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The RObust Header Compression (ROHC) Framework

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Abstract

The Robust Header Compression (ROHC) protocol provides an efficient, flexible, and future-proof header compression concept. It is designed to operate efficiently and robustly over various link technologies with different characteristics.

The ROHC framework, along with a set of compression profiles, was initially defined in RFC 3095. To improve and simplify the ROHC specifications, this document explicitly defines the ROHC framework and the profile for uncompressed separately. More specifically, the definition of the framework does not modify or update the definition of the framework specified by RFC 3095.

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1. Introduction

For many types of networks, reducing the deployment and operational costs by improving the usage of the bandwidth resources is of vital importance. Header compression over a link is possible because some of the information carried within the header of a packet becomes compressible between packets belonging to the same flow.

For links where the overhead of the IP header(s) is problematic, the total size of the header may be significant. Applications carrying data carried within RTP [13] will then, in addition to link-layer framing, have an IPv4 [10] header (20 octets), a UDP [12] header (8 octets), and an RTP header (12 octets), for a total of 40 octets. With IPv6 [11], the IPv6 header is 40 octets for a total of 60 octets. Applications transferring data using TCP [14] will have 20 octets for the transport header, for a total size of 40 octets for IPv4 and 60 octets for IPv6.

The relative gain for specific flows (or applications) depends on the size of the payload used in each packet. For applications such as Voice-over-IP, where the size of the payload containing coded speech can be as small as 15-20 octets, this gain will be quite significant. Similarly, relative gains for TCP flows carrying large payloads (such as file transfers) will be less than for flows carrying smaller payloads (such as application signaling, e.g., session initiation).

As more and more wireless link technologies are being deployed to carry IP traffic, care must be taken to address the specific characteristics of these technologies within the header compression algorithms. Legacy header compression schemes, such as those defined in [16] and [17], have been shown to perform inadequately over links where both the lossy behavior and the round-trip times are non-negligible, such as those observed for example in wireless links and IP tunnels.

In addition, a header compression scheme should handle the often non-trivial residual errors, i.e., where the lower layer may pass a packet that contains undetected bit errors to the decompressor. It should also handle loss and reordering before the compression point, as well as on the link between the compression and decompression points [7].

The Robust Header Compression (ROHC) protocol provides an efficient, flexible, and future-proof header compression concept. It is designed to operate efficiently and robustly over various link technologies with different characteristics.

RFC 3095 [3] defines the ROHC framework along with an initial set of compression profiles. To improve and simplify the specification, the framework and the profiles' parts have been split into separate documents. This document explicitly defines the ROHC framework, but it does not modify or update the definition of the framework specified by RFC 3095; both documents can be used independently of each other. This also implies that implementations based on either definition will be compatible and interoperable with each other. However, it is the intent to let this specification replace RFC 3095 as the base specification for all profiles defined in the future.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [1].

2.1. Acronyms

This section lists most acronyms used for reference.

ACK	Acknowledgment.
CID	Context Identifier.
CO	Compressed Packet Format.
CRC	Cyclic Redundancy Check.
IR	Initialization and Refresh.
IR-DYN	Initialization and Refresh, Dynamic part.
LSB	Least Significant Bit(s).
MRRU	Maximum Reconstructed Reception Unit.
MSB	Most Significant Bit(s).
MSN	Master Sequence Number.
NACK	Negative Acknowledgment.
ROHC	RObust Header Compression.

2.2. ROHC Terminology

Context

The context of the compressor is the state it uses to compress a header. The context of the decompressor is the state it uses to decompress a header. Either of these or the two in combination are usually referred to as "context", when it is clear which is intended. The context contains relevant information from previous headers in the packet flow, such as static fields and possible reference values for compression and decompression. Moreover, additional information describing the packet flow is also part of

the context, for example, information about the change behavior of fields (e.g., the IP Identifier behavior, or the typical inter-packet increase in sequence numbers and timestamps).

Context damage

When the context of the decompressor is not consistent with the context of the compressor, decompression may fail to reproduce the original header. This situation can occur when the context of the decompressor has not been initialized properly or when packets have been lost or damaged between the compressor and decompressor.

Packets which cannot be decompressed due to inconsistent contexts are said to be lost due to context damage. Packets that are decompressed but contain errors due to inconsistent contexts are said to be damaged due to context damage.

Context repair mechanism

Context repair mechanisms are used to resynchronize the contexts, an important task since context damage causes loss propagation. Examples of such mechanisms are NACK-based mechanisms, and the periodic refreshes of important context information, usually done in unidirectional operation. There are also mechanisms that can reduce the context inconsistency probability, for example, repetition of the same type of information in multiple packets and CRCs that protect context-updating information.

CRC-8 validation

The CRC-8 validation refers to the validation of the integrity against bit error(s) in a received IR and IR-DYN header using the 8-bit CRC included in the IR/IR-DYN header.

CRC verification

The CRC verification refers to the verification of the result of a decompression attempt using the 3-bit CRC or 7-bit CRC included in the header of a compressed packet format.

Damage propagation

Delivery of incorrect decompressed headers due to context damage, that is, due to errors in (i.e., loss of or damage to) previous header(s) or feedback.

Error detection

Detection of errors by lower layers. If error detection is not perfect, there will be residual errors.

Error propagation

Damage propagation or loss propagation.

ROHC profile

A ROHC profile is a compression protocol, which specifies how to compress specific header combinations. A ROHC profile may be tailored to handle a specific set of link characteristics, e.g., loss characteristics, reordering between compression points, etc. ROHC profiles provide the details of the header compression framework defined in this document, and each compression profile is associated with a unique ROHC profile identifier [21]. When setting up a ROHC channel, the set of profiles supported by both endpoints of the channel is negotiated, and when initializing new contexts, a profile identifier from this negotiated set is used to associate each compression context with one specific profile.

Link

A physical transmission path that constitutes a single IP hop.

Loss propagation

Loss of headers, due to errors in (i.e., loss of or damage to) previous header(s) or feedback.

Packet flow

A sequence of packets where the field values and change patterns of field values are such that the headers can be compressed using the same context.

Residual error

Errors introduced during transmission and not detected by lower-layer error detection schemes.

ROHC channel

A logical unidirectional point-to-point channel carrying ROHC packets from one compressor to one decompressor, optionally carrying ROHC feedback information on the behalf of another

compressor-decompressor pair operating on a separate ROHC channel in the opposite direction. See also [5].

This document also makes use of the conceptual terminology defined by "ROHC Terminology and Channel Mapping Examples", RFC 3759 [5].

