAN devices do not implement a "retransmission timer". At the end of a window the ACK corresponding to this window is transmitted by the network gateway in the RX1 or RX2 receive slot of the device. If this ACK is not received the device sends an all-0 (or an all-1) fragment with no payload to request an ACK retransmission. The periodicity between retransmission of the all-0/all-1 fragments is device/application specific and may be different for each device (not specified). The gateway implements an "inactivity timer". The default recommended duration of this timer is 12h. This value is mainly driven by application requirements and may be changed.

RuleID	DTag	W	FCN	Payload	
+ -----	+ -----	+ -----	+ -----	+ -----	+ -----
3 bits	1 bit	1 bit	3 bits		

Figure 4: All fragment except the last one. Header size is 8 bits.

RuleID	DTag	W	FCN	MIC	Payload	
+ -----	+ -----	+ -----	+ -----	+ -----	+ -----	+ -----
3 bits	1 bit	1 bit	3 bits	32 bits		

Figure 5: All-1 fragment detailed format for the last fragment.
Header size is 8 bits.

The format of an all-0 or all-1 acknowledge is:

RuleID	DTag	W	Encoded bitmap	Padding (0s)	
+ -----	+ -----	+ -----	+ -----	+ -----	+ -----
3 bits	1 bit	1 bit	3 or 8 bits	0 or 3 bits	

Figure 6: ACK format for All-0 windows. Header size is 1 or 2 bytes.

RuleID	DTag	W	C	Encoded bitmap (if C = 0)	Padding (0s)	
+ -----	+ -----	+ -----	+ -----	+ -----	+ -----	+ -----
3 bits	1 bit	1 bit	1 bit	2 or 8 bits	0 or 2 bits	

Figure 7: ACK format for All-1 windows. Header size is 1 or 2 bytes.

5.4.2. Downlinks: From gateway to device

In that case the device is the fragmentation receiver, and the SCHC gateway the fragmentation transmitter. The following fields are common to all devices.

- o SCHC fragmentation reliability mode : ACK_ALWAYS
- o Window size : 1 , The FCN field is encoded on 1 bits
- o DTag : 1bit. This field is used to clearly separate two consecutive fragmentation sessions. A LoRaWAN device cannot interleave several fragmented SCHC datagrams.
- o MIC calculation algorithm: CRC32 using 0xEDB88320 (i.e. the reverse representation of the polynomial used e.g. in the Ethernet standard [RFC3385])

- o MAX_ACK_REQUESTS : 8

RuleID	DTag	W	FCN	Payload
-----	-----	-----	-----	-----
3 bits	1 bit	1 bit	1 bits	X bytes + 2 bits

Figure 8: All fragments but the last one. Header size is 6 bits.

RuleID	DTag	W	FCN	MIC	Payload	Padding (0s)
-----	-----	-----	-----	-----	-----	-----
3 bits	1 bit	1 bit	1 bits	32 bits	X bytes	0 to 7 bits

Figure 9: All-1 Fragment Detailed Format for the Last Fragment.
Header size is 6 bits.

The format of an all-0 or all-1 acknowledge is:

RuleID	DTag	W	Encoded bitmap	Padding (0s)
-----	-----	-----	-----	-----
3 bits	1 bit	1 bit	1 bit	2 bits

Figure 10: ACK format for All-0 windows. Header size is 8 bits.

RuleID	DTag	W	C = 1	Padding (0s)
-----	-----	-----	-----	-----
3 bits	1 bit	1 bit	1 bit	2 bits

Figure 11: ACK format for All-1 windows, MIC is correct. Header size is 8 bits.

RuleID	DTag	W	b'111	0xFF (all 1's)
-----	-----	-----	-----	-----
3 bits	1 bit	1 bit	3 bits	8 bits

Figure 12: Receiver ABORT packet (following an all-1 packet with incorrect MIC). Header size is 16 bits.

Class A and classB&C devices do not manage retransmissions and timers in the same way.

