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

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

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

This document also specifies a fragmentation and reassembly mechanism that is 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 two maximum payload size.

The SCHC header compression and fragmentation mechanisms are independent of the specific LPWAN technology over which they are used. Note that this document defines generic functionalities and advisedly offers flexibility with regard to parameter settings and mechanism choices. Such settings and choices are expected to be made in other technology-specific documents.

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This Internet-Draft will expire on December 31, 2018.

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1. Introduction

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

Header compression is needed to efficiently bring Internet connectivity to the node within an LPWAN network. Some LPWAN networks properties can be exploited to get an efficient header compression:

- The network topology is star-oriented, which means that all packets 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 Network Gateways (NGW).

- Because devices embed built-in applications, the traffic flows to be compressed are known in advance. Indeed, new applications cannot be easily installed in LPWAN devices, as they would in computers or smartphones.

The Static Context Header Compression (SCHC) is defined for this environment. SCHC uses a context, in which information about header fieds is stored. This context is static: the values of the header fields do not change over time. This avoids complex resynchronization mechanisms, that would be incompatible with LPWAN characteristics. In most cases, a small context 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.

LPWAN technologies impose some strict limitations on traffic. For instance, devices are sleeping most of the time and MAY receive data during short periods of time after transmission to preserve battery. LPWAN technologies are also characterized, among others, by a very reduced data unit and/or payload size (see [RFC8376]). However, some of these technologies do not provide fragmentation functionality, therefore the only option for them to support the IPv6 MTU requirement of 1280 bytes [RFC8200] is to use a fragmentation protocol at the adaptation layer, below IPv6. In response to this need, this document also defines a fragmentation/reassembly mechanism, which supports the IPv6 MTU requirement over LPWAN technologies. Such functionality has been designed under the assumption that there is no out-of-sequence delivery of data units between the entity performing fragmentation and the entity performing reassembly.

Note that this document defines generic functionality and purposefully offers flexibility with regard to parameter settings and mechanism choices. Such settings and choices are expected to be made in other, technology-specific 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 technologies have similar network architectures but different terminologies. Using the terminology defined in [RFC8376], we can identify different types of 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), which 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 LPWAN-AAA Server, which controls the user authentication and the applications.

o Application Server (App)

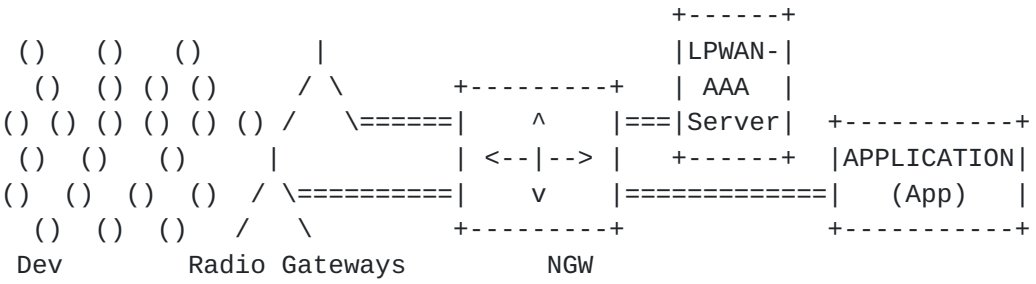


Figure 1: LPWAN Architecture

4. Terminology

This section defines the terminology and acronyms used in this document.

Note that 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".

- Abort. A SCHC Fragment format to signal the other end-point that the on-going fragment transmission is stopped and finished.

- All-0. The SCHC Fragment format for the last fragment of a window that is not the last one of a SCHC Packet (see window in this glossary).

- All-1. The SCHC Fragment format for the last fragment of the SCHC Packet.

- All-0 empty. An All-0 SCHC Fragment without payload. It is used to request the SCHC ACK with the encoded Bitmap when the Retransmission Timer expires, in a window that is not the last one of a packet.

- All-1 empty. An All-1 SCHC Fragment without payload. It is used to request the SCHC ACK with the encoded Bitmap when the Retransmission Timer expires in the last window of a packet.

- App: LPWAN Application. An application sending/receiving IPv6 packets to/from the Device.

- AppIID: Application Interface Identifier. The IID that identifies the application server interface.

- Bi: Bidirectional. Characterises a Rule Entry that applies to headers of packets travelling in either direction (Up and Dw, see this glossary).

- Bitmap: a bit field in the SCHC ACK message that tells the sender which SCHC Fragments in a window of fragments were correctly received.

- C: Checked bit. Used in an acknowledgement (SCHC ACK) header to determine if the MIC locally computed by the receiver matches (1) the received MIC or not (0).

- CDA: Compression/Decompression Action. Describes the reciprocal pair of actions that are performed at the compressor to compress a

header field and at the decompressor to recover the original header field value.

- Compression Residue. The bits that need to be sent (beyond the Rule ID itself) after applying the SCHC compression over each header field.

- Context: A set of Rules used to compress/decompress headers.

- Dev: Device. A node connected to an LPWAN. A Dev SHOULD implement SCHC.

- DevIID: Device Interface Identifier. The IID that identifies the Dev interface.

- DI: Direction Indicator. This field tells which direction of packet travel (Up, Dw or Bi) a Rule applies to. This allows for assymmetric processing.

- DTag: Datagram Tag. This SCHC F/R header field is set to the same value for all SCHC Fragments carrying the same SCHC Packet.

- Dw: Downlink direction for compression/decompression in both sides, from SCHC C/D in the network to SCHC C/D in the Dev.

- FCN: Fragment Compressed Number. This SCHC F/R header field carries an efficient representation of a larger-sized fragment number.

- Field Description. A line in the Rule table.

- FID: Field Identifier. This is an index to describe the header fields in a Rule.

- FL: Field Length is the length of the packet header field. It is expressed in 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.

- FP: Field Position is a value that is used to identify the position where each instance of a field appears in the header.

- IID: Interface Identifier. See the IPv6 addressing architecture [RFC7136]

- Inactivity Timer. A timer used after receiving a SCHC Fragment to detect when, due to a communication error, there is no possibility to continue an on-going fragmented SCHC Packet transmission.

- L2: Layer two. The immediate lower layer SCHC interfaces with. It is provided by an underlying LPWAN technology.

- 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.

- MIC: Message Integrity Check. A SCHC F/R header field computed over the fragmented SCHC Packet and potential fragment padding, used for error detection after SCHC Packet reassembly.

- MO: Matching Operator. An operator used to match a value contained in a header field with a value contained in a Rule.

- 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.

- Retransmission Timer. A timer used by the SCHC Fragment sender during an on-going fragmented SCHC Packet transmission to detect possible link errors when waiting for a possible incoming SCHC ACK.

- Rule: A set of header field values.

- Rule entry: A column in a Rule that describes a parameter of the header field.

- Rule ID: 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.

- SCHC ACK: A SCHC acknowledgement for fragmentation. This message is used to report on the success of reception of a set of SCHC Fragments. See Section 8 for more details.

- SCHC C/D: Static Context Header Compression Compressor/ Decompressor. A mechanism used on both sides, at the Dev and at the network, to achieve Compression/Decompression of headers. SCHC C/D uses Rules to perform compression and decompression.

- SCHC F/R: Static Context Header Compression Fragmentation/ Reassembly. A protocol used on both sides, at the Dev and at the network, to achieve Fragmentation/Reassembly of SCHC Packets. SCHC F/R has three reliability modes.

- SCHC Fragment: A data unit that carries a subset of a SCHC Packet. SCHC F/R is needed when the size of a SCHC packet exceeds the available payload size of the underlying L2 technology data unit. See Section 8.

- 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.

- TV: Target value. A value contained in a Rule that will be matched with the value of a header field.

- Up: Uplink direction for compression/decompression in both sides, from the Dev SCHC C/D to the network SCHC C/D.

- W: Window bit. A SCHC Fragment header field used in ACK-on-Error or ACK-Always mode Section 8, which carries the same value for all SCHC Fragments of a window.

- Window: A subset of the SCHC Fragments needed to carry a SCHC Packet (see Section 8).

5. SCHC overview

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

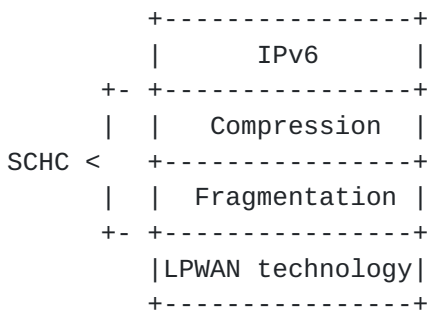
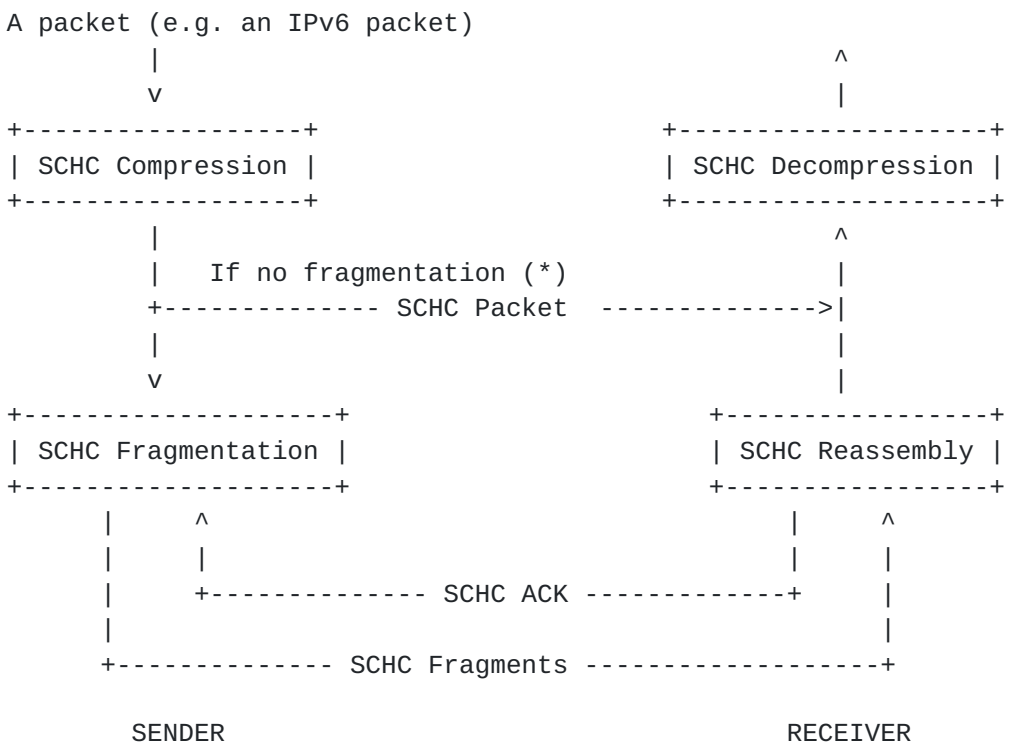


Figure 2: Protocol stack comprising IPv6, SCHC and an LPWAN technology

As per this document, when a packet (e.g. an IPv6 packet) needs to be transmitted, header compression is first applied to the packet. The resulting packet after header compression (whose header may or may not actually be smaller than that of the original packet) is called a SCHC Packet. If the SCHC Packet size exceeds the layer 2 (L2) MTU, fragmentation is then applied to the SCHC Packet. The SCHC Packet or the SCHC Fragments are then transmitted over the LPWAN. The reciprocal operations take place at the receiver. This process is illustrated in Figure 3.



*: the decision to use Fragmentation or not is left to each LPWAN technology over which SCHC is applied. See LPWAN technology-specific documents.

Figure 3: SCHC operations taking place at the sender and the receiver

The SCHC Packet is composed of the Compressed Header followed by the payload from the original packet (see Figure 4). The Compressed Header itself is composed of a Rule ID and a Compression Residue. The Compression Residue may be absent, see Section 7. Both the Rule ID and the Compression Residue potentially have a variable size, and generally are not a mutiple of bytes in size.

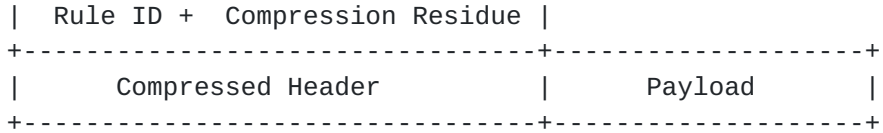


Figure 4: SCHC Packet

The Fragment Header size is variable and depends on the Fragmentation parameters. The Fragment payload contains a part of the SCHC Packet Compressed Header, a part of the SCHC Packet Payload or both. Its

size depends on the L2 data unit, see Section 8. The SCHC Fragment has the following format:

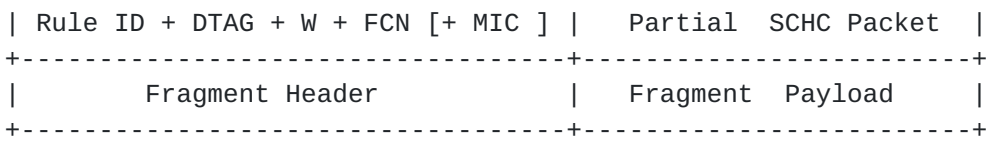


Figure 5: SCHC Fragment

The SCHC ACK is only used for Fragmentation. It has the following format:

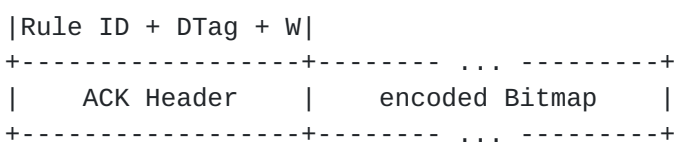


Figure 6: SCHC ACK

The SCHC ACK Header and the encoded Bitmap both have variable size.

Figure 7 below maps the functional elements of Figure 3 onto the LPWAN architecture elements of Figure 1.

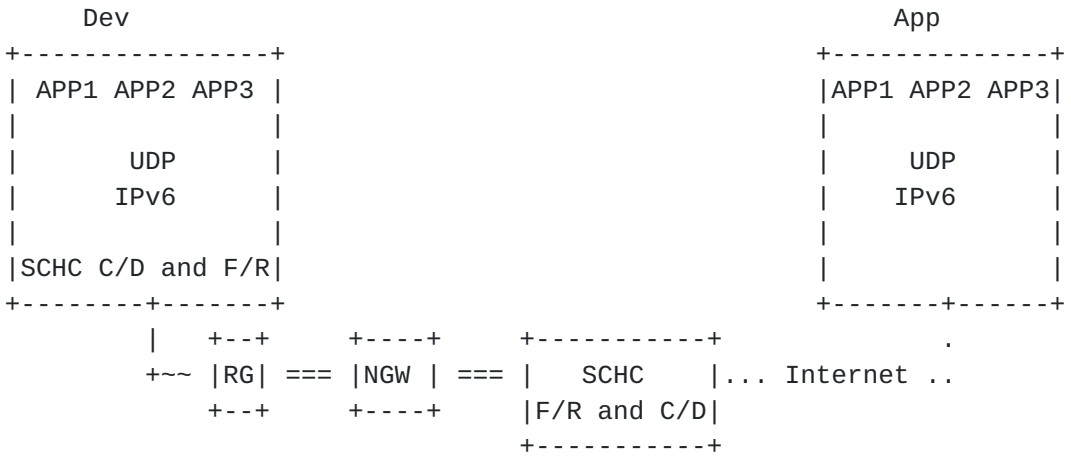


Figure 7: Architecture

SCHC C/D and SCHC F/R are located on both sides of the LPWAN transmission, i.e. on the Dev side and on the Network side.

Let's describe the operation in the Uplink direction. The Device application packets use IPv6 or IPv6/UDP protocols. Before sending

these packets, the Dev compresses their headers using SCHC C/D and, if the SCHC Packet resulting from the compression exceeds the maximum payload size of the underlying LPWAN technology, SCHC F/R is performed (see Section 8). The resulting SCHC Fragments are sent as one or more L2 frames to an LPWAN Radio Gateway (RG) which forwards them to a Network Gateway (NGW). The NGW sends the data to a SCHC F/R and then to the SCHC C/D for decompression. The SCHC F/R and C/D on the Network side can be located in the NGW or somewhere else as long as a tunnel is established between them and the NGW. Note that, 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/D and F/R on both sides MUST share the same set of Rules. After decompression, the packet can be sent over the Internet to one or several LPWAN Application Servers (App).

The SCHC C/D and F/R process is symmetrical, therefore the description of the Downlink direction trivially derives from the one above.

6. Rule ID

Rule IDs are identifiers used to select the correct context either for Compression/Decompression or for Fragmentation/Reassembly.

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.