3. Background (Informative)

This section provides a background to the subject of header compression. The fundamental ideas are described together with a discussion about the history of header compression schemes. The motivations driving the development of the various schemes are discussed and their drawbacks identified, thereby providing the foundations for the design of the ROHC framework and profiles [3].

3.1. Header Compression Fundamentals

Header compression is possible because there is significant redundancy between header fields; within the headers of a single packet, but in particular between consecutive packets belonging to the same flow. On the path end-to-end, the entire header information is necessary for all packets in the flow, but over a single link, some of this information becomes redundant and can be reduced, as long as it is transparently recovered at the receiving end of the link. The header size can be reduced by first sending field information that is expected to remain static for (at least most of) the lifetime of the packet flow. Further compression is achieved for the fields carrying information that changes more dynamically by using compression methods tailored to their respective assumed change behavior.

To achieve compression and decompression, some necessary information from past packets is maintained in a context. The compressor and the decompressor update their respective contexts upon certain, not necessarily synchronized, events. Impairment events may lead to inconsistencies in the decompressor context (i.e., context damage), which in turn may cause incorrect decompression. A Robust Header Compression scheme needs mechanisms to minimize the possibility of context damage, in combination with mechanisms for context repair.

3.2. A Short History of Header Compression

The first header compression scheme, compressed TCP (CTCP) [15], was introduced by Van Jacobson. CTCP, also often referred to as VJ compression, compresses the 40 octets of the TCP/IP header down to 4 octets. CTCP uses delta encoding for sequentially changing fields. The CTCP compressor detects transport-level retransmissions and sends a header that updates the entire context when they occur. This

repair mechanism does not require any explicit signaling between the compressor and decompressor.

A general IP header compression scheme, IP header compression [16], improves somewhat on CTCP. IP Header Compression (IPHC) can compress arbitrary IP, TCP, and UDP headers. When compressing non-TCP headers, IPHC does not use delta encoding and is robust. The repair mechanism of CTCP is augmented with negative acknowledgments, called CONTEXT_STATE messages, which speeds up the repair. This context repair mechanism is thus limited by the round-trip time of the link. IPHC does not compress RTP headers.

CRTP [17] is an RTP extension to IPHC. CRTP compresses the 40 octets of IPv4/UDP/RTP headers to a minimum of 2 octets when the UDP Checksum is not enabled. If the UDP Checksum is enabled, the minimum CRTP header is 4 octets.

On lossy links with long round-trip times, CRTP does not perform well [20]. Each packet lost over the link causes decompression of several subsequent packets to fail, because the context becomes invalidated during at least one link round-trip time from the lost packet. Unfortunately, the large headers that CRTP sends when updating the context waste additional bandwidth.

CRTP uses a local repair mechanism known as TWICE, which was introduced by IPHC. TWICE derives its name from the observation that when the flow of compressed packets is regular, the correct guess when one packet is lost between the compression points is to apply the update in the current packet twice. While TWICE improves CRTP performance significantly, [20] also found that even with TWICE, CRTP doubled the number of lost packets.

An enhanced variant of CRTP, called eCRTP [19], means to improve the robustness of CRTP in the presence of reordering and packet losses, while keeping the protocol almost unchanged from CRTP. As a result, eCRTP does provide better means to implement some degree of robustness, albeit at the expense of additional overhead, leading to a reduction in compression efficiency in comparison to CRTP.

4. Overview of Robust Header Compression (ROHC) (Informative)

4.1. General Principles

As mentioned earlier, header compression is possible per-link due to the fact that there is much redundancy between header field values within packets, and especially between consecutive packets belonging to the same flow. To utilize these properties for header compression, there are a few essential steps to consider.

The first step consists of identifying and grouping packets together into different "flows", so that packet-to-packet redundancy is maximized in order to improve the compression ratio. Grouping packets into flows is usually based on source and destination host (IP) addresses, transport protocol type (e.g., UDP or TCP), process (port) numbers, and potentially additional unique application identifiers, such as the synchronization source (SSRC) in RTP [13]. The compressor and decompressor each establish a context for the packet flow and identify the context with a Context Identifier (CID) included in each compressed header.

The second step is to understand the change patterns of the various header fields. On a high level, header fields fall into one of the following classes:

INFERRED These fields contain values that can be inferred from other fields or external sources, for example, the size of the frame carrying the packet can often be derived from the link layer protocol, and thus does not have to be transmitted by the compression scheme.

STATIC Fields classified as STATIC are assumed to be constant throughout the lifetime of the packet flow. The value of each field is thus only communicated initially.

STATIC-DEF Fields classified as STATIC-DEF are used to define a packet flow as discussed above. Packets for which respective values of these fields differ are treated as belonging to different flows. These fields are in general compressed as STATIC fields.

STATIC-KNOWN Fields classified as STATIC-KNOWN are expected to have well-known values, and therefore their values do not need to be communicated.

CHANGING These fields are expected to vary randomly, either within a limited value set or range, or in some other manner. CHANGING fields are usually handled in more sophisticated ways based on a more detailed classification of their expected change patterns.

Finally, the last step is to choose the encoding method(s) that will be applied onto different fields based on classification. The encoding methods, in combination with the identified field behavior, provide the input to the design of the compressed header formats. The analysis of the probability distribution of the identified change patterns then provides the means to optimize the packet formats,

where the most frequently occurring change patterns for a field should be encoded within the most efficient format(s).

However, compression efficiency has to be traded against two other properties: the robustness of the encoding to losses and errors between the compressor and the decompressor, and the ability to detect and cope with errors in the decompression process.

4.2. Compression Efficiency, Robustness, and Transparency

The performance of a header compression protocol can be described with three parameters: its compression efficiency, its robustness, and its compression transparency.

Compression efficiency

The compression efficiency is determined by how much the average header size is reduced by applying the compression protocol.

Robustness

A robust protocol tolerates packet losses, residual bit errors, and out-of-order delivery on the link over which header compression takes place, without losing additional packets or introducing additional errors in decompressed headers.

Compression transparency

The compression transparency is a measure of the extent to which the scheme maintains the semantics of the original headers. If all decompressed headers are bitwise identical to the corresponding original headers, the scheme is transparent.

4.3. Developing the ROHC Protocol

The challenge in developing a header compression protocol is to conciliate compression efficiency and robustness while maintaining transparency, as increasing robustness will always come at the expense of a lower compression efficiency, and vice-versa. The scheme should also be flexible enough in its design to minimize the impacts from the varying round-trip times and loss patterns of links where header compression will be used.