5.4.2.1. Class A devices

Class A devices can only receive in an RX slot following the transmission of an uplink. Therefore there cannot be a concept of "retransmission timer" for a gateway talking to classA devices for downlink fragmentation.

The device replies with an ACK fragment to every single fragment received from the gateway (because the window size is 1). Following the reception of a FCN=0 fragment (fragment that is not the last fragment of the packet or ACK-request), the device MUST transmit the ACK fragment until it receives the fragment of the next window. The device shall transmit up to MAX_ACK_REQUESTS ACK fragments before aborting. The device should transmit those ACK as soon as possible while taking into consideration eventual local radio regulation on duty-cycle, to progress the fragmentation session as quickly as possible. The ACK bitmap is 1 bit long and is always 1.

Following the reception of a FCN=1 fragment (the last fragment of a datagram) and if the MIC is correct, the device shall transmit the ACK with the "MIC is correct" indicator bit set. This message might be lost therefore the gateway may request a retransmission of this ACK in the next downlink. The device SHALL keep this ACK message in memory until it receives a downlink from the gateway different from an ACK-request indicating that the gateway has received the ACK message.

Following the reception of a FCN=1 fragment (the last fragment of a datagram) and if the MIC is NOT correct, the device shall transmit a receiver-ABORT fragment. The device SHALL keep this ABORT message in memory until it receives a downlink from the gateway different from an ACK-request indicating that the gateway has received the ABORT message. The fragmentation receiver (device) does not implement retransmission timer and inactivity timer.

The fragmentation sender (the gateway) implements an inactivity timer with default duration 12 hours. Once a fragmentation session is started, if the gateway has not received any ACK or receiver-ABORT message 12 hours after the last message from the device was received, the gateway may flush the fragmentation context. For devices with very low transmission rates (example 1 packet a day in normal operation) , that duration may be extended, but this is application specific.

5.4.2.2. Class B or C devices

Class B&C devices can receive in scheduled RX slots or in RX slots following the transmission of an uplink. The device replies with an ACK fragment to every single fragment received from the gateway (because the window size is 1). Following the reception of a FCN=0 fragment (fragment that is not the last fragment of the packet or ACK-request), the device MUST always transmit the corresponding ACK fragment even if that fragment has already been received. The ACK bitmap is 1 bit long and is always 1. If the gateway receives this ACK, it proceeds to send the next window fragment. If the retransmission timer elapses and the gateway has not received the ACK of the current window it retransmits the last fragment. The gateway tries retransmitting up to MAX_ACK_REQUESTS times before aborting.

Following the reception of a FCN=1 fragment (the last fragment of a datagram) and if the MIC is correct, the device shall transmit the ACK with the "MIC is correct" indicator bit set. If the gateway receives this ACK, the current fragmentation session has succeeded and its context can be cleared.

If the retransmission timer elapses and the gateway has not received the all-1 ACK it retransmits the last fragment with the payload (not an ACK-request without payload). The gateway tries retransmitting up to MAX_ACK_REQUESTS times before aborting.

The device SHALL keep the all-1 ACK message in memory until it receives a downlink from the gateway different from the last (FCN=1) fragment indicating that the gateway has received the ACK message. Following the reception of a FCN=1 fragment (the last fragment of a datagram) and if the MIC is NOT correct, the device shall transmit a receiver-ABORT fragment. The retransmission timer is used by the gateway (the sender), the optimal value is very much application specific but here are some recommended default values. For classB devices, this timer trigger is a function of the periodicity of the classB ping slots. The recommended value is equal to 3 times the classB ping slot periodicity. For classC devices which are nearly constantly receiving, the recommended value is 30 seconds. This means that the device shall try to transmit the ACK within 30 seconds of the reception of each fragment. The inactivity timer is implemented by the device to flush the context in-case it receives nothing from the gateway over an extended period of time. The recommended value is 12 hours for both classB&C devices.

6. Security considerations

As this document is only providing parameters that are expected to be better suited for LoRaWAN networks for [I-D.ietf-lpwan-ipv6-static-context-hc]. As such, this parameters does not contribute to any new security issues in addition of those identified in [I-D.ietf-lpwan-ipv6-static-context-hc].