The Rule IDs are used:

- In the SCHC C/D context, to identify the Rule (i.e., the set of Field Descriptions) that is used to compress a packet header.

- At least one Rule ID MAY be allocated to tagging packets for which SCHC compression was not possible (no matching Rule was found).

- In SCHC F/R, to identify the specific modes and settings of SCHC Fragments being transmitted, and to identify the SCK ACKs, including their modes and settings. Note that in the case of bidirectional communication, at least two Rule ID values are therefore needed for F/R.

7. Static Context Header Compression

In order to perform header compression, this document defines a mechanism called Static Context Header Compression (SCHC), which is based on using context, i.e. a set of Rules to compress or decompress

headers. SCHC avoids context synchronization, which is the most bandwidth-consuming operation in other header compression mechanisms such as RoHC [RFC5795]. Since the nature of packets is highly predictable in LPWAN networks, static contexts MAY be stored beforehand to omit transmitting some information over the air. 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 on both ends 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 provides the closest match to 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. How Rules are generated is out of the scope of this document. The Rules MAY be changed at run-time but the way to do this will be specified in another document.

The context contains a list of Rules (cf. Figure 8). 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).

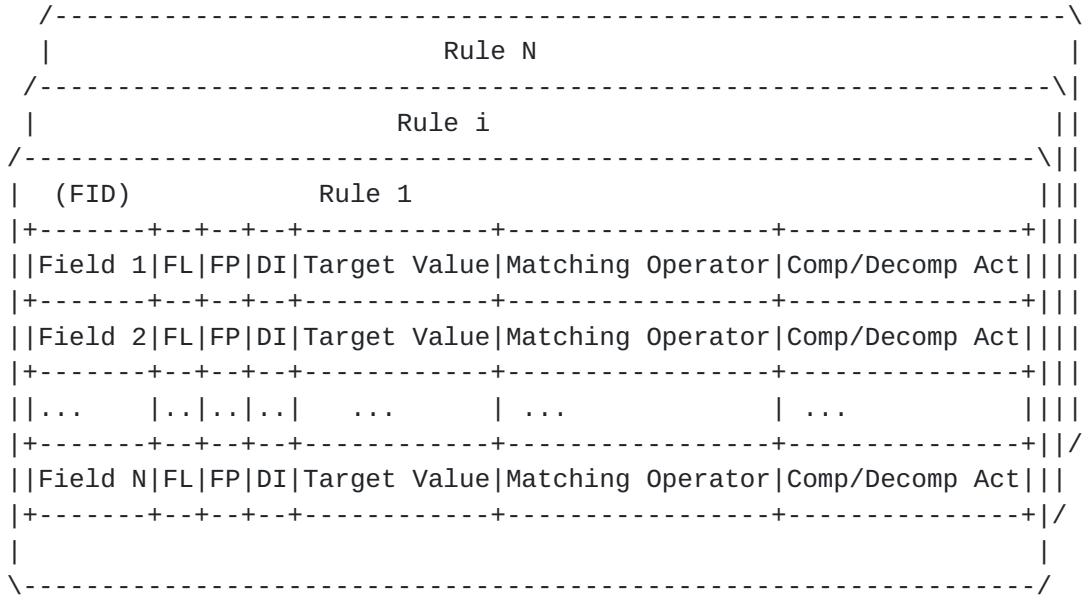


Figure 8: Compression/Decompression Context

A Rule does not describe how to parse a packet header to find each field. This MUST be known from the compressor/decompressor. Rules only describe the compression/decompression behavior for each header field. In a Rule, the Field Descriptions are listed in the order in which the fields appear in the packet header.

A Rule also describes what Compression Residue is sent. The Compression Residue is assembled by concatenating the residues for each field, in the order the Field Descriptions appear in the Rule.

The Context describes the header fields and its values with the following entries:

- Field ID (FID) is a unique value to define the header field.

- Field Length (FL) represents the length of the 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 in the corresponding protocol specification. The type defines the process to compute the length, its unit (bits, bytes,...) and the value to be sent before the Compression Residue.

- Field Position (FP): most often, a field only occurs once in a packet header. Some fields may occur multiple times in a header. FP indicates which occurrence this Field Description applies to. The default value is 1 (first occurence).

- 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 travelling both Up and Dw.

- Target Value (TV) is the value used to make the match with the packet header field. The Target Value can be of any type (integer, strings, etc.). For instance, it can be a single value or a more complex structure (array, list, etc.), such as a JSON or a CBOR structure.

- 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.

- Compression Decompression Action (CDA) describes the compression and decompression processes to be performed after the MO is applied. Some CDAs MAY require 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 a Dev. Hence, multiple Dev instances MAY use the same Rule ID to define different header compression contexts. To identify the correct Rule ID, the SCHC C/D needs to correlate the Rule ID with the Dev identifier to find the appropriate Rule to be applied.

7.3. Packet processing

The compression/decompression process follows several steps:

- Compression Rule selection: The goal is to identify which Rule(s) will be used to compress the packet's headers. When doing decompression, on the network side the SCHC C/D needs to find the correct Rule based on the L2 address and 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 only holds Rules that apply to itself. The Rule will be selected by matching the Fields Descriptions to the packet header as described below. When the selection of a Rule is done, this Rule is used to compress the header. The detailed steps for compression Rule selection are the following:

  * The first step is to choose the Field Descriptions by their direction, using the Direction Indicator (DI). A Field Description that does not correspond to the appropriate DI will be ignored. If all the fields of the packet do not have a Field Description with the correct DI, the Rule is discarded and SCHC C/D proceeds to explore the next Rule.

  * When the DI has matched, then the next step is to identify the fields according to Field Position (FP). If FP does not correspond, the Rule is not used and the SCHC C/D proceeds to consider the next Rule.

  * Once the DI and the FP correspond to the header information, 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 all the fields in the packet's header satisfy all the matching operators (MO) of a Rule (i.e. all MO results are True), the fields of the header are then compressed according to the Compression/Decompression Actions (CDAs) and a compressed header (with possibly a Compression Residue) SHOULD be obtained. Otherwise, the next Rule is tested.

  * If no eligible Rule is found, then the header MUST be sent without compression. This MAY require the use of the SCHC F/R process.

- Sending: If an eligible Rule is found, the Rule ID is sent to the other end followed by the Compression Residue (which could be empty) and directly followed by the payload. The Compression Residue is the concatenation of the Compression Residues for each field according to the CDAs for that Rule. The way the Rule ID is sent depends on the specific underlying LPWAN technology. For example, it can be either included in an L2 header or sent in the first byte of the L2 payload. (Cf. Figure 9). This process will be specified in the LPWAN technology-specific document and is out of the scope of the present document. On LPWAN technologies that are byte-oriented, the compressed header concatenated with the original packet payload is padded to a multiple of 8 bits, if needed. See Section 9 for details.

- Decompression: When doing decompression, on the network side the SCHC C/D needs to find the correct Rule based on the L2 address and 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 only holds Rules that apply to itself.

  The receiver identifies the sender through its device-id (e.g. MAC address, if exists) and selects the appropriate Rule from the Rule ID. If a source identifier is present in the L2 technology, it is used to select the Rule ID. This Rule describes the compressed header format and associates the values to the header fields. The receiver applies the CDA action to reconstruct the original header fields. The CDA application order can be different from the order given by the Rule. For instance, Compute-* SHOULD be applied at the end, after all the other CDAs.

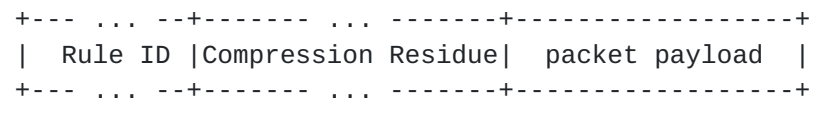


Figure 9: SCHC C/D Packet Format

7.4. Matching operators

Matching Operators (MOs) are functions used by both SCHC C/D endpoints involved in the header compression/decompression. They are not typed and can be indifferently 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:

- equal: The match result is True if a field value in a packet and the value in the TV are equal.

- ignore: No check is done between a field value in a packet and a TV in the Rule. The result of the matching is always true.

- MSB(x): A match is obtained if the most significant 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 length must be a multiple of the unit. For example, x must be multiple of 8 if the unit of the variable length is in bytes.

- match-mapping: With match-mapping, the Target Value is a list of values. Each value of the list is identified by a short ID (or 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 headers fields, and inversely, the action taken by the decompressor to restore the original value.

Action	Compression	Decompression
not-sent	elided	use value stored in context
value-sent	send	build from received value
mapping-sent	send index	value from index on a table
LSB	send LSB	TV, received value
compute-length	elided	compute length
compute-checksum	elided	compute UDP checksum
DevIID	elided	build IID from L2 Dev addr
AppIID	elided	build IID from L2 App addr

Figure 10: Compression and Decompression Actions

Figure 10 summarizes the basic functions that can be used to compress and decompress a field. The first column lists the actions name. The second and third columns outline the reciprocal compression/ decompression behavior for each action.

Compression is done in order that Fields Descriptions appear in a Rule. The result of each Compression/Decompression Action is appended to the working Compression Residue in that same order. The receiver knows the size of each compressed field which can be given by the Rule or MAY be sent with the compressed header.

If the field is identified as being variable in the Field Description, then the size of the Compression Residue value (using the unit defined in the FL) MUST be sent first using the following coding:

- If the size is between 0 and 14, it is sent as a 4-bits integer.

- For values between 15 and 254, the first 4 bits sent are set to 1 and the size is sent using 8 bits integer.

- For higher values of size, the first 12 bits are set to 1 and the next two bytes contain the size value as a 16 bits integer.

If a field is not present in the packet but exists in the Rule and its FL is specified as being variable, size 0 MUST be sent to denote its absence.

7.5.1. not-sent CDA

The not-sent function is generally used when the field value is specified in a Rule and therefore known by both the Compressor and the Decompressor. This action is generally 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 Compression 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.

7.5.2. value-sent CDA

The value-sent action is generally used when the field value is not known by both the Compressor and the Decompressor. The value is sent as a residue in the compressed message header. Both Compressor and Decompressor MUST know the size of the field, either implicitly (the size is known by both sides) or by explicitly indicating the length in the Compression Residue, as defined in Section 7.5. This function is generally used with the "ignore" MO.

7.5.3. mapping-sent CDA

The mapping-sent is used to send a smaller index (the index into the Target Value list of values) instead of the original value. This function 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 and the mapping-sent CDA appends the corresponding index to the Compression Residue to be sent. 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.

7.5.4. 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 number of bits sent is the original header field length minus the length specified in the MSB(x) MO.

The compressor sends the Least Significant Bits (e.g. LSB of the length field). The decompressor concatenates the x most significant bits of Target Value and the received residue.

If this action needs to be done on a variable length field, the size of the Compression Residue in bytes MUST be sent as described in Section 7.5.

7.5.5. DevIID, AppIID CDA

These functions 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 current LPWAN technologies frames contain a single 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 LPWAN technology and MAY depend on the Device ID size.

In the downlink direction (Dw), at the compressor, this DevIID CDA may be used to generate the L2 addresses on the LPWAN, based on the packet destination address.

7.5.6. Compute-*

Some fields are elided during compression and reconstructed during decompression. This is the case for length and checksum, so:

- compute-length: computes the length assigned to this field. This CDA MAY be used to compute IPv6 length or UDP length.

- compute-checksum: computes a checksum from the information already received by the SCHC C/D. This field MAY be used to compute UDP checksum.

8. Fragmentation

8.1. Overview

In LPWAN technologies, the L2 data unit size typically varies from tens to hundreds of bytes. The SCHC F/R (Fragmentation /Reassembly) MAY be used either because after applying SCHC C/D or when SCHC C/D is not possible the entire SCHC Packet still exceeds the L2 data unit.

The SCHC F/R functionality defined in this document has been designed under the assumption that data unit out-of-sequence delivery will not

happen between the entity performing fragmentation and the entity performing reassembly. This assumption allows reducing the complexity and overhead of the SCHC F/R mechanism.

This document also assumes that the L2 data unit size does not vary while a fragmented SCHC Packet is being transmitted.

To adapt the SCHC F/R to the capabilities of LPWAN technologies, it is required to enable optional SCHC Fragment retransmission and to allow for a range of reliability options for sending the SCHC Fragments. This document does not make any decision with regard to which SCHC Fragment delivery reliability mode will be used over a specific LPWAN technology. These details will be defined in other technology-specific documents.

SCHC F/R uses the knowledge of the L2 Word size (see Section 4) to encode some messages. Therefore, SCHC MUST know the L2 Word size. SCHC F/R generates SCHC Fragments and SCHC ACKs that are, for most of them, multiples of L2 Words. The padding overhead is kept to the absolute minimum. See Section 9.

8.2. Fragmentation Tools

This subsection describes the different tools that are used to enable the SCHC F/R functionality defined in this document, such as fields in the SCHC F/R header frames (see the related formats in Section 8.4), windows and timers.

- Rule ID. The Rule ID is present in the SCHC Fragment header and in the SCHC ACK header formats. The Rule ID in a SCHC Fragment header is used to identify that a SCHC Fragment is being carried, which SCHC F/R reliability mode is used and which window size is used. The Rule ID in the SCHC Fragment header also allows interleaving non-fragmented SCHC Packets and SCHC Fragments that carry other SCHC Packets. The Rule ID in a SCHC ACK identifies the message as a SCHC ACK.

- Fragment Compressed Number (FCN). The FCN is included in all SCHC Fragments. This field can be understood as a truncated, efficient representation of a larger-sized fragment number, and does not carry an absolute SCHC Fragment number. There are two FCN reserved values that are used for controlling the SCHC F/R process, as described next:

  * The FCN value with all the bits equal to 1 (All-1) denotes the last SCHC Fragment of a packet. The last window of a packet is called an All-1 window.

* The FCN value with all the bits equal to 0 (All-0) denotes the last SCHC Fragment of a window that is not the last one of the packet. Such a window is called an All-0 window.

The rest of the FCN values are assigned in a sequentially decreasing order, which has the purpose to avoid possible ambiguity for the receiver that might arise under certain conditions. In the SCHC Fragments, this field is an unsigned integer, with a size of N bits. In the No-ACK mode, the size is set to 1 bit (N=1), All-0 is used in all SCHC Fragments and All-1 for the last one. For the other reliability modes, it is recommended to use a number of bits (N) equal to or greater than 3. Nevertheless, the appropriate value of N MUST be defined in the corresponding technology-specific profile documents. For windows that are not the last one of a fragmented SCHC Packet, the FCN for the last SCHC Fragment in such windows is an All-0. This indicates that the window is finished and communication proceeds according to the reliability mode in use. The FCN for the last SCHC Fragment in the last window is an All-1, indicating the last SCHC Fragment of the SCHC Packet. It is also important to note that, in the No-ACK mode or when N=1, the last SCHC Fragment of the packet will carry a FCN equal to 1, while all previous SCHC Fragments will carry a FCN to 0. For further details see Section 8.5. The highest FCN in the window, denoted MAX_WIND_FCN, MUST be a value equal to or smaller than 2^N-2. (Example for N=5, MAX_WIND_FCN MAY be set to 23, then subsequent FCNs are set sequentially and in decreasing order, and the FCN will wrap from 0 back to 23).

o Datagram Tag (DTag). The DTag field, if present, is set to the same value for all SCHC Fragments carrying the same SCHC packet, and to different values for different SCHC Packets. Using this field, the sender can interleave fragments from different SCHC Packets, while the receiver can still tell them apart. In the SCHC Fragment formats, the size of the DTag field is T bits, which MAY be set to a value greater than or equal to 0 bits. For each new SCHC Packet processed by the sender, DTag MUST be sequentially increased, from 0 to 2^T - 1 wrapping back from 2^T - 1 to 0. In the SCHC ACK format, DTag carries the same value as the DTag field in the SCHC Fragments for which this SCHC ACK is intended. When there is no Dtag, there can be only one SCHC Packet in transit. Only after all its fragments have been transmitted can another SCHC Packet be sent. The length of DTag, denoted T, is not specified in this document because it is technology dependant. It will be defined in the corresponding technology-specific documents, based on the number of simultaneous packets that are to be supported.

- W (window): W is a 1-bit field. This field carries the same value for all SCHC Fragments of a window, and it is complemented for the next window. The initial value for this field is 0. In the SCHC ACK format, this field also has a size of 1 bit. In all SCHC ACKs, the W bit carries the same value as the W bit carried by the SCHC Fragments whose reception is being positively or negatively acknowledged by the SCHC ACK.