To achieve this, the header compression scheme must provide facilities for the decompressor to verify decompression and detect potential context damage, as well as context recovery mechanisms such as feedback. Header compression schemes prior to the ones developed

by the Robust Header Compression (ROHC) WG were not designed with the above high-level objectives in mind.

The ROHC WG has developed header compression solutions to meet the needs of present and future link technologies. While special attention has been put towards meeting the more stringent requirements stemming from the characteristics of wireless links, the results are equally applicable to many other link technologies.

RFC 3095 [3], "RObust Header Compression (ROHC): Framework and four profiles: RTP, UDP, ESP, and uncompressed", was published in 2001, as the first output of the ROHC WG. ROHC is a general and extendable framework for header compression, on top of which profiles can be defined for compression of different protocols headers. RFC 3095 introduced a number of new compression techniques, and was successful at living up to the requirements placed on it, as described in [18].

Interoperability testing of RFC 3095 confirms the capabilities of ROHC to meet its purposes, but feedback from implementers has also indicated that the protocol specification is complex and sometimes obscure. Most importantly, a clear distinction between framework and profiles is not obvious in [3], which also makes development of additional profiles troublesome. This document therefore aims at explicitly specifying the ROHC framework, while a companion document [8] specifies revised versions of the compression profiles of RFC 3095.

4.4. Operational Characteristics of the ROHC Channel

Robust header compression can be used over many type of link technologies. The ROHC framework provides flexibility for profiles to address a wide range of applications, and this section lists some of the operational characteristics of the ROHC channel (see also [5]).

Multiplexing over a single logical channel

The ROHC channel provides a mechanism to identify a context within the general ROHC packet format. The CID makes it possible for a logical channel that supports ROHC to transport multiple header-compressed flows, while still making it possible for a channel to be dedicated to one single packet flow without any CID overhead. More specifically, ROHC uses a distinct context identifier space per logical channel, and the context identifier can be omitted for one of the flows over the ROHC channel when configured to use a small CID space.

Establishment of channel parameters

A link layer defining support for the ROHC channel must provide the means to establish header compression channel parameters (see Section 5.1). This can be achieved through a negotiation mechanism, static provisioning, or some out-of-band signaling.

Packet type identification

The ROHC channel defines a packet type identifier space, and puts restrictions with respect to the use of a number of identifiers that are common for all ROHC profiles. Identifiers that have no restrictions, i.e., identifiers that are not defined by this document, are available to each profile. The identifier is part of each compressed header, and this makes it possible for the link that supports the ROHC channel to allocate one single link layer payload type for ROHC.

Out-of-order delivery between compression endpoints

Each profile defines its own level of robustness, including tolerance to reordering of packets before but especially between compression endpoints, if any.

For profiles specified in [3], the channel between the compressor and decompressor is required to maintain in-order delivery of the packets, i.e., the definition of these profiles assumes that the decompressor always receives packets in the same order as the compressor sent them. The impacts of reordering on the performance of these profiles is described in [7]. However, reordering before the compression point is handled, i.e., these profiles make no assumption that the compressor will receive packets in-order.

For the ROHCv2 profiles specified in [8], their definitions assume that the decompressor can receive packets out-of-order, i.e., not in the same order that the compressor sent them. Reordering before the compression point is also dealt with.

Duplication of packets

The link supporting the ROHC channel is required to not duplicate packets (however, duplication of packets can occur before they reach the compressor, i.e., there is no assumption that the compressor will receive only one copy of each packet).

Framing

The link layer must provide framing that makes it possible to distinguish frame boundaries and individual frames.

Error detection/protection

ROHC profiles should be designed to cope with residual errors in the headers delivered to the decompressor. CRCs are used to detect decompression failures and to prevent or reduce damage propagation. However, it is recommended that lower layers deploy error detection for ROHC headers and that ROHC headers with high residual error rates not be delivered.

4.5. Compression and Master Sequence Number (MSN)

Compression of header fields is based on the establishment of a function to a sequence number, called the master sequence number (MSN). This function describes the change pattern of the field with respect to a change in the MSN.

Change patterns include, for example, fields that increase monotonically or by a small value, fields that seldom change,and fields that remain unchanging for the entire lifetime of the packet flow, in which case the function to the MSN is equivalent to a constant value.

The compressor first establishes functions for each of the header fields, and then reliably communicates the MSN. When the change pattern of the field does not match the established function, i.e., the existing function gives a result that is different from the field in the header being compressed, additional information can be sent to update the parameters of that function.

The MSN is defined per profile. It can be either derived directly from one of the fields of the protocol being compressed (e.g., the RTP SN [8]), or it can be created and maintained by the compressor (e.g., the MSN for compression of UDP in profile 0x0102 [8] or the MSN in ROHC-TCP [9]).

4.6. Static and Dynamic Parts of a Context

A compression context can be conceptually divided into two different parts, the static context and the dynamic context, each based on the properties of the fields that are being compressed.

The static part includes the information necessary to compress and decompress the fields whose change behavior is classified as STATIC, STATIC-KNOWN, or STATIC-DEF (as described in Section 4.1 above).

The dynamic part includes the state maintained for all the other fields, i.e., those that are classified as CHANGING.

5. The ROHC Framework (Normative)

This section normatively defines the parts common to all ROHC profiles, i.e., the framework. The framework specifies the requirements and functionality of the ROHC channel, including how to handle multiple compressed packet flows over the same channel.

Finally, this section specifies encoding methods used in the packet formats that are common to all profiles. These encoding methods may be reused within profile specifications for encoding fields in profile-specific parts of a packet format, without requiring their redefinition.

5.1. The ROHC Channel

5.1.1. Contexts and Context Identifiers

Associated with each compressed flow is a context. The context is the state that the compressor and the decompressor maintain in order to correctly compress or decompress the headers of the packet in the flow. Each context is identified using a CID.

A context is considered to be a new context when the CID is associated with a profile for the first time since the creation of the ROHC channel, or when the CID gets associated from the reception of an IR (this does not apply to the IR-DYN) with a different profile than the profile in the context.

Context information is conceptually kept in a table. The context table is indexed using the CID, which is sent along with compressed headers and feedback information.

The CID space can be either small, which means that CIDs can take the values 0 through 15, or large, which means that CIDs take values between 0 and 2^14 - 1 = 16383. Whether the CID space is large or small MUST be established, possibly by negotiation, before any compressed packet may be sent over the ROHC channel.

The CID space is distinct for each channel, i.e., CID 3 over channel A and CID 3 over channel B do not refer to the same context, even if the endpoints of A and B are the same nodes. In particular, CIDs for

any pair of ROHC channels are not related (two associated ROHC channels serving as feedback channels for one another do not even need to have CID spaces of the same size).