7. Acknowledgements

TBD

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Appendix A. Examples

Appendix B. Note

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SCHC over Sigfox LPWAN
draft-zuniga-lpwan-schc-over-sigfox-06

Abstract

The Static Context Header Compression (SCHC) specification describes a header compression scheme and a fragmentation functionality for Low Power Wide Area Network (LPWAN) technologies. SCHC offers a great level of flexibility that can be tailored for different LPWAN technologies.

The present document provides the optimal parameters and modes of operation when SCHC is implemented over a Sigfox LPWAN.

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1. Introduction

The Static Context Header Compression (SCHC) specification [I-D.ietf-lpwan-ipv6-static-context-hc] defines a header compression scheme and a fragmentation functionality. Both can be used on top of all the LPWAN systems defined in [RFC8376]. These LPWAN systems have similar characteristics such as star-oriented topologies, network architecture, connected devices with built-in applications, etc.

SCHC offers a great level of flexibility to accommodate all these LPWAN systems. Even though there are a great number of similarities between LPWAN technologies, some differences exist with respect to the transmission characteristics, payload sizes, etc. Hence, there are optimal parameters and modes of operation that can be used when SCHC is used on top of a specific LPWAN.

This document describes the recommended parameters and modes of operation to be used when SCHC is implemented over a Sigfox LPWAN.

2. Terminology

It is assumed that the reader is familiar with the terms and mechanisms defined in [RFC8376] and in [I-D.ietf-lpwan-ipv6-static-context-hc].

3. Static Context Header Compression

The Static Context Header Compression (SCHC) described in [I-D.ietf-lpwan-ipv6-static-context-hc] takes advantage of the predictability of data flows existing in LPWAN networks to avoid context synchronization. Nonetheless, these contexts must be stored and configured on both ends. This can be done either by using a provisioning protocol, by out of band means, or by pre-provisioning them (for instance at manufacturing time). The way the contexts are configured and stored on both ends is out of the scope of this document.

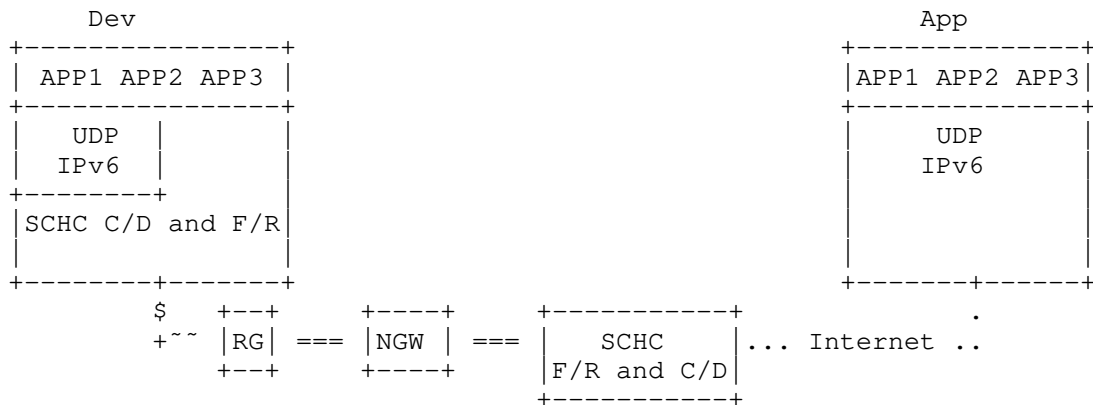


Figure 1: Architecture

Figure 1 represents the architecture for compression/decompression and fragmentation/reassembly, which is based on [RFC8376] terminology, where the Radio Gateway is a Sigfox Base Station and the Network Gateway is the Sigfox Cloud.