- Message Integrity Check (MIC). This field is computed by the sender over the complete SCHC Packet and before SCHC fragmentation. The MIC allows the receiver to check errors in the reassembled packet, while it also enables compressing the UDP checksum by use of SCHC compression. The CRC32 as 0xEDB88320 (i.e. the reverse representation of the polynomial used e.g. in the Ethernet standard [RFC3385]) is recommended as the default algorithm for computing the MIC. Nevertheless, other algorithms MAY be required and are defined in the technology-specific documents as well as the length in bits of the MIC used.

- C (MIC checked): C is a 1-bit field. This field is used in the SCHC ACK packets to report the outcome of the MIC check, i.e. whether the reassembled packet was correctly received or not. A value of 1 represents a positive MIC check at the receiver side (i.e. the MIC computed by the receiver matches the received MIC).

- Retransmission Timer. A SCHC Fragment sender uses it after the transmission of a window to detect a transmission error of the SCHC ACK corresponding to this window. Depending on the reliability mode, it will lead to a request a SCHC ACK retransmission (in ACK-Always mode) or it will trigger the transmission of the next window (in ACK-on-Error mode). The duration of this timer is not defined in this document and MUST be defined in the corresponding technology-specific documents.

- Inactivity Timer. A SCHC Fragment receiver uses it to take action when there is a problem in the transmission of SCHC fragments. Such a problem could be detected by the receiver not getting a single SCHC Fragment during a given period of time. When this happens, an Abort message will be sent (see related text later in this section). Initially, and each time a SCHC Fragment is received, the timer is reinitialized. The duration of this timer is not defined in this document and MUST be defined in the corresponding technology-specific document.

- Attempts. This counter counts the requests for a missing SCHC ACK. When it reaches the value MAX_ACK_REQUESTS, the sender assumes there are recurrent SCHC Fragment transmission errors and determines that an Abort is needed. The default value

MAX_ACK_REQUESTS is not stated in this document, and it is expected to be defined in the corresponding technology-specific document. The Attempts counter is defined per window. It is initialized each time a new window is used.

- Bitmap. The Bitmap is a sequence of bits carried in a SCHC ACK. Each bit in the Bitmap corresponds to a SCHC fragment of the current window, and provides feedback on whether the SCHC Fragment has been received or not. The right-most position on the Bitmap reports if the All-0 or All-1 fragment has been received or not. Feedback on the SCHC fragment with the highest FCN value is provided by the bit in the left-most position of the Bitmap. In the Bitmap, a bit set to 1 indicates that the SCHC Fragment of FCN corresponding to that bit position has been correctly sent and received. The text above describes the internal representation of the Bitmap. When inserted in the SCHC ACK for transmission from the receiver to the sender, the Bitmap is shortened for energy/bandwidth optimisation, see more details in Section 8.4.3.1.

- Abort. On expiration of the Inactivity timer, or when Attempts reaches MAX_ACK_REQUESTS or upon occurrence of some other error, the sender or the receiver may use the Abort. When the receiver needs to abort the on-going fragmented SCHC Packet transmission, it sends the Receiver-Abort format. When the sender needs to abort the transmission, it sends the Sender-Abort format. None of the Aborts are acknowledged.

8.3. Reliability modes

This specification defines three reliability modes: No-ACK, ACK-Always, and ACK-on-Error. ACK-Always and ACK-on-Error operate on windows of SCHC Fragments. A window of SCHC Fragments is a subset of the full set of SCHC Fragments needed to carry a SCHC Packet.

- No-ACK. No-ACK is the simplest SCHC Fragment reliability mode. The receiver does not generate overhead in the form of acknowledgements (ACKs). However, this mode does not enhance reliability beyond that offered by the underlying LPWAN technology. In the No-ACK mode, the receiver MUST NOT issue SCHC ACKs. See further details in Section 8.5.1.

- ACK-Always. The ACK-Always mode provides flow control using a windowing scheme. This mode is also able to handle long bursts of lost SCHC Fragments since detection of such events can be done before the end of the SCHC Packet transmission as long as the window size is short enough. However, such benefit comes at the expense of SCHC ACK use. In ACK-Always, the receiver sends a SCHC ACK after a window of SCHC Fragments has been received. The SCHC

ACK is used to inform the sender which SCHC Fragments in the current window have been well received. Upon a SCHC ACK reception, the sender retransmits the lost SCHC Fragments. When a SCHC ACK is lost and the sender has not received it by the expiration of the Retransmission Timer, the sender uses a SCHC ACK request by sending the All-0 empty SCHC Fragment when it is not the last window and the All-1 empty Fragment when it is the last window. The maximum number of SCHC ACK requests is MAX_ACK_REQUESTS. If MAX_ACK_REQUESTS is reached, the transmission needs to be aborted. See further details in Section 8.5.2.

- ACK-on-Error. The ACK-on-Error mode is suitable for links offering relatively low L2 data unit loss probability. In this mode, the SCHC Fragment receiver reduces the number of SCHC ACKs transmitted, which MAY be especially beneficial in asymmetric scenarios. The receiver transmits a SCHC ACK only after the complete window transmission and if at least one SCHC Fragment of this window has been lost. An exception to this behavior is in the last window, where the receiver MUST transmit a SCHC ACK, including the C bit set based on the MIC checked result, even if all the SCHC Fragments of the last window have been correctly received. The SCHC ACK gives the state of all the SCHC Fragments of the current window (received or lost). Upon a SCHC ACK reception, the sender retransmits any lost SCHC Fragments based on the SCHC ACK. If a SCHC ACK is not transmitted back by the receiver at the end of a window, the sender assumes that all SCHC Fragments have been correctly received. When a SCHC ACK is lost, the sender assumes that all SCHC Fragments covered by the lost SCHC ACK have been successfully delivered, so the sender continues transmitting the next window of SCHC Fragments. If the next SCHC Fragments received belong to the next window and it is still expecting fragments from the previous window, the receiver will abort the on-going fragmented packet transmission. See further details in Section 8.5.3.

The same reliability mode MUST be used for all SCHC Fragments of a SCHC Packet. The decision on which reliability mode will be used and whether the same reliability mode applies to all SCHC Packets is an implementation problem and is out of the scope of this document.

Note that the reliability mode choice is not necessarily tied to a particular characteristic of the underlying L2 LPWAN technology, e.g. the No-ACK mode MAY be used on top of an L2 LPWAN technology with symmetric characteristics for uplink and downlink. This document does not make any decision as to which SCHC Fragment reliability modes are relevant for a specific LPWAN technology.

Examples of the different reliability modes described are provided in Appendix B.

8.4. Fragmentation Formats

This section defines the SCHC Fragment format, including the All-0 and All-1 formats and their "empty" variations, the SCHC ACK format and the Abort formats.

A SCHC Fragment conforms to the general format shown in Figure 11. It comprises a SCHC Fragment Header and a SCHC Fragment Payload. In addition, the last SCHC Fragment carries as many padding bits as needed to fill up an L2 Word. The SCHC Fragment Payload carries a subset of the SCHC Packet. The SCHC Fragment is the data unit passed on to the L2 for transmission.

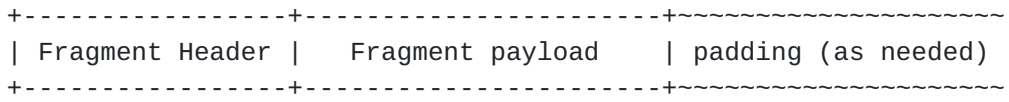


Figure 11: SCHC Fragment general format. Presence of a padding field is optional

8.4.1. Fragments that are not the last one

In ACK-Always or ACK-on-Error, SCHC Fragments except the last one SHALL conform to the detailed format defined in Figure 12.

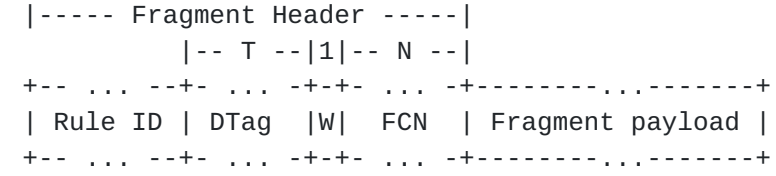


Figure 12: Fragment Detailed Format for Fragments except the Last One, ACK-Always and ACK-on-Error

In the No-ACK mode, SCHC Fragments except the last one SHALL conform to the detailed format defined in Figure 13.

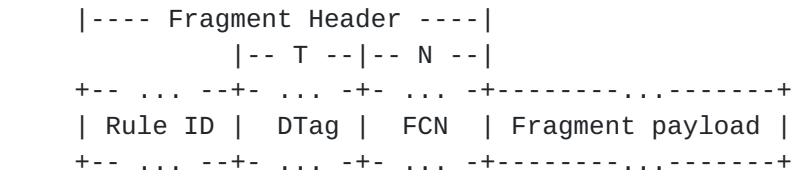


Figure 13: Fragment Detailed Format for Fragments except the Last One, No-ACK mode

The total size of the fragment header is not necessarily a multiple of the L2 Word size. To build the fragment payload, SCHC F/R MUST take from the SCHC Packet a number of bits that makes the SCHC Fragment an exact multiple of L2 Words. As a consequence, no padding bit is used for these fragments.

8.4.1.1. All-0 fragment

The All-0 format is used for sending the last SCHC Fragment of a window that is not the last window of the SCHC Packet.

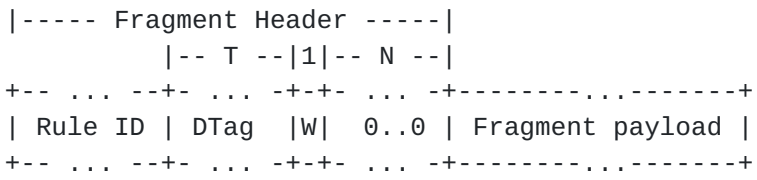


Figure 14: All-0 fragment detailed format

This is simply an instance of the format described in Figure 12. An All-0 fragment payload MUST be at least the size of an L2 Word. The rationale is that the All-0 empty fragment (see Section 8.4.1.2) needs to be distinguishable from the All-0 regular fragment, even in the presence of padding.

8.4.1.2. All-0 empty fragment

The All-0 empty fragment is an exception to the All-0 fragment described above. It is used by a sender to request the retransmission of a SCHC ACK by the receiver. It is only used in ACK-Always mode.

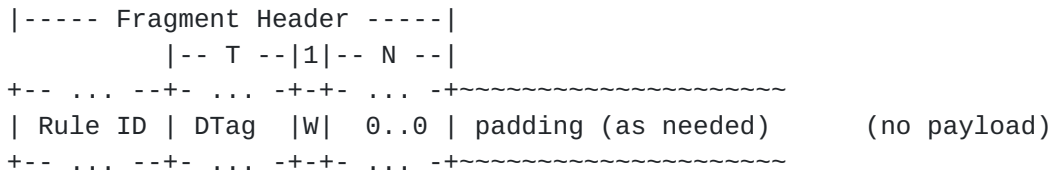


Figure 15: All-0 empty fragment detailed format

The size of the All-0 fragment header is generally not a multiple of the L2 Word size. Therefore, an All-0 empty fragment generally needs padding bits. The padding bits are always less than an L2 Word.

Since an All-0 payload MUST be at least the size of an L2 Word, a receiver can distinguish an All-0 empty fragment from a regular All-0 fragment, even in the presence of padding.

8.4.2. All-1 fragment

In the No-ACK mode, the last SCHC Fragment of a SCHC Packet SHALL contain a SCHC Fragment header that conforms to the detailed format shown in Figure 16.

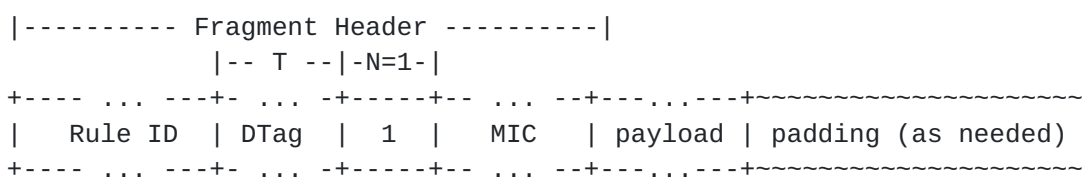


Figure 16: All-1 Fragment Detailed Format for the Last Fragment, No-ACK mode

In ACK-Always or ACK-on-Error mode, the last fragment of a SCHC Packet SHALL contain a SCHC Fragment header that conforms to the detailed format shown in Figure 17.

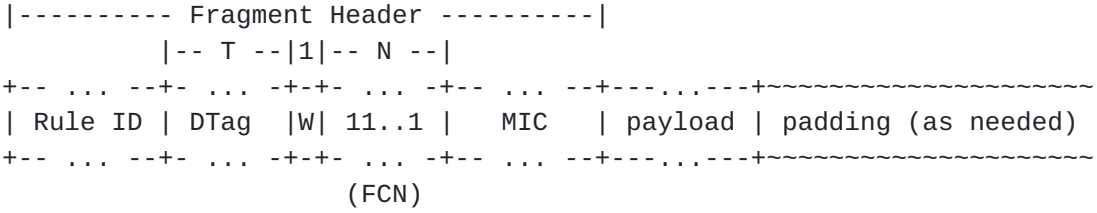


Figure 17: All-1 Fragment Detailed Format for the Last Fragment, ACK-Always or ACK-on-Error

The total size of the All-1 SCHC Fragment header is generally not a multiple of the L2 Word size. The All-1 fragment being the last one of the SCHC Packet, SCHC F/R cannot freely choose the payload size to align the fragment to an L2 Word. Therefore, padding bits are generally appended to the All-1 fragment to make it a multiple of L2 Words in size.

The MIC MUST be computed on the payload and the padding bits. The rationale is that the SCHC Reassembler needs to check the correctness of the reassembled SCHC packet but has no way of knowing where the payload ends. Indeed, the latter requires decompressing the SCHC Packet.

An All-1 fragment payload MUST be at least the size of an L2 Word. The rationale is that the All-1 empty fragment (see Section 8.4.2.1) needs to be distinguishable from the All-1 fragment, even in the presence of padding. This may entail saving an L2 Word from the previous fragment payload to make the payload of this All-1 fragment big enough.

The values for N, T and the length of MIC are not specified in this document, and SHOULD be determined in other documents (e.g. technology-specific profile documents).

The length of the MIC MUST be at least an L2 Word size. The rationale is to be able to distinguish a Sender-Abort (see Section 8.4.4) from an All-1 Fragment, even in the presence of padding.

8.4.2.1. All-1 empty fragment

The All-1 empty fragment format is an All-1 fragment format without a payload (see Figure 18). It is used by a fragment sender, in either ACK-Always or ACK-on-Error, to request a retransmission of the SCHC ACK for the All-1 window.

The size of the All-1 empty fragment header is generally not a multiple of the L2 Word size. Therefore, an All-1 empty fragment generally needs padding bits. The padding bits are always less than an L2 Word.

Since an All-1 payload MUST be at least the size of an L2 Word, a receiver can distinguish an All-1 empty fragment from a regular All-1 fragment, even in the presence of padding.

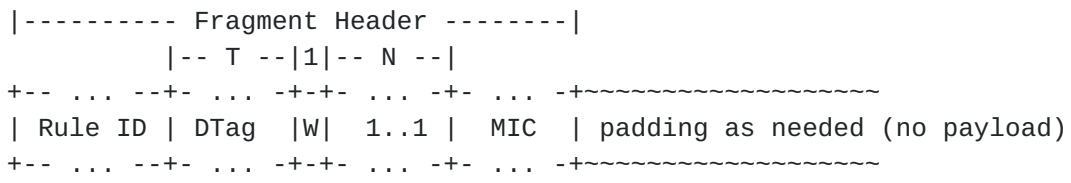


Figure 18: All-1 for Retries format, also called All-1 empty

8.4.3. SCHC ACK format

The format of a SCHC ACK that acknowledges a window that is not the last one (denoted as All-0 window) is shown in Figure 19.

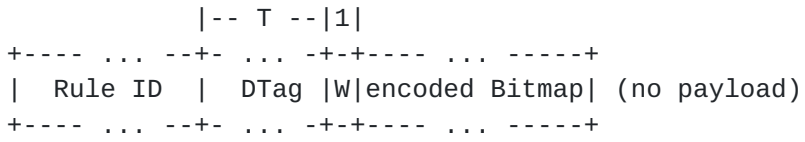


Figure 19: ACK format for All-0 windows

To acknowledge the last window of a packet (denoted as All-1 window), a C bit (i.e. MIC checked) following the W bit is set to 1 to indicate that the MIC check computed by the receiver matches the MIC present in the All-1 fragment. If the MIC check fails, the C bit is set to 0 and the Bitmap for the All-1 window follows.