5.1.2. Per-Channel Parameters

The ROHC channel is based on a number of parameters that form part of the established channel state and the per-context state. The state of the ROHC channel MUST be established before the first ROHC packet may be sent, which may be achieved using negotiation protocols provided by the link layer (see also [4], which describes an option for negotiation of ROHC parameters for PPP). This section describes some of this channel state information in an abstract way:

LARGE_CIDS: Boolean; if false, the small CID representation (0 octets or 1 prefix octet, covering CID 0 to 15) is used; if true, the large CID representation (1 or 2 embedded CID octets covering CID 0 to 16383) is used. See also 5.1.1 and 5.2.1.3.

MAX_CID: Non-negative integer; highest CID number to be used by the compressor (note that this parameter is not coupled to, but in effect further constrained by, LARGE_CIDS). This value represents an agreement by the decompressor that it can provide sufficient memory resources to host at least MAX_CID+1 contexts; the decompressor MUST maintain established contexts within this space until either the CID gets re-used by the establishment of a new context, or until the channel is taken down.

PROFILES: Set of non-negative integers, where each integer indicates a profile supported by both the compressor and the decompressor. A profile is identified by a 16-bit value, where the 8 LSB bits indicate the actual profile, and the 8 MSB bits indicate the variant of that profile. The ROHC compressed header format identifies the profile used with only the 8 LSB bits; this means that if multiple variants of the same profile are available for a ROHC channel, the PROFILES set after negotiation MUST NOT include more than one variant of the same profile. The compressor MUST NOT compress using a profile that is not in PROFILES.

FEEDBACK_FOR: Optional reference to a ROHC channel in the opposite direction between the same compression endpoints. If provided, this parameter indicates to which other ROHC channel any feedback sent on this ROHC channel refers (see [5]).

MRRU: Non-negative integer. Maximum Reconstructed Reception Unit. This is the size of the largest reconstructed unit in octets that the decompressor is expected to reassemble from segments (see Section 5.2.5). This size includes the segmentation CRC. If MRRU

is negotiated to be 0, segmentation MUST NOT be used on the channel, and received segments MUST be discarded by the decompressor.

5.1.3. Persistence of Decompressor Contexts

As part of the negotiated channel parameters, the compressor and decompressor have through the MAX_CID parameter agreed on the highest context identification (CID) number to be used. By agreeing on the MAX_CID, the decompressor also agrees to provide memory resources to host at least MAX_CID+1 contexts, and an established context with a CID within this negotiated space SHOULD be kept by the decompressor until either the CID gets re-used, or the channel is taken down or re-negotiated.

5.2. ROHC Packets and Packet Types

This section uses the following convention in the diagrams when representing various ROHC packet types, formats, and fields:

- colons ":" indicate that the part is optional
- slashes "/" indicate variable length

The ROHC packet type indication scheme has been designed to provide optional padding, a feedback packet type, an optional Add-CID octet (which includes 4 bits of CID), and a simple segmentation and reassembly mechanism.

The following packet types are reserved at the ROHC framework level:

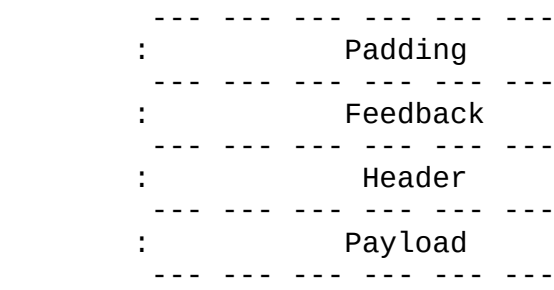
```
11100000 : Padding
1110nnnn : Add-CID octet (nnnn=CID with values 0x1 through 0xF)
11110    : Feedback
11111000 : IR-DYN packet
1111110  : IR packet
1111111  : Segment
```

Other packet types can be defined and used by individual profiles:

```
0        : available (not reserved by ROHC framework)
10       : available (not reserved by ROHC framework)
110      : available (not reserved by ROHC framework)
1111101  : available (not reserved by ROHC framework)
11111001 : available (not reserved by ROHC framework)
```

5.2.1. General Format of ROHC Packets

A ROHC packet has the following general format:



Padding: Any number (zero or more) of padding octets, where the format of a padding octet is as defined in Section 5.2.1.1.

Feedback: Any number (zero or more) of feedback elements, where the format of a feedback element is as defined in Section 5.2.4.1.

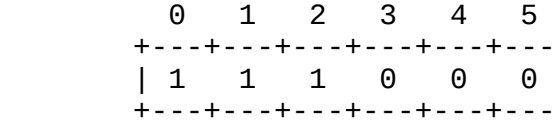
Header: Either a profile-specific CO header (see Section 5.2.1.3), an IR or IR-DYN header (see Section 5.2.2), or a ROHC Segment (see Section 5.2.5). There can be at most one Header in a ROHC packet, but it may also be omitted (if the packet contains Feedback only).

Payload: Corresponds to zero or more octets of payload from the uncompressed packet, starting with the first octet in the uncompressed packet after the last header compressible by the current profile.

At least one of Feedback or Header MUST be present.

5.2.1.1. Format of the Padding Octet

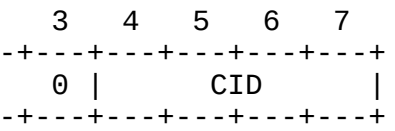
Padding octet:



Note: The Padding octet MUST NOT be interpreted as an Add-CID octet for CID 0.

5.2.1.2. Format of the Add-CID Octet

Add-CID octet:

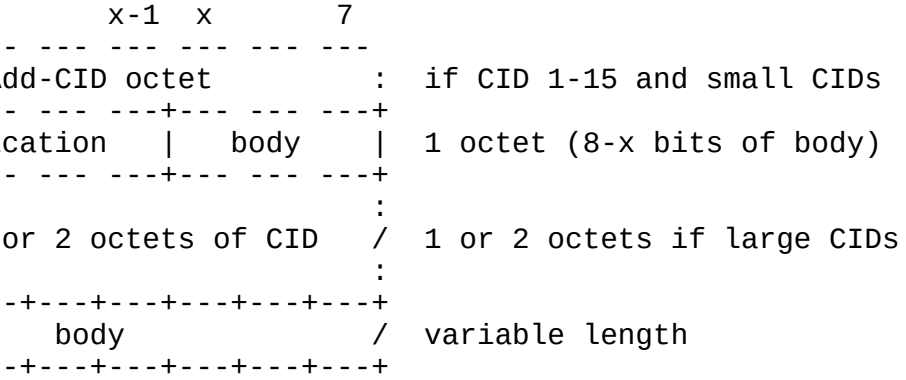


CID: 0x1 through 0xF indicates CIDs 1 through 15.