The Device is sending applications flows that are compressed and/or fragmented by a Static Context Header Compression Compressor/Decompressor (SCHC C/D) to reduce headers size and/or fragment the packet. The resulting information is sent over a layer two (L2) frame to a LPWAN Radio Gateway (RG) which forwards the frame to a Network Gateway (NGW).

4. SCHC over Sigfox

In the case of the global Sigfox network, RGs (or base stations) are distributed over the multiple countries where the Sigfox LPWAN service is provided. On the other hand, the NGW (or Cloud-based Core network) is a single entity that connects to all Sigfox base stations in the world.

Uplink Sigfox transmissions occur in repetitions over different times and frequencies. Besides these time and frequency diversities, the Sigfox network also provides space diversity, as potentially an uplink message will be received by several base stations. Since all messages are self-contained and base stations forward them all back to the same Core network (NGW), multiple input copies can be combined at the NGW and hence provide for extra reliability based on the triple diversity (i.e. time, space and frequency). A detailed description of the Sigfox Radio Protocol can be found in [sigfox-spec].

The NGW communicates with the Network SCHC C/D for compression/decompression and/or for fragmentation/reassembly. The Network SCHC C/D shares the same set of rules as the Dev SCHC C/D. The Network SCHC C/D can be collocated with the NGW or it could be in another place, as long as a tunnel is established between the NGW and the SCHC C/D. After decompression and/or reassembly, the packet can be forwarded over the Internet to one (or several) LPWAN Application Server(s) (App).

The SCHC C/D process is bidirectional, so the same principles can be applied on both uplink and downlink.

4.1. SCHC Rules

The RuleID MUST be sent at the beginning of the SCHC header. The total number of rules to be used affects directly the Rule ID field size, and therefore the total size of the fragmentation header. For this reason, it is recommended to keep the number of rules that are defined for a specific device to the minimum possible.

4.2. Packet processing

TBD

5. Fragmentation

The SCHC specification [I-D.ietf-lpwan-ipv6-static-context-hc] defines a generic fragmentation functionality that allows sending data packets larger than the maximum size of a Sigfox data frame.

The functionality also defines a mechanism to send reliably multiple frames, by allowing to resend selectively any lost frames.

The SCHC fragmentation supports several modes of operation. These modes have different advantages and disadvantages depending on the specifics of the underlying LPWAN technology and Use Case. This section describes how the SCHC fragmentation functionality should optimally be implemented when used over a Sigfox LPWAN for the most typical use case applications.

5.1. Fragmentation headers

A list of fragmentation header fields, their sizes as well as suggested modes for SCHC fragmentation over Sigfox are provided in this section.

5.2. Uplink fragment transmissions

Uplink transmissions are completely asynchronous and can take place in any random frequency of the allowed uplink bandwidth allocation. Hence, devices can go to deep sleep mode, and then wake up and transmit whenever there is a need to send any information to the network. In that way, there is no need to perform any network attachment, synchronization, or other procedure before transmitting a data packet. All data packets are self contained with all the required information for the network to process them accordingly.

Since uplink transmissions occur asynchronously, an SCHC fragment can be transmitted at any given time by the Dev.

5.2.1. Uplink No-ACK mode

No-ACK is RECOMMENDED to be used for transmitting short, non-critical packets that require fragmentation.

The recommended Fragmentation Header size is 8 bits, and it is composed as follows:

The recommended Rule ID size is: 2 bits

The recommended DTag size (T) is: 2 bits

Fragment Compressed Number (FCN) size (N): 4 bits

As per [I-D.ietf-lpwan-ipv6-static-context-hc], in the No-ACK mode the W (window) field is not present.

When fragmentation is used to transport IP frames, the Message Integrity Check (MIC) size, M: TBD bits

The algorithm for computing the MIC field MUST be TBD.

5.2.2. Uplink ACK-Always mode

TBD

5.2.3. Uplink ACK-on-Error mode

ACK-on-Error is RECOMMENDED for larger packets that need to be sent reliably, since it leads to a reduced number of ACKs in the lower capacity downlink channel.

In the most generic case, the Fragmentation Header size is 8 bits and it is composed as follows:

The recommended Rule ID size is: 2 bits.