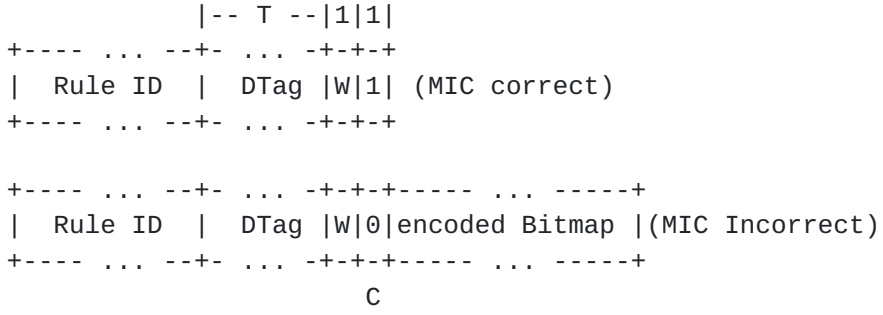


Figure 20: Format of a SCHC ACK for All-1 windows

The Rule ID and Dtag values in the SCHC ACK messages MUST be identical to the ones used in the SCHC Fragments that are being acknowledged. This allows matching the SCHC ACK and the corresponding SCHC Fragments.

The Bitmap carries information on the reception of each fragment of the window as described in Section 8.2.

See Appendix D for a discussion on the size of the Bitmaps.

In order to reduce the SCK ACK size, the Bitmap that is actually transmitted is shortened ("encoded") as explained in Section 8.4.3.1.

8.4.3.1. Bitmap Encoding

The SCHC ACK that is transmitted is truncated by applying the following algorithm: the longest contiguous sequence of bits that starts at an L2 Word boundary of the SCHC ACK, where the bits of that sequence are all set to 1, are all part of the Bitmap and finish exactly at the end of the Bitmap, if one such sequence exists, MUST NOT be transmitted. Because the SCHC Fragment sender knows the actual Bitmap size, it can reconstruct the original Bitmap from the shortened bitmap.

When shortening effectively takes place, the SCHC ACK is a multiple of L2 Words, and padding MUST NOT be appended. When shortening does not happen, padding bits MUST be appended as needed to fill up the last L2 Word.

Figure 21 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.

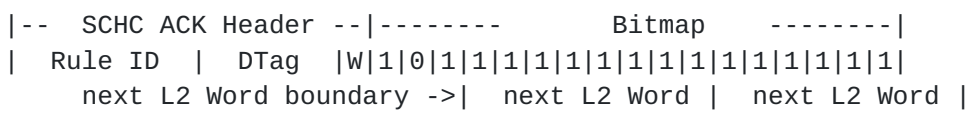


Figure 21: A non-encoded Bitmap

Figure 22 shows that the last 14 bits are not sent.

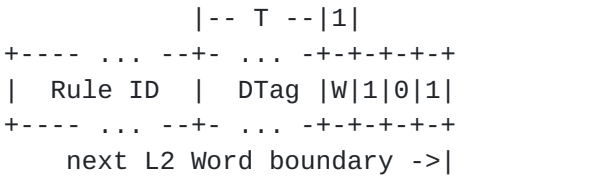


Figure 22: Optimized Bitmap format

Figure 23 shows an example of a SCHC ACK with FCN ranging from 6 down to 0, where the Bitmap indicates that the second and the fifth SCHC Fragments have not been correctly received.

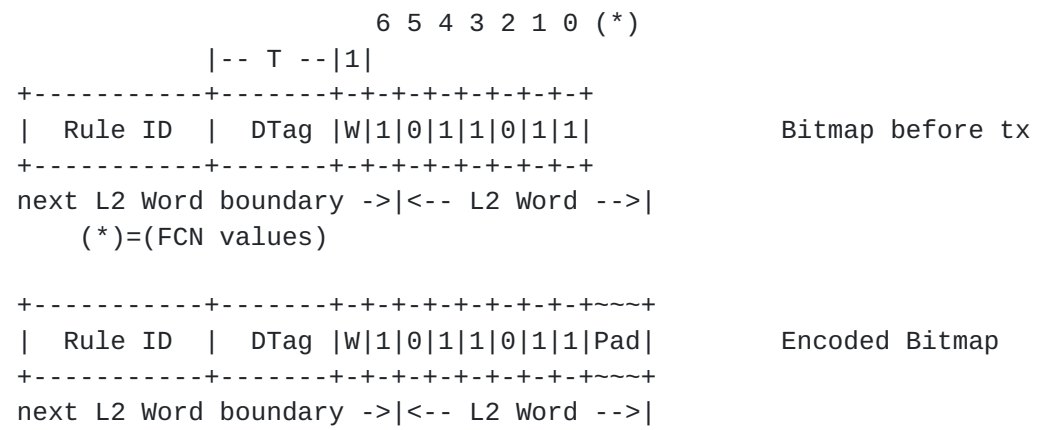


Figure 23: Example of a Bitmap before transmission, and the transmitted one, for a window that is not the last one

Figure 24 shows an example of a SCHC ACK with FCN ranging from 6 down to 0, where MIC check has failed but the Bitmap indicates that there is no missing SCHC Fragment.

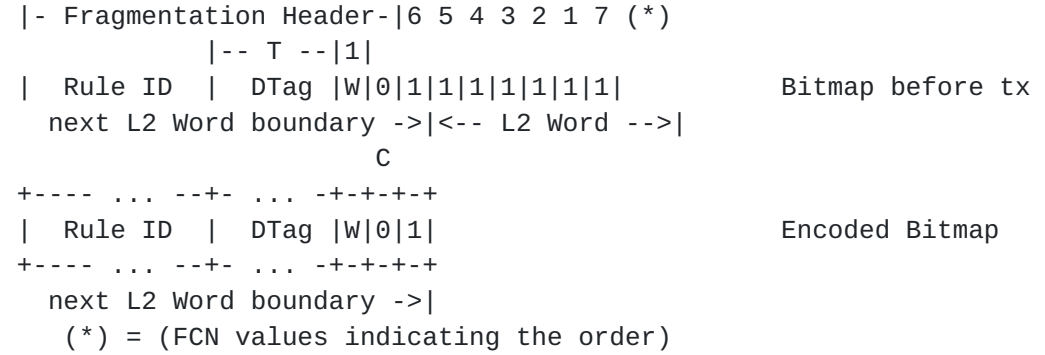


Figure 24: Example of the Bitmap in ACK-Always or ACK-on-Error for the last window

8.4.4. Abort formats

When a SCHC Fragment sender needs to abort the on-going fragmented SCHC Packet transmission, it sends a Sender-Abort. The Sender-Abort format (see Figure 25) is a variation of the All-1 fragment, with neither a MIC nor a payload. All-1 fragments contain at least a MIC. The absence of the MIC indicates a Sender-Abort.

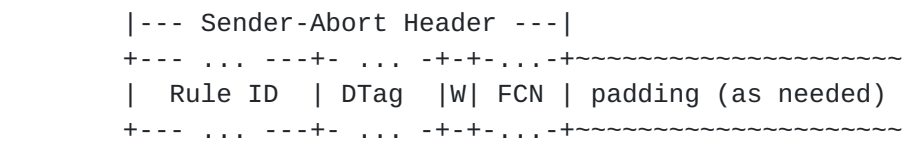


Figure 25: Sender-Abort format. All FCN field bits in this format are set to 1

The size of the Sender-Abort header is generally not a multiple of the L2 Word size. Therefore, a Sender-Abort generally needs padding bits.

Since an All-1 fragment MIC MUST be at least the size of an L2 Word, a receiver can distinguish a Sender-Abort from an All-1 fragment, even in the presence of padding.

When a SCHC Fragment receiver needs to abort the on-going fragmented SCHC Packet transmission, it transmits a Receiver-Abort. The Receiver-Abort format is a variation on the SCHC ACK format, creating an exception in the encoded Bitmap algorithm. As shown in Figure 26, a Receiver-Abort is coded as a SCHC ACK message with a shortened Bitmap set to 1 up to the first L2 Word boundary, followed by an extra L2 Word full of 1's. Such a message never occurs in a regular acknowledgement and is detected as a Receiver-Abort.

The Rule ID and Dtag values in the Receive-Abort message MUST be identical to the ones used in the fragments of the SCHC Packet the transmission of which is being aborted.

A Receiver-Abort is aligned to L2 Words, by design. Therefore, padding MUST NOT be appended.

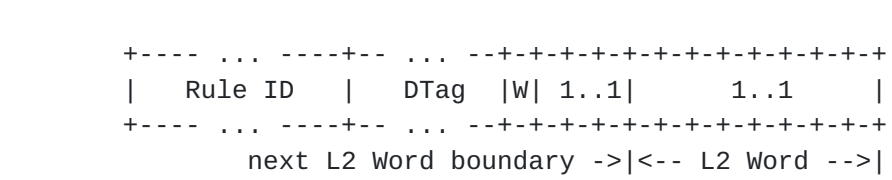


Figure 26: Receiver-Abort format

Neither the Sender-Abort nor the Receiver-Abort messages are ever acknowledged or retransmitted.

Use cases for the Sender-Abort and Receiver-Abort messages are explained in Section 8.5 or Appendix C.

8.5. Baseline mechanism

If after applying SCHC header compression (or when SCHC header compression is not possible) the SCHC Packet does not fit within the payload of a single L2 data unit, the SCHC Packet SHALL be broken into SCHC Fragments and the fragments SHALL be sent to the fragment receiver. The fragment receiver needs to identify all the SCHC Fragments that belong to a given SCHC Packet. To this end, the receiver SHALL use:

- The sender's L2 source address (if present),
- The destination's L2 address (if present),
- Rule ID,
- DTag (if present).

Then, the fragment receiver MAY determine the SCHC Fragment reliability mode that is used for this SCHC Fragment based on the Rule ID in that fragment.

After a SCHC Fragment reception, the receiver starts constructing the SCHC Packet. It uses the FCN and the arrival order of each SCHC Fragment to determine the location of the individual fragments within the SCHC Packet. For example, the receiver MAY place the fragment payload within a payload reassembly buffer at the location determined from the FCN, the arrival order of the SCHC Fragments, and the fragment payload sizes. In ACK-on-Error or ACK-Always, the fragment receiver also uses the W bit in the received SCHC Fragments. Note that the size of the original, unfragmented packet cannot be determined from fragmentation headers.

Fragmentation functionality uses the FCN value to transmit the SCHC Fragments. It has a length of N bits where the All-1 and All-0 FCN values are used to control the fragmentation transmission. The rest of the FCN numbers MUST be assigned sequentially in a decreasing order, the first FCN of a window is RECOMMENDED to be MAX_WIND_FCN, i.e. the highest possible FCN value depending on the FCN number of bits.

In all modes, the last SCHC Fragment of a packet MUST contain a MIC which is used to check if there are errors or missing SCHC Fragments and MUST use the corresponding All-1 fragment format. Note that a SCHC Fragment with an All-0 format is considered the last SCHC Fragment of the current window.

If the receiver receives the last fragment of a SCHC Packet (All-1), it checks for the integrity of the reassembled SCHC Packet, based on the MIC received. In No-ACK, if the integrity check indicates that the reassembled SCHC Packet does not match the original SCHC Packet (prior to fragmentation), the reassembled SCHC Packet MUST be discarded. In ACK-on-Error or ACK-Always, a MIC check is also performed by the fragment receiver after reception of each subsequent SCHC Fragment retransmitted after the first MIC check.

Notice that the SCHC ACK for the All-1 window carries one more bit (the C bit) compared to the SCHC ACKs for the previous windows. See Appendix D for a discussion on various options to deal with this "bump" in the SCHC ACK.

There are three reliability modes: No-ACK, ACK-Always and ACK-on-Error. In ACK-Always and ACK-on-Error, a jumping window protocol uses two windows alternatively, identified as 0 and 1. A SCHC Fragment with all FCN bits set to 0 (i.e. an All-0 fragment) indicates that the window is over (i.e. the SCHC Fragment is the last one of the window) and allows to switch from one window to the next one. The All-1 FCN in a SCHC Fragment indicates that it is the last fragment of the packet being transmitted and therefore there will not be another window for this packet.

8.5.1. No-ACK

In the No-ACK mode, there is no feedback communication from the fragment receiver. The sender will send all the SCHC fragments of a packet without any possibility of knowing if errors or losses have occurred. As, in this mode, there is no need to identify specific SCHC Fragments, a one-bit FCN MAY be used. Consequently, the FCN All-0 value is used in all SCHC fragments except the last one, which carries an All-1 FCN and the MIC. The receiver will wait for SCHC Fragments and will set the Inactivity timer. The receiver will use the MIC contained in the last SCHC Fragment to check for errors. When the Inactivity Timer expires or if the MIC check indicates that the reassembled packet does not match the original one, the receiver will release all resources allocated to reassembling this packet. The initial value of the Inactivity Timer will be determined based on the characteristics of the underlying LPWAN technology and will be defined in other documents (e.g. technology-specific profile documents).

8.5.2. ACK-Always

In ACK-Always, the sender transmits SCHC Fragments by using the two-jumping-windows procedure. A delay between each SCHC fragment can be added to respect local regulations or other constraints imposed by

the applications. Each time a SCHC fragment is sent, the FCN is decreased by one. When the FCN reaches value 0, if there are more SCHC Fragments remaining to be sent, the sender transmits the last SCHC Fragment of this window using the All-0 fragment format. It then starts the Retransmission Timer and waits for a SCHC ACK. Otherwise, if FCN reaches 0 and the sender transmits the last SCHC Fragment of the SCHC Packet, the sender uses the All-1 fragment format, which includes a MIC. The sender sets the Retransmission Timer and waits for the SCHC ACK to know if transmission errors have occurred.

The Retransmission Timer is dimensioned based on the LPWAN technology in use. When the Retransmission Timer expires, the sender sends an All-0 empty (resp. All-1 empty) fragment to request again the SCHC ACK for the window that ended with the All-0 (resp. All-1) fragment just sent. The window number is not changed.

After receiving an All-0 or All-1 fragment, the receiver sends a SCHC ACK with an encoded Bitmap reporting whether any SCHC fragments have been lost or not. When the sender receives a SCHC ACK, it checks the W bit carried by the SCHC ACK. Any SCHC ACK carrying an unexpected W bit value is discarded. If the W bit value of the received SCHC ACK is correct, the sender analyzes the rest of the SCHC ACK message, such as the encoded Bitmap and the MIC. If all the SCHC Fragments sent for this window have been well received, and if at least one more SCHC Fragment needs to be sent, the sender advances its sending window to the next window value and sends the next SCHC Fragments. If no more SCHC Fragments have to be sent, then the fragmented SCHC Packet transmission is finished.

However, if one or more SCHC Fragments have not been received as per the SCHC ACK (i.e. the corresponding bits are not set in the encoded Bitmap) then the sender resends the missing SCHC Fragments. When all missing SCHC Fragments have been retransmitted, the sender starts the Retransmission Timer, even if an All-0 or an All-1 has not been sent as part of this retransmission and waits for a SCHC ACK. Upon receipt of the SCHC ACK, if one or more SCHC Fragments have not yet been received, the counter Attempts is increased and the sender resends the missing SCHC Fragments again. When Attempts reaches MAX_ACK_REQUESTS, the sender aborts the on-going fragmented SCHC Packet transmission by sending a Sender-Abort message and releases any resources for transmission of the packet. The sender also aborts an on-going fragmented SCHC Packet transmission when a failed MIC check is reported by the receiver or when a SCHC Fragment that has not been sent is reported in the encoded Bitmap.

On the other hand, at the beginning, the receiver side expects to receive window 0. Any SCHC Fragment received but not belonging to

the current window is discarded. All SCHC Fragments belonging to the correct window are accepted, and the actual SCHC Fragment number managed by the receiver is computed based on the FCN value. The receiver prepares the encoded Bitmap to report the correctly received and the missing SCHC Fragments for the current window. After each SCHC Fragment is received, the receiver initializes the Inactivity Timer. When the Inactivity Timer expires, the transmission is aborted by the receiver sending a Receiver-Abort message.

When an All-0 fragment is received, it indicates that all the SCHC Fragments have been sent in the current window. Since the sender is not obliged to always send a full window, some SCHC Fragment number not set in the receiver memory may not correspond to losses. The receiver sends the corresponding SCHC ACK, the Inactivity Timer is set and the transmission of the next window by the sender can start.

If an All-0 fragment has been received and all SCHC Fragments of the current window have also been received, the receiver then expects a new Window and waits for the next SCHC Fragment. Upon receipt of a SCHC Fragment, if the window value has not changed, the received SCHC Fragments are part of a retransmission. A receiver that has already received a SCHC Fragment SHOULD discard it, otherwise, it updates the Bitmap. If all the bits of the Bitmap are set to one, the receiver MUST send a SCHC ACK without waiting for an All-0 fragment and the Inactivity Timer is initialized.