Note: The Padding octet looks like an Add-CID octet for CID 0.

5.2.1.3. General Format of Header

All ROHC packet types have the following general Header format:



type indication: ROHC packet type.

body: Interpreted according to the packet type indication and CID information, as defined by individual profiles.

Thus, the header either starts with a packet type indication or has a packet type indication immediately following an Add-CID octet.

When the ROHC channel is configured with a small CID space:

- If an Add-CID immediately precedes the packet type indication, the packet has the CID of the Add-CID; otherwise, it has CID 0.

- A small CID with the value 0 is represented using zero bits; therefore, a flow associated with CID 0 has no CID overhead in the compressed header. In such case, Header starts with a packet type indication.

- A small CID with a value from 1 to 15 is represented using the Add-CID octet as described above. The Header starts with the Add-CID octet, followed by a packet type indication.

- There is no large CID in the Header.

When the ROHC channel is configured with a large CID space:

- The large CID is always present and is represented using the encoding scheme of Section 5.3.2, limited to two octets. In this case, the Header starts with a packet type indication.

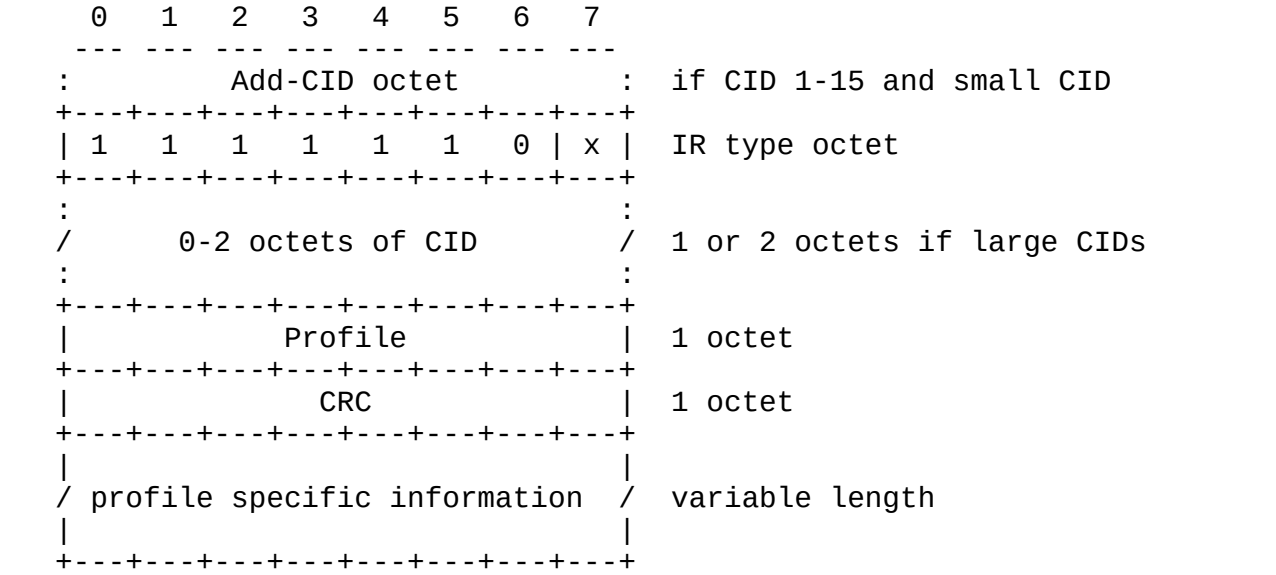
5.2.2. Initialization and Refresh (IR) Packet Types

IR packet types contain a profile identifier, which determines how the rest of the header is to be interpreted. They also associate a profile with a context. The stored profile parameter further determines the syntax and semantics of the packet type identifiers and packet types used with a specific context.

The IR and IR-DYN packets always update the context for all context-updating fields carried in the header. They never clear the context, except when initializing a new context (see Section 5.1.1), or unless the profile indicated in the Profile field specifies otherwise.

5.2.2.1. ROHC IR Packet Type

The IR header associates a CID with a profile, and typically also initializes the context. It can typically also refresh all (or parts of) the context. For IR, Header has the following general format:



x: Profile specific information. Interpreted according to the profile indicated in the Profile field of the IR header.

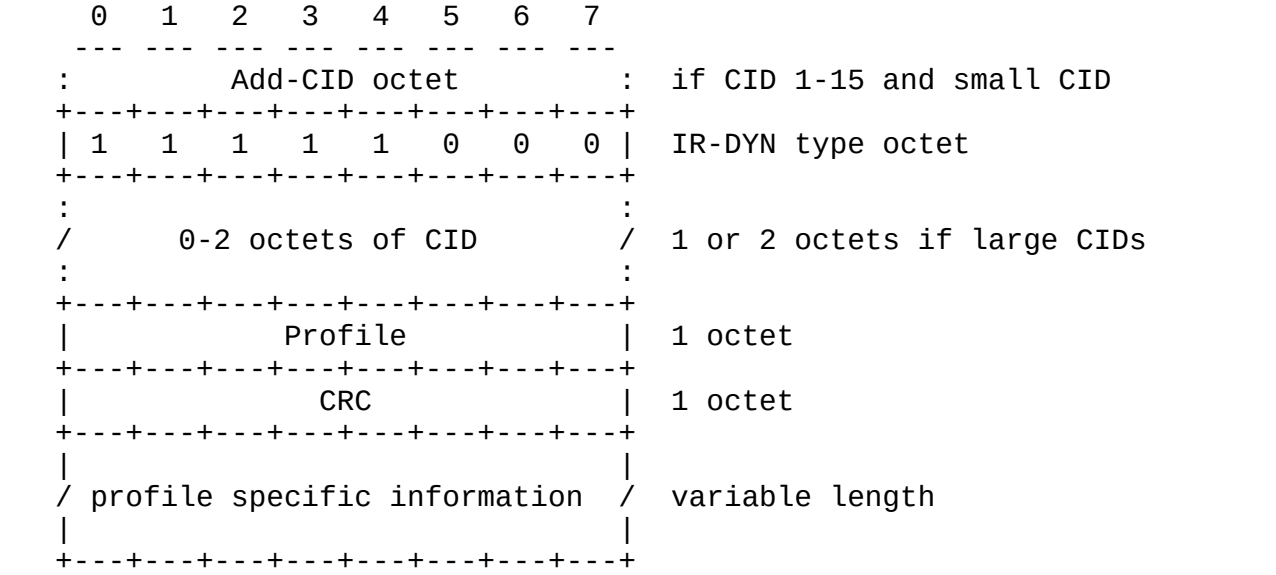
Profile: The profile associated with the CID. In the IR header, the profile identifier is abbreviated to the 8 least significant bits (see Section 5.1.2).