The recommended DTag size (T) is: 1 bit.

The recommended Window (W) size is: 2 bits.

Fragment Compressed Number (FCN) size (N): 3 bits.

For the ACK-on-Error fragmentation mode(s), a single window size is RECOMMENDED.

The value of MAX_ACK_REQUESTS SHOULD be 2, and the value of MAX_WIND_FCN SHOULD be 6 (or 0b110, which allows a maximum window size of 7 fragments).

When fragmentation is used to transport IP frames, the Message Integrity Check (MIC) size, M: TBD bits

The algorithm for computing the MIC field MUST be TBD.

5.3. Downlink fragment transmissions

In some LPWAN technologies, as part of energy-saving techniques, downlink transmission is only possible immediately after an uplink transmission. This allows the device to go in a very deep sleep mode and preserve battery, without the need to listen to any information from the network. This is the case for Sigfox-enabled devices, which can only listen to downlink communications after performing an uplink transmission and requesting a downlink.

When there are fragments to be transmitted in the downlink, an uplink message is required to trigger the downlink communication. In order to avoid potentially high delay for fragmented datagram transmission in the downlink, the fragment receiver MAY perform an uplink transmission as soon as possible after reception of a downlink fragment that is not the last one. Such uplink transmission MAY be triggered by sending a SCHC message, such as a SCHC ACK. However, other data messages can equally be used to trigger DL communications.

For reliable downlink fragment transmission, the ACK-Always mode is RECOMMENDED.

The recommended Fragmentation Header size is: 8 bits

The recommended Rule ID size is: 2 bits.

The recommended DTag size (T) is: 2 bits.

Fragment Compressed Number (FCN) size (N): 3 bits.

As per [I-D.ietf-lpwan-ipv6-static-context-hc], in the ACK-Always mode a Window (W) 1-bit field must be present.

For the ACK-Always fragmentation mode(s), a single window size is RECOMMENDED.

The value of MAX_ACK_REQUESTS SHOULD be 2, and the value of MAX_WIND_FCN SHOULD be 6 (or 0b110, which allows a maximum window size of 7 fragments).

When fragmentation is used to transport IP frames, the Message Integrity Check (MIC) size, M: TBD bits

The algorithm for computing the MIC field MUST be TBD.

Sigfox downlink frames have a fixed length of 8 bytes, which means that default SCHC algorithm for padding cannot be used. Therefore, the 3 last bits of the fragmentation header are used to indicate in bytes the size of the padding. A size of 000 means that the full remaining frame is used to carry payload, a value of 001 indicates that the last byte contains padding, and so on.

6. Padding

The Sigfox payload fields have different characteristics in uplink and downlink.

Uplink frames can contain a payload size from 0 to 96 bits, that is 0 to 12 bytes. The radio protocol allows sending zero bits or one single bit of information for binary applications (e.g. status), or an integer number of bytes. Therefore, for 2 or more bits of payload it is required to add padding to the next integer number of bytes. The reason for this flexibility is to optimize transmission time and hence save battery consumption at the device.

Downlink frames on the other hand have a fixed length. The payload length must be 64 bits (i.e. 8 bytes). Hence, if less information bits are to be transmitted, padding would be necessary and it should be performed as described in the previous section.

7. Security considerations

The radio protocol authenticates and ensures the integrity of each message. This is achieved by using a unique device ID and an AES-128 based message authentication code, ensuring that the message has been generated and sent by the device with the ID claimed in the message.

Application data can be encrypted at the application level or not, depending on the criticality of the use case. This flexibility allows providing a balance between cost and effort vs. risk. AES-128 in counter mode is used for encryption. Cryptographic keys are independent for each device. These keys are associated with the device ID and separate integrity and confidentiality keys are pre-provisioned. A confidentiality key is only provisioned if confidentiality is to be used.

The radio protocol has protections against reply attacks, and the cloud-based core network provides firewalling protection against undesired incoming communications.

8. Acknowledgements

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