On the other hand, if the window value of the next received SCHC Fragment is set to the next expected window value, this means that the sender has received a correct encoded Bitmap reporting that all SCHC Fragments have been received. The receiver then updates the value of the next expected window.

When an All-1 fragment is received, it indicates that the last SCHC Fragment of the packet has been sent. Since the last window is not always full, the MIC will be used by the receiver to detect if all SCHC Fragments of the packet have been received. A correct MIC indicates the end of the transmission but the receiver MUST stay alive for an Inactivity Timer period to answer to any empty All-1 fragments the sender MAY send if SCHC ACKs sent by the receiver are lost. If the MIC is incorrect, some SCHC Fragments have been lost. The receiver sends the SCHC ACK regardless of successful fragmented SCHC Packet reception or not, the Inactitivity Timer is set. In case of an incorrect MIC, the receiver waits for SCHC Fragments belonging to the same window. After MAX_ACK_REQUESTS, the receiver will abort the on-going fragmented SCHC Packet transmission by transmitting a the Receiver-Abort format. The receiver also aborts upon Inactivity Timer expiration by sending a Receiver-Abort message.

If the sender receives a SCK ACK with a Bitmap containing a bit set for a SCHC Fragment that it has not sent during the transmission phase of this window, it MUST abort the whole fragmentation and transmission of this SCHC Packet.

8.5.3. ACK-on-Error

The senders behavior for ACK-on-Error and ACK-Always are similar. The main difference is that in ACK-on-Error the SCHC ACK with the encoded Bitmap is not sent at the end of each window but only when at least one SCHC Fragment of the current window has been lost. Except for the last window where a SCHC ACK MUST be sent to finish the transmission.

In ACK-on-Error, the Retransmission Timer expiration is considered as a positive acknowledgement for all windows but the last one. This timer is set after sending an All-0 or an All-1 fragment. For an All-0 fragment, on timer expiration, the sender resumes operation and sends the SCHC Fragments of the next window.

If the sender receives a SCHC ACK, it checks the window value. SCHC ACKs with an unexpected window number are discarded. If the window number in the received SCHC ACK is correct, the sender verifies if the receiver has received all SCHC fragments of the current window. When at least one SCHC Fragment has been lost, the counter Attempts is increased by one and the sender resends the missing SCHC Fragments again. When Attempts reaches MAX_ACK_REQUESTS, the sender sends a Sender-Abort message and releases all resources for the on-going fragmented SCHC Packet transmission. When the retransmission of the missing SCHC Fragments is finished, the sender starts listening for a SCHC ACK (even if an All-0 or an All-1 has not been sent during the retransmission) and initializes the Retransmission Timer.

After sending an All-1 fragment, the sender listens for a SCHC ACK, initializes Attempts, and starts the Retransmission Timer. If the Retransmission Timer expires, Attempts is increased by one and an empty All-1 fragment is sent to request the SCHC ACK for the last window. If Attempts reaches MAX_ACK_REQUESTS, the sender aborts the on-going fragmented SCHC Packet transmission by transmitting the Sender-Abort fragment.

At the end of any window, if the sender receives a SCK ACK with a Bitmap containing a bit set for a SCHC Fragment that it has not sent during the transmission phase of that window, it MUST abort the whole fragmentation and transmission of this SCHC Packet.

Unlike the sender, the receiver for ACK-on-Error has a larger amount of differences compared with ACK-Always. First, a SCHC ACK is not

sent unless there is a lost SCHC Fragment or an unexpected behavior. With the exception of the last window, where a SCHC ACK is always sent regardless of SCHC Fragment losses or not. The receiver starts by expecting SCHC Fragments from window 0 and maintains the information regarding which SCHC Fragments it receives. After receiving a SCHC Fragment, the Inactivity Timer is set. If no further SCHC Fragment are received and the Inactivity Timer expires, the SCHC Fragment receiver aborts the on-going fragmented SCHC Packet transmission by transmitting the Receiver-Abort data unit.

Any SCHC Fragment not belonging to the current window is discarded. The actual SCHC Fragment number is computed based on the FCN value. When an All-0 fragment is received and all SCHC Fragments have been received, the receiver updates the expected window value and expects a new window and waits for the next SCHC Fragment.
If the window value of the next SCHC Fragment has not changed, the received SCHC Fragment is a retransmission. A receiver that has already received a Fragment discard it. If all SCHC Fragments of a window (that is not the last one) have been received, the receiver does not send a SCHC ACK. While the receiver waits for the next window and if the window value is set to the next value, and if an All-1 fragment with the next value window arrived the receiver knows that the last SCHC Fragment of the packet has been sent. Since the last window is not always full, the MIC will be used to detect if all SCHC Fragments of the window have been received. A correct MIC check indicates the end of the fragmented SCHC Packet transmission. An ACK is sent by the SCHC Fragment receiver. In case of an incorrect MIC, the receiver waits for SCHC Fragments belonging to the same window or the expiration of the Inactivity Timer. The latter will lead the receiver to abort the on-going SCHC fragmented packet transmission by transmitting the Receiver-Abort message.

If, after receiving an All-0 fragment the receiver missed some SCHC Fragments, the receiver uses a SCHC ACK with the encoded Bitmap to ask the retransmission of the missing fragments and expect to receive SCHC Fragments with the actual window. While waiting the retransmission an All-0 empty fragment is received, the receiver sends again the SCHC ACK with the encoded Bitmap, if the SCHC Fragments received belongs to another window or an All-1 fragment is received, the transmission is aborted by sending a Receiver-Abort fragment. Once it has received all the missing fragments it waits for the next window fragments.

8.6. Supporting multiple window sizes

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 carried by a large number of SCHC Fragments. However, when the number of SCHC Fragments required to carry a packet is low, a smaller window size, and thus a shorter Bitmap, MAY be sufficient to provide feedback on all SCHC Fragments. If multiple window sizes are supported, the Rule ID MAY be used to signal the window size in use for a specific packet transmission.

Note that the same window size MUST be used for the transmission of all SCHC Fragments that belong to the same SCHC Packet.

8.7. Downlink SCHC Fragment transmission

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 frame that requires an L2 ACK) or it MAY be triggered from an upper layer.

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 Inactivity Timer is used) 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 Inactivity 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 Inactivity timer for the SCHC ACK is stopped. However, if the Inactivity timer expires, the SCHC ACK is resent and the Inactivity timer is reinitialized and restarted.

The default initial value for the Inactivity timer, as well as the maximum number of retries for a specific SCHC ACK, denoted MAX_ACK_RETRIES, are not defined in this document, and need to be defined in other documents (e.g. technology-specific profiles). The initial value of the Inactivity 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 can find an opportunity for that transmission.

When the SCHC Fragment sender transmits the All-1 fragment, it starts its Retransmission Timer with a large timeout value (e.g. several times that of the initial Inactivity timer). If a SCHC ACK is received before expiration of this timer, the SCHC Fragment sender retransmits any lost SCHC Fragments 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 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 fragment is long enough to allow several SCHC ACK retries if the All-1 fragment has not;been received by the SCHC Fragment receiver, and it also assumes that it is unlikely that several ACKs become all lost).

9. Padding management

SCHC C/D and SCHC F/R operate on bits, not bytes. SCHC itself does not have any alignment prerequisite. If the Layer 2 below SCHC constrains the L2 Data Unit to align to some boundary, called L2 Words (for example, bytes), SCHC will meet that constraint and produce messages with the correct alignement. This may entail adding extra bits (called padding bits).

When padding occurs, the number of appended bits is strictly less than the L2 Word size.

Padding happens at most once for each Packet going through the full SCHC chain, i.e. Compression and (optionally) SCHC Fragmentation (see Figure 2). If a SCHC Packet is sent unfragmented (see Figure 27), it is padded as needed. If a SCHC Packet is fragmented, only the last fragment is padded as needed.

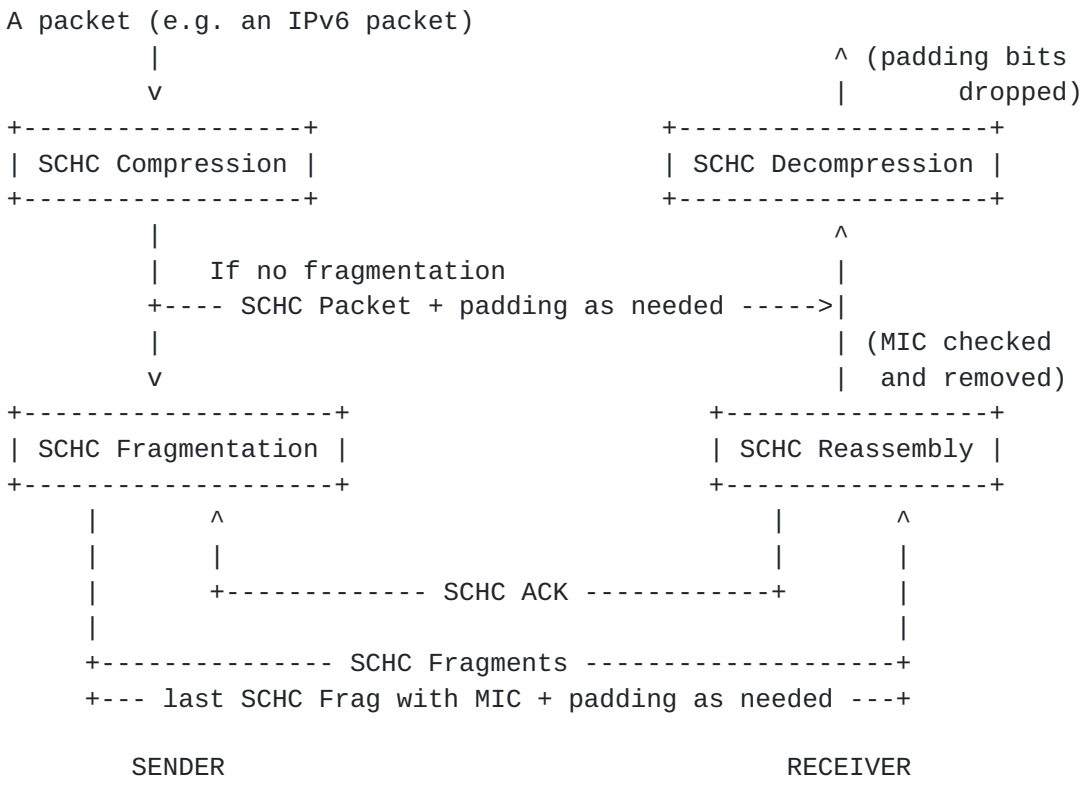


Figure 27: SCHC operations, including padding as needed

Each technology-specific document MUST specify the size of the L2 Word. The L2 Word might actually be a single bit, in which case at most zero bits of padding will be appended to any message, i.e. no padding will take place at all.

10. SCHC Compression for IPv6 and UDP headers

This section lists the different IPv6 and UDP header fields and how they can be compressed.

10.1. IPv6 version field

This field always holds the same value. Therefore, in the Rule, TV is set to 6, MO to "equal" 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, two possibilities can be considered depending on the variability of the value:

- 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".

- 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(y).

10.3. Flow label field

If the Flow Label 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, two possibilities can be considered:

- 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".

- 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(y).

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-IPv6-length".

If the payload length needs to be sent and does not need to be coded in 16 bits, the TV can be set to 0x0000, the MO set to MSB(16-s) where 's' is the number of bits to code the maximum length, and CDA is set to LSB(s).

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 and Downlink. In Uplink, since there is no IP forwarding between the Dev and the SCHC C/D, the value is relatively constant. On the other hand, the Downlink value depends of Internet routing and MAY change more frequently. One neat way of processing this field is to use the Direction Indicator (DI) to distinguish both directions:

- in the Uplink, 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".

- in the Downlink, send the value: TV is not set, MO is set to "ignore" and CDA is set to "value-sent".

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 frame (source or destination).

10.7.1. IPv6 source and destination prefixes

Both ends MUST be synchronized with the appropriate prefixes. For a specific flow, the source and destination prefixes can be unique and stored in the context. It can be either a link-local prefix or a global prefix. 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 29

Otherwise, the TV contains the prefix, the MO is set to "equal" 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". Note that the LPWAN technology generally carries a single identifier corresponding to the DEV. Therefore AppIID cannot be used.

For privacy reasons or if the DEV address is changing over time, a static value that is not equal to the DEV address SHOULD be used. In that case, the TV contains the static value, the MO operator is set to "equal" and the CDF is set to "not-sent". [RFC7217] provides some methods that MAY be used to derive this static identifier.

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 extenso 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 extensions

No Rule is currently defined that processes IPv6 extensions. If such extensions are needed, their compression/decompression Rules can be based on the MOs and CDAs described above.

10.9. UDP source and destination port

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 frame (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. In that case, the TV is not set, the MO is set to "ignore" and the CDA is set to "compute-length".

If the payload is small, the TV can be set to 0x0000, the MO set to "MSB" and the CDA to "LSB".

In other cases, the length SHOULD be sent and the CDA is replaced by "value-sent".

10.11. UDP Checksum field

The UDP checksum operation is mandatory with IPv6 [RFC8200] for most packets but recognizes that there are exceptions to that default behavior.

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] also stipulates that any node implementing zero-checksum mode must follow the requirements specified in "Applicability Statement for the Use of IPv6 UDP Datagrams with Zero Checksums" [RFC6936].

6LoWPAN Header Compression [RFC6282] also authorizes to send UDP datagram that are deprived of the checksum protection when an upper layer guarantees the integrity of the UDP payload and pseudo-header all the way between the compressor that elides the UDP checksum and the decompressor that computes again it. A specific example of this is when a Message Integrity Check (MIC) protects the compressed message all along that path with a strength that is identical or better to the UDP checksum.

In a similar fashion, this specification allows a SCHC compressor to elide the UDP checks when another layer guarantees an identical or better 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-checksum".

In particular, when SCHC fragmentation is used, a fragmentation MIC 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, then compressor MAY elide the UDP checksum. Whether and when the UDP Checksum is elided is to be specified in the technology-specific documents.

Since the compression happens before the fragmentation, implementors 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

12.1. Security considerations for SCHC Compression/Decompression

A malicious header compression could cause the reconstruction of a wrong packet that does not match with the original one. Such a corruption MAY be detected with end-to-end authentication and integrity mechanisms. Header Compression does not add more security problem than what is already needed in a transmission. For instance, to avoid an attack, never re-construct a packet bigger than some configured size (with 1500 bytes as generic default).

12.2. Security considerations for SCHC Fragmentation/Reassembly

This subsection describes potential attacks to LPWAN SCHC F/R and suggests possible countermeasures.

A node can perform a buffer reservation attack by sending a first SCHC Fragment to a target. Then, the receiver will reserve buffer space for the IPv6 packet. 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. The (low) cost to mount this attack is linear with

the number of buffers at the target node. However, the cost for an attacker can be increased if individual SCHC Fragments of multiple packets can be stored in the reassembly buffer. To further increase the attack cost, the reassembly buffer can be split into SCHC Fragment-sized buffer slots. Once a packet is complete, it is processed normally. If buffer overload occurs, a receiver can discard packets based on the sender behavior, which MAY help identify which SCHC Fragments have been sent by an attacker.

In another type of attack, the malicious node is required to have overhearing capabilities. If an attacker can overhear a SCHC Fragment, it can send a spoofed duplicate (e.g. with random payload) to the destination. If the LPWAN technology does not support suitable protection (e.g. source authentication and frame counters to prevent replay attacks), a receiver cannot distinguish legitimate from spoofed SCHC Fragments. Therefore, the original IPv6 packet will be considered corrupt and will be dropped. To protect resource-constrained nodes from this attack, it has been proposed to establish a binding among the SCHC Fragments to be transmitted by a node, by applying content-chaining to the different SCHC Fragments, based on cryptographic hash functionality. The aim of this technique is to allow a receiver to identify illegitimate SCHC Fragments.

Further attacks MAY involve sending overlapped fragments (i.e. comprising some overlapping parts of the original IPv6 datagram). Implementers SHOULD make sure that the correct operation is not affected by such event.

In ACK-on-Error, a malicious node MAY force a SCHC Fragment sender to resend a SCHC Fragment a number of times, with the aim to increase consumption of the SCHC Fragment sender's resources. To this end, the malicious node MAY repeatedly send a fake ACK to the SCHC Fragment sender, with a Bitmap that reports that one or more SCHC Fragments have been lost. In order to mitigate this possible attack, MAX_ACK_RETRIES MAY be set to a safe value which allows to limit the maximum damage of the attack to an acceptable extent. However, note that a high setting for MAX_ACK_RETRIES benefits SCHC Fragment reliability modes, therefore the trade-off needs to be carefully considered.