CRC: 8-bit CRC (see Section 5.3.1.1).

Profile specific information: The content of this part of the IR header is defined by the individual profiles. It is interpreted according to the profile indicated in the Profile field.

5.2.2.2. ROHC IR-DYN Packet Type

In contrast to the IR header, the IR-DYN header can never initialize a non-initialized context. However, it can redefine what profile is associated with a context, if the profile indicated in the IR-DYN header allows this. Thus, this packet type is also reserved at the framework level. The IR-DYN header typically also initializes or refreshes parts of a context. For IR-DYN, Header has the following general format:



Profile: The profile associated with the CID. This is abbreviated in the same way as in IR packets.

CRC: 8-bit CRC (see Section 5.3.1.1).

Profile specific information: The content of this part of the IR-DYN header is defined by the individual profiles. It is interpreted according to the profile indicated in the Profile field.

5.2.3. ROHC Initial Decompressor Processing

Initially, all contexts are in no context state. Thus, all packets referencing a non-initialized context, except packets that have enough information on the static fields, cannot be decompressed by the decompressor.

When the decompressor receives a packet of type IR, the profile indicated in the IR packet determines how it is to be processed.

- If the 8-bit CRC fails to verify the integrity of the Header, the packet MUST NOT be decompressed and delivered to upper layers. If a profile is indicated in the context, the logic of that profile determines what, if any, feedback is to be sent. If no profile is noted in the context, the logic used to determine what, if any, feedback to send is up to the implementation. However, it may be suitable to take no further actions, as any part of the IR header covered by the CRC may have caused the failure.

When the decompressor receives a packet of type IR-DYN, the profile indicated in the IR-DYN packet determines how it is to be processed.

- If the 8-bit CRC fails to verify the integrity of the header, the packet MUST NOT be decompressed and delivered to upper layers. If a profile is indicated in the context, the logic of that profile determines what, if any, feedback is to be sent. If no profile is noted in the context, the logic used to determine what, if any, feedback to send is up to the implementation. However, it may be suitable to take no further actions, as any part of the IR-DYN header covered by the CRC may have caused the failure.

- If the context has not already been initialized, the packet MUST NOT be decompressed and delivered to upper layers. The logic of the profile indicated in the IR-DYN header (if verified by the 8-bit CRC), determines what, if any, feedback is to be sent.

If a parsing error occurs for any packet type, the decompressor MUST discard the packet without further processing. For example, a CID field is present in the compressed header when the large CID space is used for the ROHC channel, and the field is coded using the self-describing variable-length encoding of Section 5.3.2; if the field starts with 110 or 111, this would generate a parsing error for the decompressor because this field must not be encoded with a size larger than 2 octets.

It is RECOMMENDED that profiles disallow the decompressor to make a decompression attempt for packets carrying only a 3-bit CRC after it has invalidated some or all of the entire dynamic context, until a packet that contains sufficient information on the dynamic fields is received, decompressed, and successfully verified by a 7- or 8-bit CRC.

5.2.4. ROHC Feedback

Feedback carries information from the decompressor to compressor. Feedback can be sent over a ROHC channel that operates in the same direction as the feedback.

The general ROHC packet format allows transport of feedback using interspersion or piggybacking (see [5]), or a combination of both, over a ROHC channel. This is facilitated by the following properties:

Reserved packet type:

A feedback packet type is reserved at the framework level. The packet type can carry variable-length feedback information.

CID information:

The feedback information sent on a particular channel is passed to, and interpreted by, the compressor associated with feedback on that channel. Thus, each feedback element contains CID information from the channel for which the feedback is sent. The ROHC feedback scheme thus requires that a channel carries feedback to at most one compressor. How a compressor is associated with the feedback for a particular channel is outside the scope of this specification. See also [5].

Length information:

The length of a feedback element can be determined by examining the first few octets of the feedback. This enables piggybacking of feedback, and also the concatenation of more than one feedback element in a packet. The length information thus decouples the decompressor from the associated same-side compressor, as the decompressor can extract the feedback information from the compressed header without parsing its content and hand over the extracted information.

The association between compressor-decompressor pairs operating in opposite directions, for the purpose of exchanging piggyback and/or interspersed feedback, SHOULD be maintained for the lifetime of the ROHC channel. Otherwise, it is RECOMMENDED that the compressor be notified if the feedback channel is no longer available: the compressor SHOULD then restart compression by creating a new context for each packet flow, and SHOULD use a CID value that was not previously associated with the profile used to compress the flow.

5.2.4.1. ROHC Feedback Format

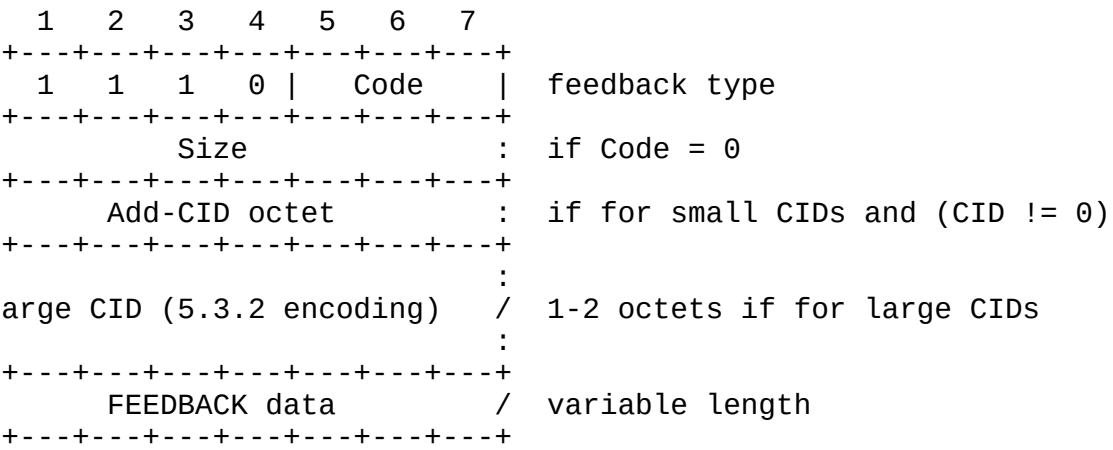
ROHC defines three different categories of feedback messages: acknowledgment (ACK), negative ACK (NACK), and NACK for the entire context (STATIC-NACK). Other types of information may be defined in profile-specific feedback information.

ACK : Acknowledges successful decompression of a packet. Indicates that the decompressor considers its context to be valid.

NACK : Indicates that the decompressor considers some or all of the dynamic part of its context invalid.

STATIC-NACK : Indicates that the decompressor considers its entire static context invalid, or that it has not been established.

Feedback sent on a ROHC channel consists of one or more concatenated feedback elements, where each feedback element has the following format:



Code: 0 indicates that a Size octet is present.
1-7 indicates the size of the feedback data field, in octets.

Size: Indicates the size of the feedback data field, in octets.

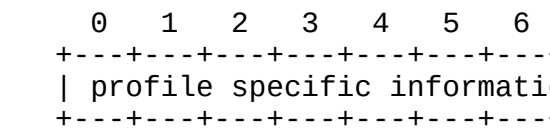
FEEDBACK data: FEEDBACK-1 or FEEDBACK-2 (see below).

CID information in a feedback element indicates the context for which feedback is sent. The LARGE_CIDS parameter that controls whether a large CID is present is taken from the channel state of the receiving compressor's channel, not from the state of the channel carrying the feedback.

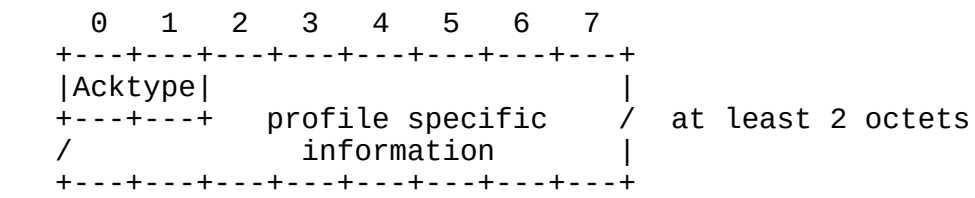
The large CID field, if present, is encoded according to Section 5.3.2, and it MUST NOT be encoded using more than 2 octets.

The FEEDBACK data field can have either of the following two formats:

FEEDBACK-1:



FEEDBACK-2:



Acktype: 0 = ACK
1 = NACK
2 = STATIC-NACK
3 is reserved (MUST NOT be used. Otherwise unparseable.)

5.2.5. ROHC Segmentation

ROHC defines a simple segmentation protocol. The compressor may perform segmentation, e.g., to accommodate packets that are larger than a specific size configured for the channel.

5.2.5.1. Segmentation Usage Considerations

The ROHC segmentation protocol is not particularly efficient. It is not intended to replace link layer segmentation functions; these SHOULD be used whenever available and efficient for the task at hand.

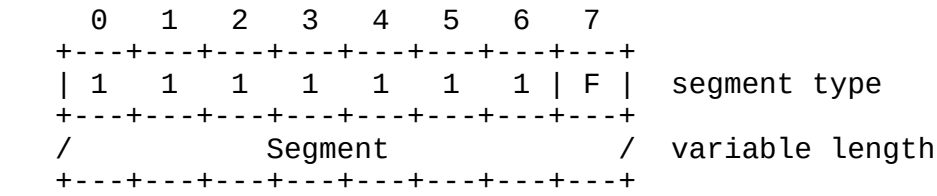
The ROHC segmentation protocol has been designed with an assumption of in-order delivery of packets between the compressor and the decompressor, using only a CRC for error detection, and no sequence numbers. If in-order delivery cannot be guaranteed, ROHC segmentation MUST NOT be used.

The segmentation protocol also assumes that all segments of a ROHC packet corresponding to one context are received without interference from other ROHC packets over the channel, including any ROHC packet corresponding to a different context. Based on this assumption, segments do not carry CID information, and therefore cannot be associated with a specific context until all segments have been received and the whole unit has been reconstructed.

5.2.5.2. Segmentation Protocol

ROHC segmentation is applied to the combination of the Header and the Payload fields of the ROHC packet, as defined in Section 5.2.1.

Segment format:

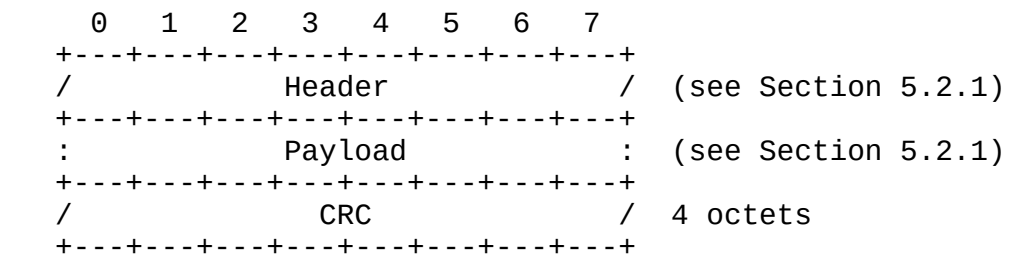


F: Final bit. If set, it indicates that this is the last segment of a reconstructed unit.

Padding and/or Feedback may precede the segment type octet. There is no per-segment CID, but CID information is of course part of the reconstructed unit. The reconstructed unit MUST NOT contain padding, segments, or feedback.

When a final segment is received, the decompressor reassembles the segment carried in this packet and any non-final segments that immediately preceded it into a single reconstructed unit, in the order they were received. All segments for one reconstructed unit have to be received consecutively and in the correct order by the decompressor. If a non-segment ROHC packet directly follows a non-final segment, the reassembly of the current reconstructed unit is aborted and the decompressor MUST discard the non-final segments so far received on this channel.

Reconstructed unit:



CRC: 32-bit CRC computed using the polynomial of Section 5.3.1.4.

If the reconstructed unit is 4 octets or less, or if the CRC fails, or if it is larger than the channel parameter MRRU (see Section

5.1.2), the reconstructed unit MUST be discarded by the decompressor. If the CRC succeeds, the reconstructed unit can be further processed.

5.3. General Encoding Methods

5.3.1. Header Compression CRCs, Coverage and Polynomials

This section describes how to calculate the CRCs used by ROHC. For all CRCs, the algorithm used to calculate the CRC is the same as the one used in [2], defined in Appendix A of this document, with the polynomials specified in subsequent sections.