13. Acknowledgements

Thanks to Carsten Bormann, Philippe Clavier, Eduardo Ingles Sanchez, Arunprabhu Kandasamy, Rahul Jadhav, Sergio Lopez Bernal, Antony Markovski, Alexander Pelov, Pascal Thubert, Juan Carlos Zuniga, Diego Dujovne, Edgar Ramos, and Shoichi Sakane for useful design consideration and comments.

14. References

14.1. Normative References

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Appendix A. SCHC Compression Examples

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

The most common case using the mechanisms defined in this document will be a LPWAN 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 Device (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 28 presents the protocol stack for this Device. IPv6 and UDP are represented with dotted lines since these protocols are compressed on the radio link.

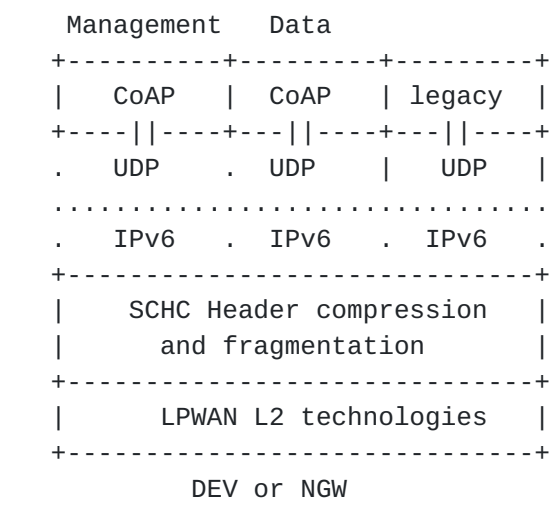


Figure 28: Simplified Protocol Stack for LP-WAN

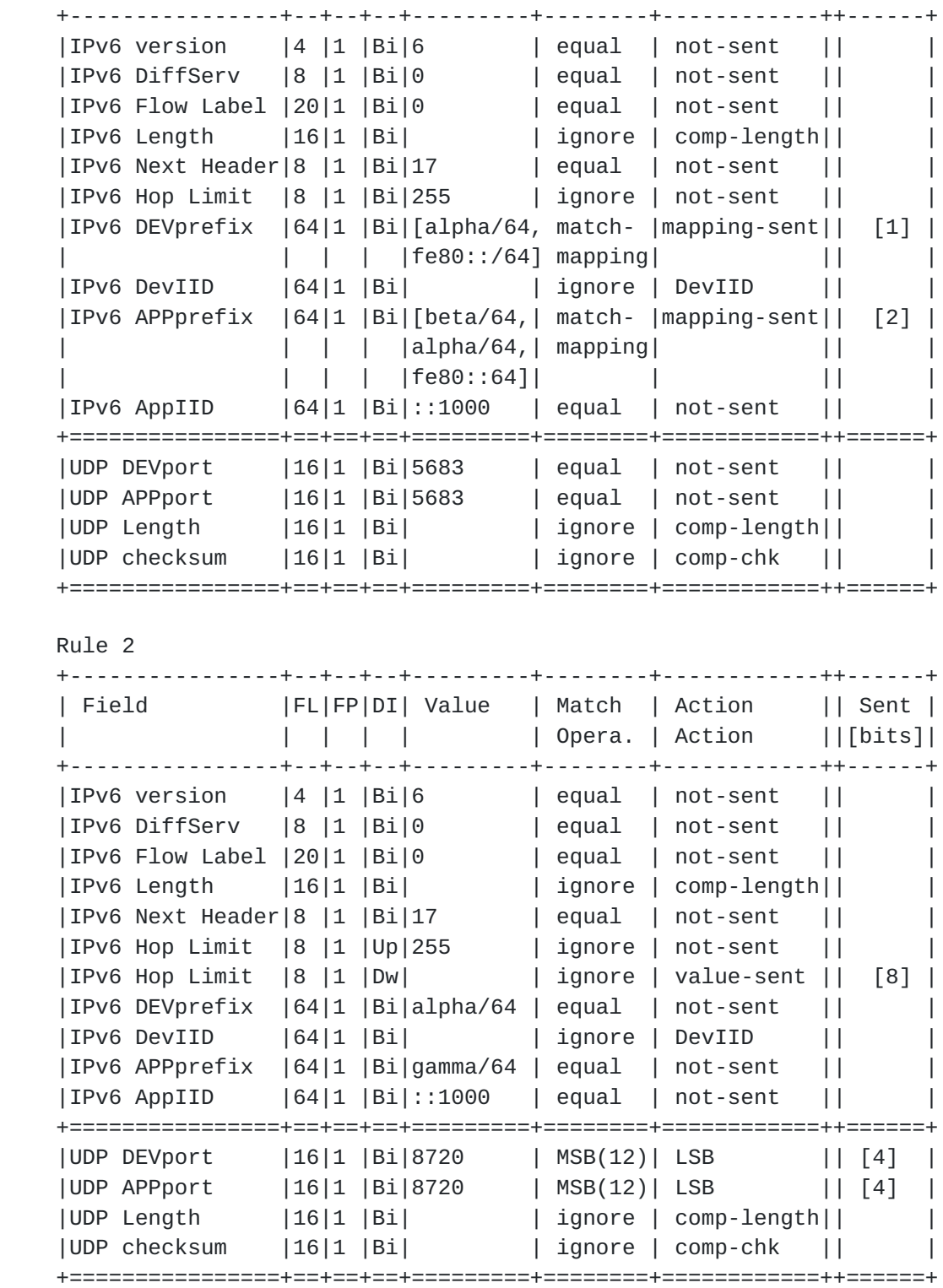
Note that in some LPWAN technologies, only the Devs have a device ID. Therefore, when such technologies are used, it is necessary to statically define an IID for the Link Local address for the SCHC C/D.

Rule 0

Field	FL	FP	DI	Value	Match Opera.	Comp Decomp Action	Sent [bits]
IPv6 version	4	1	Bi	6	equal	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	comp-length	
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	comp-length	
UDP checksum	16	1	Bi		ignore	comp-chk	

Rule 1

Field	FL	FP	DI	Value	Match Opera.	Action Action	Sent [bits]



```
+----------------+--+--+--+---------+--------+------------++------+
|IPv6 version    |4 |1 |Bi|6        | equal  | 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 | comp-length||      |
|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, match- |mapping-sent||  [1] |
|                |  |  |  |fe80::/64] mapping|            ||      |
|IPv6 DevIID     |64|1 |Bi|         | ignore | DevIID     ||      |
|IPv6 APPprefix  |64|1 |Bi|[beta/64,| match- |mapping-sent||  [2] |
|                |  |  |  |alpha/64,| mapping|            ||      |
|                |  |  |  |fe80::64]|        |            ||      |
|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 | comp-length||      |
|UDP checksum    |16|1 |Bi|         | ignore | comp-chk   ||      |
+================+==+==+==+=========+========+============++======+

Rule 2
+----------------+--+--+--+---------+--------+------------++------+
| Field          |FL|FP|DI| Value   | Match  | Action     || Sent |
|                |  |  |  |         | Opera. | Action     ||[bits]|
+----------------+--+--+--+---------+--------+------------++------+
|IPv6 version    |4 |1 |Bi|6        | equal  | 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 | comp-length||      |
|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 | comp-length||      |
|UDP checksum    |16|1 |Bi|         | ignore | comp-chk   ||      |
+================+==+==+==+=========+========+============++======+
```

Figure 29: Context Rules

All the fields described in the three Rules depicted on Figure 29 are present in the IPv6 and UDP headers. The DevIID-DID value is found in the L2 header.

The second and third Rules use global addresses. The way the Dev learns the prefix is not in the scope of the document.

The third Rule compresses port numbers to 4 bits.

Appendix B. Fragmentation Examples

This section provides examples for the different fragment reliability modes specified in this document.

Figure 30 illustrates the transmission in No-ACK mode of an IPv6 packet that needs 11 fragments. FCN is 1 bit wide.

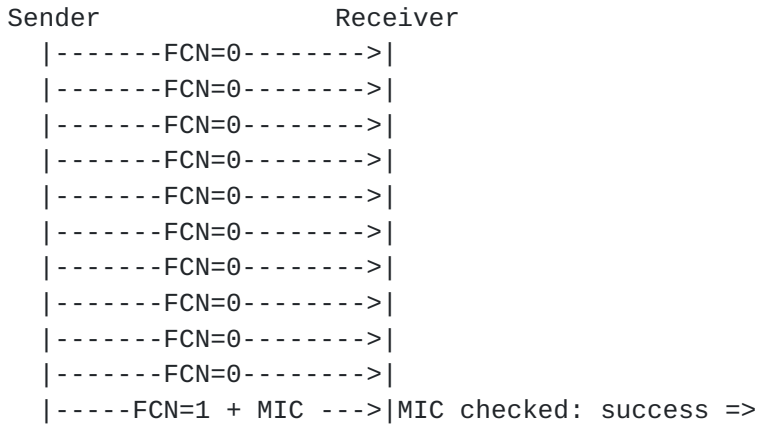


Figure 30: Transmission in No-ACK mode of an IPv6 packet carried by 11 fragments

In the following examples, N (i.e. the size if the FCN field) is 3 bits. Therefore, the All-1 FCN value is 7.

Figure 31 illustrates the transmission in ACK-on-Error of an IPv6 packet that needs 11 fragments, with MAX_WIND_FCN=6 and no fragment loss.

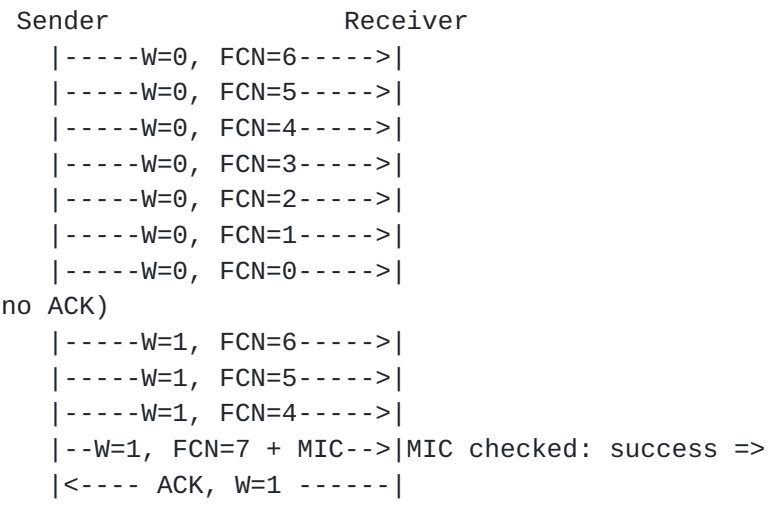


Figure 31: Transmission in ACK-on-Error mode of an IPv6 packet carried by 11 fragments, with MAX_WIND_FCN=6 and no loss.

Figure 32 illustrates the transmission in ACK-on-Error mode of an IPv6 packet that needs 11 fragments, with MAX_WIND_FCN=6 and three lost fragments.

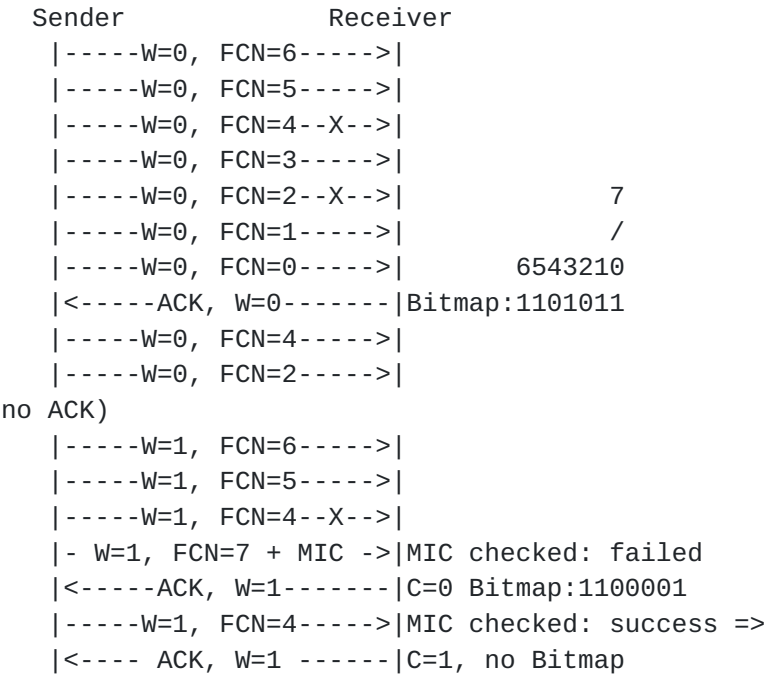


Figure 32: Transmission in ACK-on-Error mode of an IPv6 packet carried by 11 fragments, with MAX_WIND_FCN=6 and three lost fragments.

Figure 33 illustrates the transmission in ACK-Always mode of an IPv6 packet that needs 11 fragments, with MAX_WIND_FCN=6 and no loss.

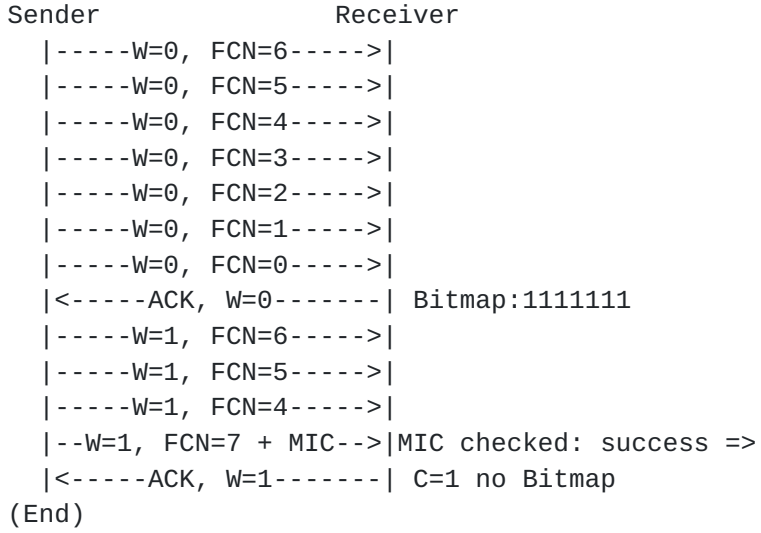


Figure 33: Transmission in ACK-Always mode of an IPv6 packet carried by 11 fragments, with MAX_WIND_FCN=6 and no lost fragment.

Figure 34 illustrates the transmission in ACK-Always mode of an IPv6 packet that needs 11 fragments, with MAX_WIND_FCN=6 and three lost fragments.

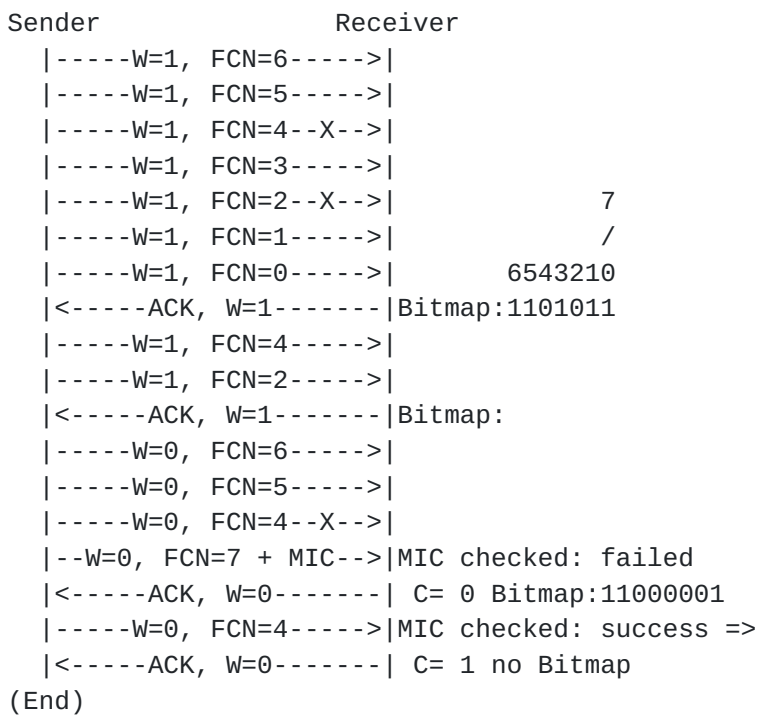


Figure 34: Transmission in ACK-Always mode of an IPv6 packet carried by 11 fragments, with MAX_WIND_FCN=6 and three lost fragments.

Figure 35 illustrates the transmission in ACK-Always mode of an IPv6 packet that needs 6 fragments, with MAX_WIND_FCN=6, three lost fragments and only one retry needed to recover each lost fragment.

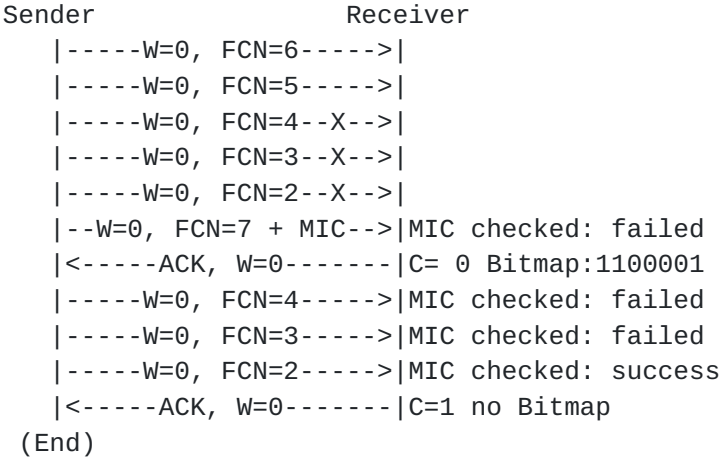


Figure 35: Transmission in ACK-Always mode of an IPv6 packet carried by 11 fragments, with MAX_WIND_FCN=6, three lost frements and only one retry needed for each lost fragment.

Figure 36 illustrates the transmission in ACK-Always mode of an IPv6 packet that needs 6 fragments, with MAX_WIND_FCN=6, three lost fragments, and the second ACK lost.

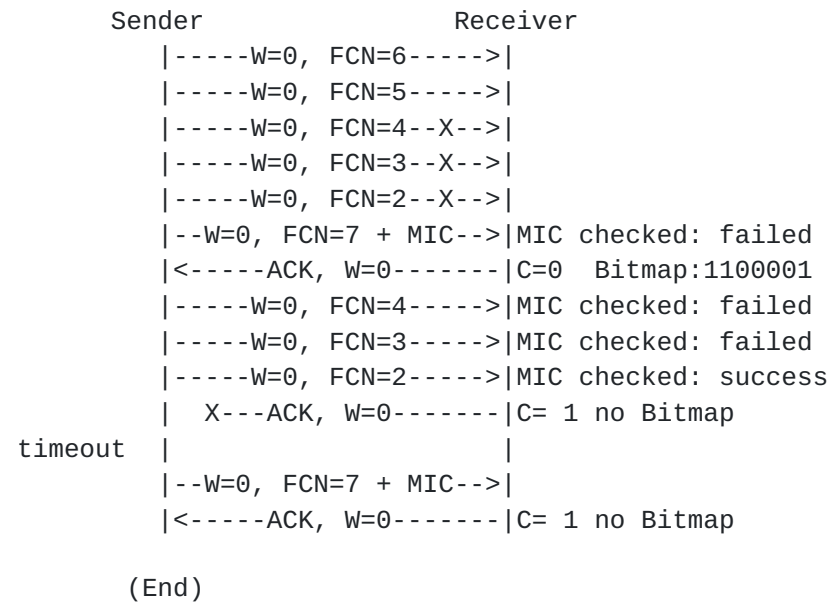


Figure 36: Transmission in ACK-Always mode of an IPv6 packet carried by 11 fragments, with MAX_WIND_FCN=6, three lost fragments, and the second ACK lost.

Figure 37 illustrates the transmission in ACK-Always mode of an IPv6 packet that needs 6 fragments, with MAX_WIND_FCN=6, with three lost fragments, and one retransmitted fragment lost again.

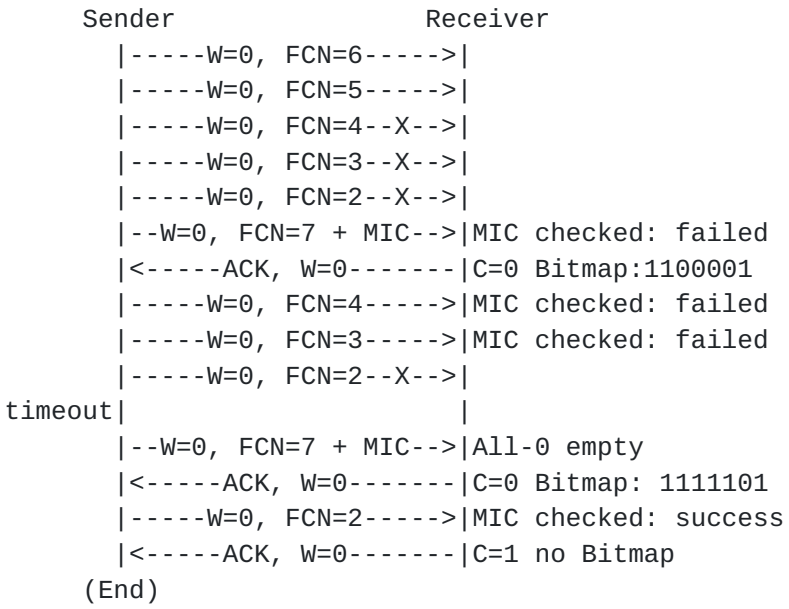


Figure 37: Transmission in ACK-Always mode of an IPv6 packet carried by 11 fragments, with MAX_WIND_FCN=6, with three lost fragments, and one retransmitted fragment lost again.

Figure 38 illustrates the transmission in ACK-Always mode of an IPv6 packet that needs 28 fragments, with N=5, MAX_WIND_FCN=23 and two lost fragments. Note that MAX_WIND_FCN=23 may be useful when the maximum possible Bitmap size, considering the maximum lower layer technology payload size and the value of R, is 3 bytes. Note also that the FCN of the last fragment of the packet is the one with FCN=31 (i.e. FCN=2^N-1 for N=5, or equivalently, all FCN bits set to 1).

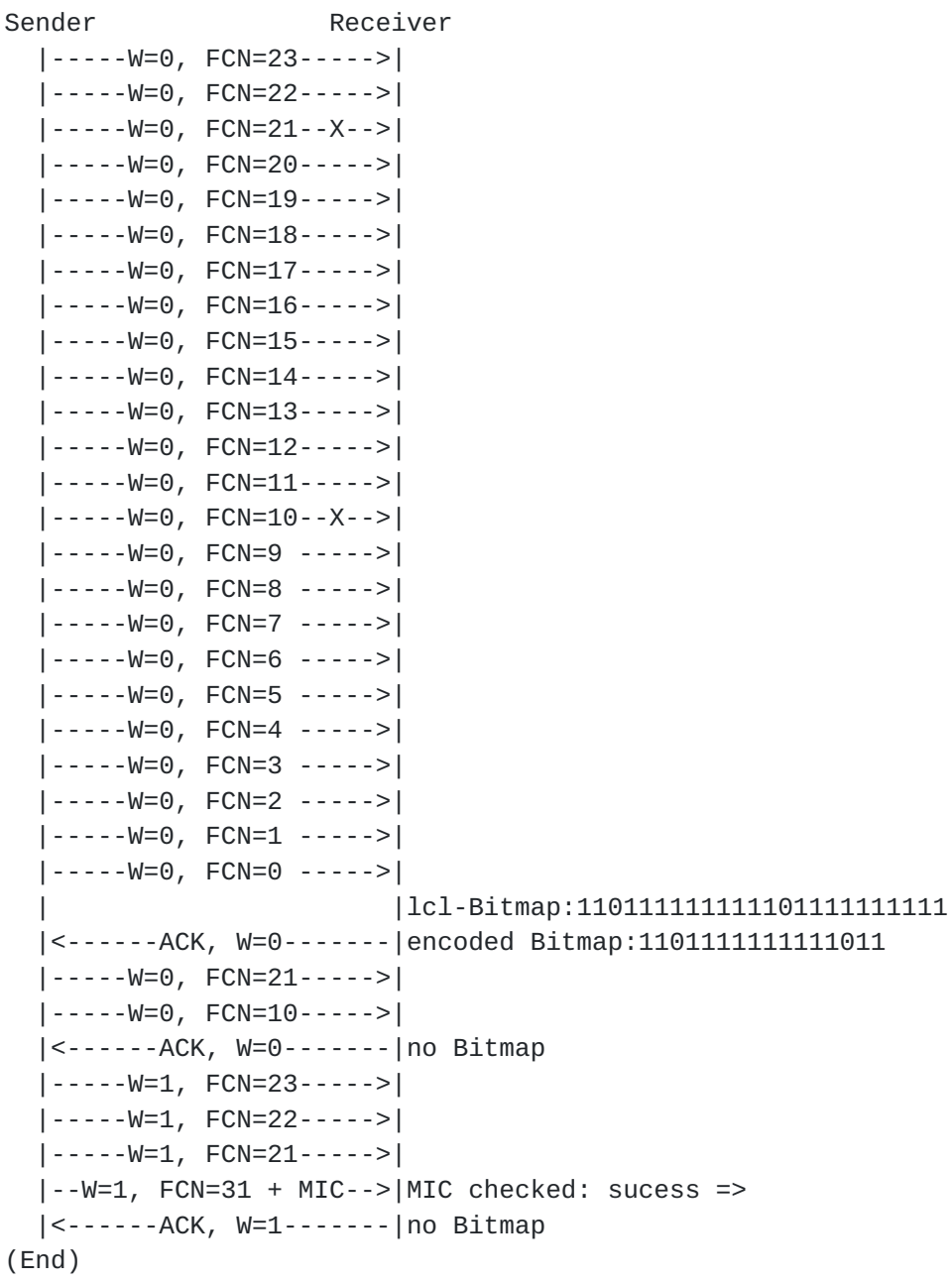


Figure 38: Transmission in ACK-Always mode of an IPv6 packet carried by 28 fragments, with N=5, MAX_WIND_FCN=23 and two lost fragments.

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:

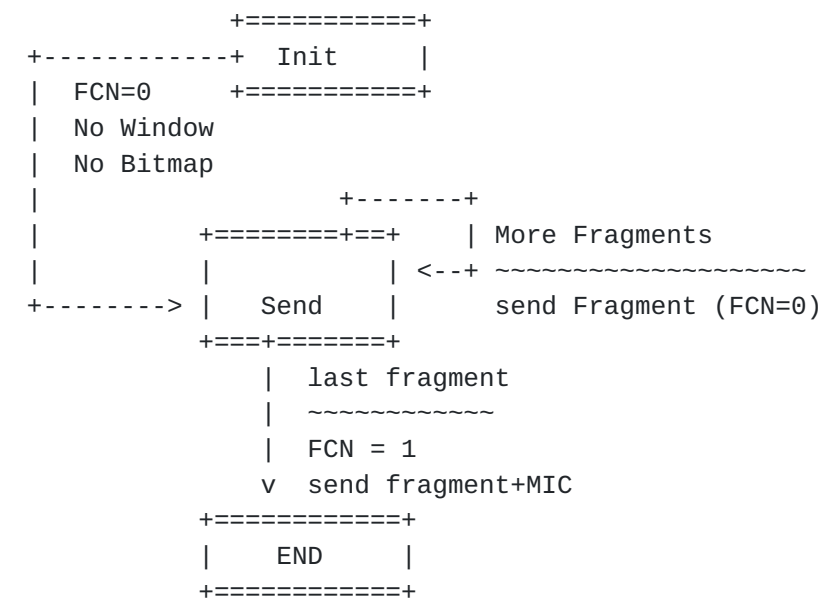


Figure 39: Sender State Machine for the No-ACK Mode

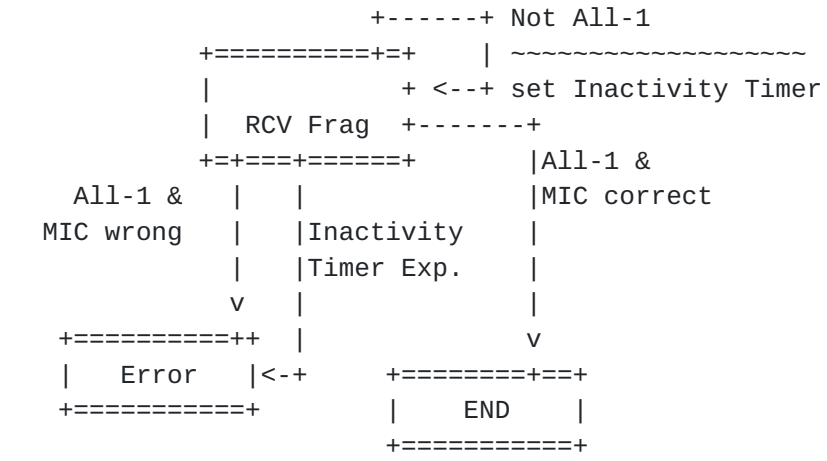


Figure 40: Receiver State Machine for the No-ACK Mode

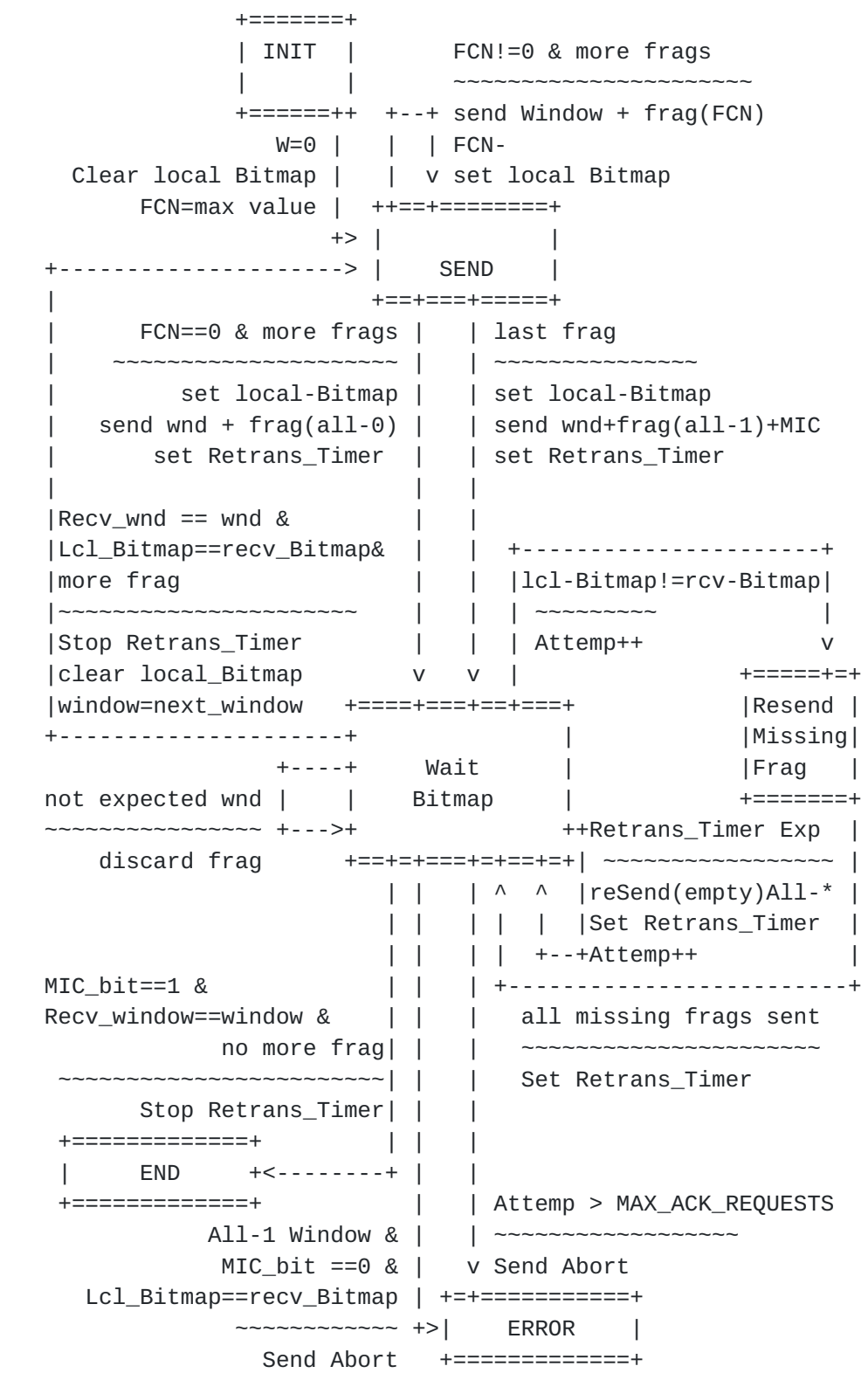
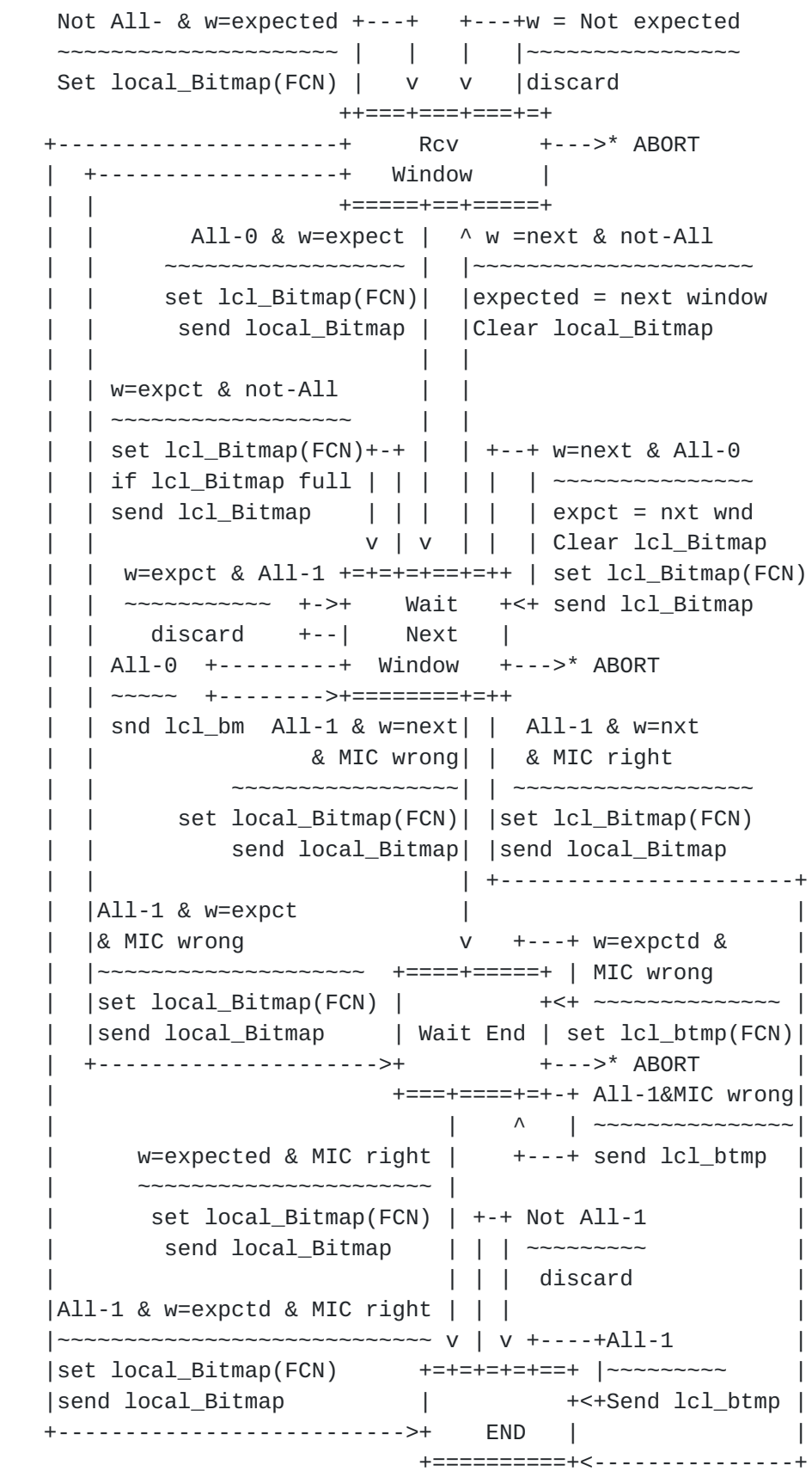


Figure 41: Sender State Machine for the ACK-Always Mode


Not All- & w=expected
Set local_Bitmap(FCN)
w = Not expected
discard
Rcv
Window
* ABORT
All-0 & w=expect
set lcl_Bitmap(FCN)
send local_Bitmap
^ w =next & not-All
expected = next window
Clear local_Bitmap
w=expct & not-All
set lcl_Bitmap(FCN)+-+
if lcl_Bitmap full
send lcl_Bitmap
w=next & All-0
expct = nxt wnd
Clear lcl_Bitmap
w=expct & All-1
discard
Wait
Next
send lcl_Bitmap
All-0
Window
* ABORT
snd lcl_bm
All-1 & w=next
& MIC wrong
All-1 & w=nxt
& MIC right
set local_Bitmap(FCN)
send local_Bitmap
All-1 & w=expct
& MIC wrong
w=expctd &
MIC wrong
set local_Bitmap(FCN)
send local_Bitmap
Wait End
set lcl_btmp(FCN)
* ABORT
All-1&MIC wrong
w=expected & MIC right
set local_Bitmap(FCN)
send local_Bitmap
send lcl_btmp
Not All-1
discard
All-1 & w=expctd & MIC right
All-1
set local_Bitmap(FCN)
send local_Bitmap
Send lcl_btmp
END

```
 --->* ABORT
      ~~~~~~~
      Inactivity_Timer = expires
  When DWN_Link
    IF Inactivity_Timer expires
       Send DWL Request
       Attemp++
```

Figure 42: Receiver State Machine for the ACK-Always Mode

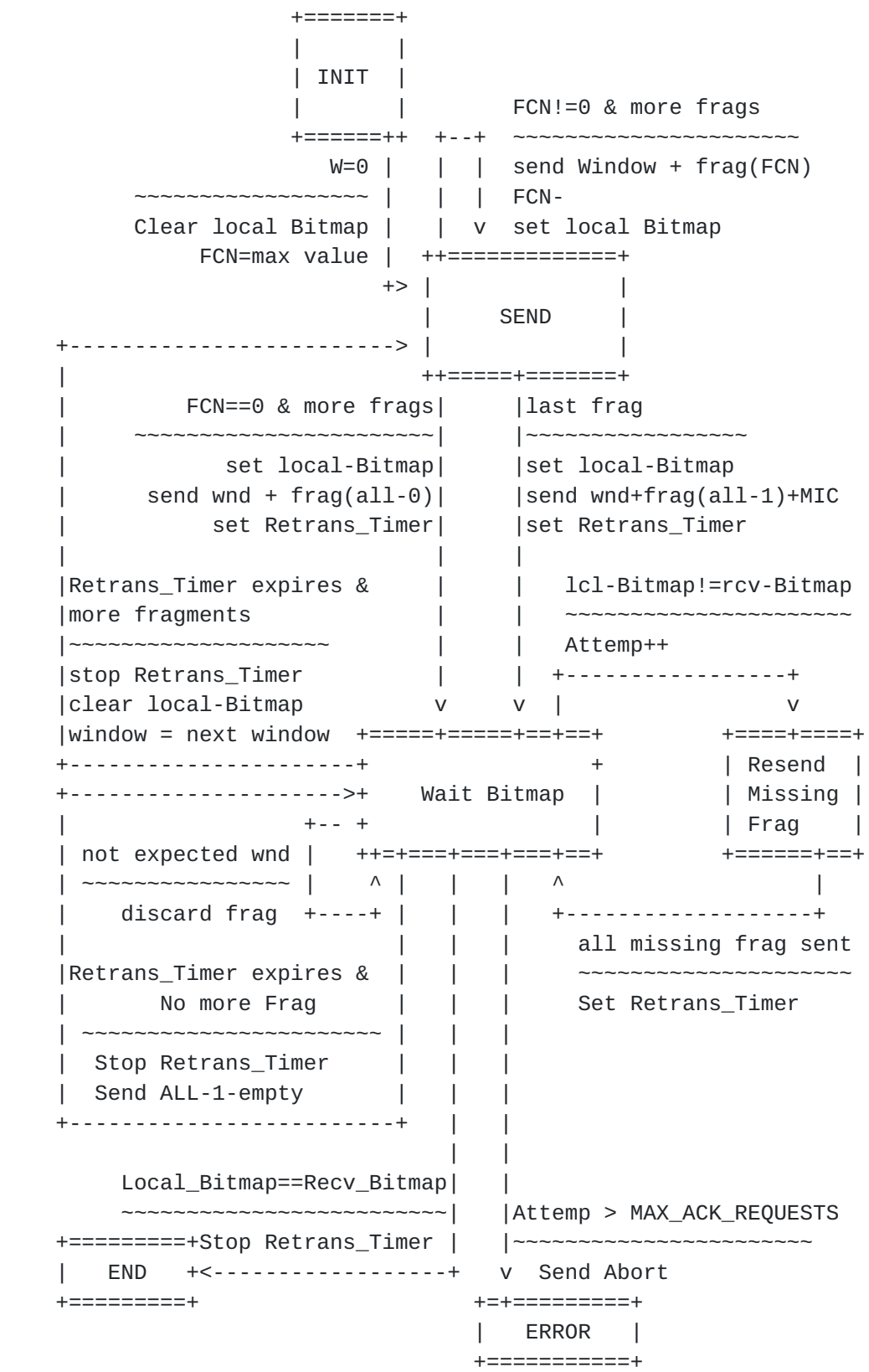


Figure 43: Sender State Machine for the ACK-on-Error Mode

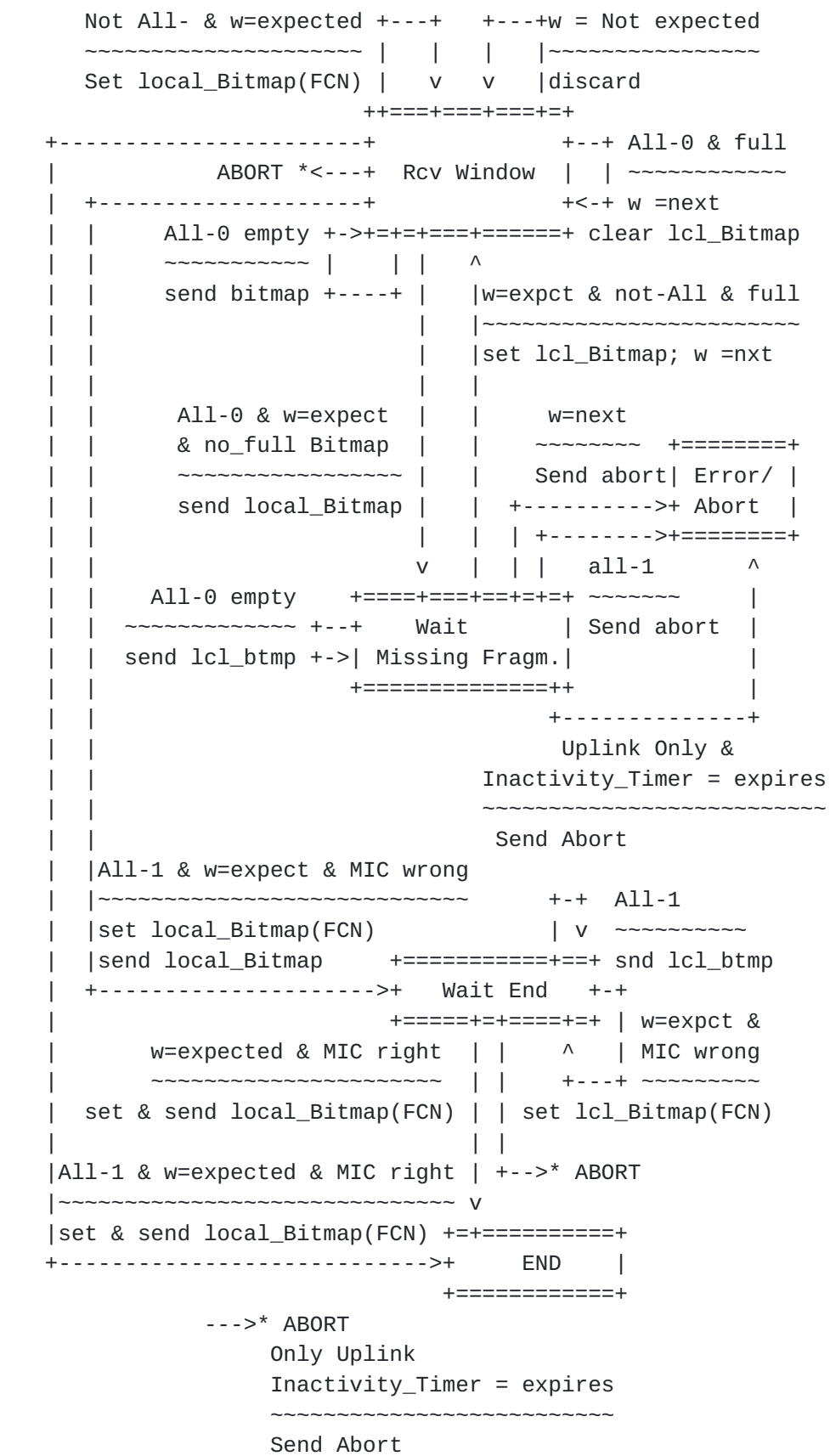

Not All- & w=expected
Set local_Bitmap(FCN)
w = Not expected
discard
ABORT
Rcv Window
All-0 & full
w =next
All-0 empty
clear lcl_Bitmap
send bitmap
w=expct & not-All & full
set lcl_Bitmap; w =nxt
All-0 & w=expect
& no_full Bitmap
send local_Bitmap
w=next
Send abort
Error/
Abort
All-0 empty
send lcl_btmp
Wait
Missing Fragm.
all-1
Send abort
Uplink Only &
Inactivity_Timer = expires
Send Abort
All-1 & w=expect & MIC wrong
set local_Bitmap(FCN)
send local_Bitmap
All-1
snd lcl_btmp
Wait End
w=expected & MIC right
MIC wrong
set & send local_Bitmap(FCN)
set lcl_Bitmap(FCN)
All-1 & w=expected & MIC right
ABORT
set & send local_Bitmap(FCN)
END
ABORT
Only Uplink
Inactivity_Timer = expires
Send Abort

Figure 44: Receiver State Machine for the ACK-on-Error Mode

Appendix D. SCHC Parameters - Ticket #15

This section gives the list of parameters that need to be defined in the technology-specific documents.

- Define the most common uses case and how SCHC may be deployed.
- LPWAN Architecture. Explain the SCHC entities (Compression and Fragmentation), how/where they are represented in the corresponding technology architecture. If applicable, explain the various potential channel conditions for the technology and the corresponding recommended use of C/D and F/R.
- L2 fragmentation decision
- Technology developers must evaluate that L2 has strong enough integrity checking to match SCHC's assumption.
- Rule ID numbering system, number of Rules
- Size of the Rule IDs
- The way the Rule ID is sent (L2 or L3) and how (describe)
- Fragmentation delivery reliability mode used in which cases (e.g. based on link channel condition)
- Define the number of bits for FCN (N) and DTag (T)
- in particular, is interleaved packet transmission supported and to what extent
- The MIC algorithm to be used and the size, if different from the default CRC32
- Retransmission Timer duration
- Inactivity Timer duration
- Define MAX_ACK_REQUEST (number of attempts)
- Padding: size of the L2 Word (for most technologies, a byte; for some technologies, a bit). Value of the padding bits (1 or 0). The value of the padding bits needs to be specified because the padding bits are included in the MIC calculation.

- Take into account that the length of Rule ID + N + T + W when possible is good to have a multiple of 8 bits to complete a byte and avoid padding

- In the ACK format to have a length for Rule ID + T + W bit into a complete number of byte to do optimization more easily

- The technology documents will describe if Rule ID is constrained by any alignment

- When fragmenting in ACK-on-Error or ACK-Always mode, it is expected that the last window (called All-1 window) will not be fully utilised, i.e. there won't be fragments with all FCN values from MAX_WIND_FCN downto 1 and finally All-1. It is worth noting that this document does not mandate that other windows (called All-0 windows) are fully utilised either. This document purposely does not specify that All-1 windows use Bitmaps with the same number of bits as All-0 windows do. By default, Bitmaps for All-0 and All-1 windows are of the same size MAX_WIND_FCN + 1. But a technology-specific document MAY revert that decision. The rationale for reverting the decision could be the following: Note that the SCHC ACK sent as a response to an All-1 fragment includes a C bit that SCHC ACK for other windows don't have. Therefore, the SCHC ACK for the All-1 window is one bit bigger. An L2 technology with a severely constrained payload size might decide that this "bump" in the SCHC ACK for the last fragment is a bad resource usage. It could thus mandate that the All-1 window is not allowed to use the FCN value 1 and that the All-1 SCHC ACK Bitmap size is reduced by 1 bit. This provides room for the C bit without creating a bump in the SCHC ACK.

And the following parameters need to be addressed in another document but not forcely in the technology-specific one:

- The way the contexts are provisioning

- The way the Rules as generated

Appendix E. Note

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