5.3.1.1. 8-bit CRCs in IR and IR-DYN Headers

The coverage for the 8-bit CRC in the IR and IR-DYN headers is profile-dependent, but it MUST cover at least the initial part of the header ending with the Profile field, including the CID or an Add-CID octet. Feedback and padding are not part of Header (Section 5.2.1) and are thus not included in the CRC calculation. As a rule of thumb for profile specifications, any other information that initializes the decompressor context SHOULD also be covered by a CRC.

More specifically, the 8-bit CRC does not cover only and entirely the original uncompressed header; therefore, it does not provide the means for the decompressor to verify a decompression attempt, or the means to verify the correctness of the entire decompressor context. However, when successful, it does provide enough robustness for the decompressor to update its context with the information carried within the IR or the IR-DYN header.

The CRC polynomial for the 8-bit CRC is:

$$C(x) = 1 + x + x^2 + x^8$$

When computing the CRC, the CRC field in the header is set to zero, and the initial content of the CRC register is set to all 1's.

5.3.1.2. 3-bit CRC in Compressed Headers

The 3-bit CRC in compressed headers is calculated over all octets of the entire original header, before compression, in the following manner.

The initial content of the CRC register is set to all 1's.

The polynomial for the 3-bit CRC is:

$$C(x) = 1 + x + x^3$$

The purpose of the 3-bit CRC is to provide the means for the decompressor to verify the outcome of a decompression attempt for small compressed headers, and to detect context damage based on aggregated probability over a number of decompression attempts. It is however too weak to provide enough success guarantees from the decompression of one single header. Therefore, compressed headers carrying a 3-bit CRC are normally not suitable to perform context repairs at the decompressor; hence, profiles should refrain from allowing decompression of such a header when some or the entire decompressor context is assumed invalid.

5.3.1.3. 7-bit CRC in Compressed Headers

The 7-bit CRC in compressed headers is calculated over all octets of the entire original header, before compression, in the following manner.

The initial content of the CRC register is set to all 1's.

The polynomial for the 7-bit CRC is:

$$C(x) = 1 + x + x^2 + x^3 + x^6 + x^7$$

The purpose of the 7-bit CRC is to provide the means for the decompressor to verify the outcome of a decompression attempt for a larger compressed header, and to provide enough protection to validate a context repair at the decompressor. The 7-bit CRC is strong enough to assume a repair to be successful from the decompression of one single header; hence, profiles may allow decompression of a header carrying a 7-bit CRC when some of the decompressor context is assumed invalid.

5.3.1.4. 32-bit Segmentation CRC

The 32-bit CRC is used by the segmentation scheme to verify the reconstructed unit, and it is thus calculated over the segmented unit, i.e., over the Header and the Payload fields of the ROHC packet.

The initial content of the CRC register is set to all 1's.

The polynomial for the 32-bit CRC is:

$$C(x) = x^0 + x^1 + x^2 + x^4 + x^5 + x^7 + x^8 + x^{10} + x^{11} + x^{12} + x^{16} + x^{22} + x^{23} + x^{26} + x^{32}.$$

The purpose of the 32-bit CRC is to verify the reconstructed unit.

5.3.2. Self-Describing Variable-Length Values

The values of many fields and compression parameters can vary widely. To optimize the transfer of such values, a variable number of octets are used to encode them. The first few bits of the first octet determine the number of octets used:

First bit is 0: 1 octet.
7 bits transferred.
Up to 127 decimal.
Encoded octets in hexadecimal: 00 to 7F

First bits are 10: 2 octets.
14 bits transferred.
Up to 16 383 decimal.
Encoded octets in hexadecimal: 80 00 to BF FF

First bits are 110: 3 octets.
21 bits transferred.
Up to 2 097 151 decimal.
Encoded octets in hexadecimal: C0 00 00 to DF FF FF

First bits are 111: 4 octets.
29 bits transferred.
Up to 536 870 911 decimal.
Encoded octets in hexadecimal: E0 00 00 00 to FF FF FF FF

5.4. ROHC UNCOMPRESSED -- No Compression (Profile 0x0000)

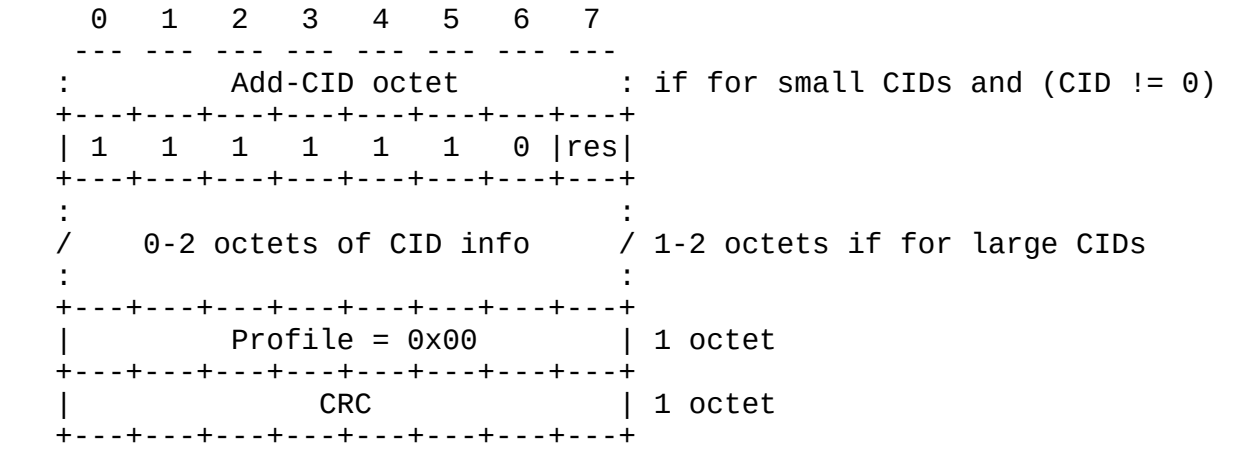
This section describes the uncompressed ROHC profile. The profile identifier for this profile is 0x0000.

Profile 0x0000 provides a way to send IP packets without compressing them. This can be used for any packet for which a compression profile is not available in the set of profiles supported by the ROHC channel, or for which compression is not desirable for some reason.

After initialization, the only overhead for sending packets using Profile 0x0000 is the size of the CID. When uncompressed packets are frequent, Profile 0x0000 should be associated with a CID the size of zero or one octet. Profile 0x0000 SHOULD be associated with at most one CID.

5.4.1. IR Packet

The initialization and refresh packet (IR packet) for Profile 0x0000 has the following Header format:

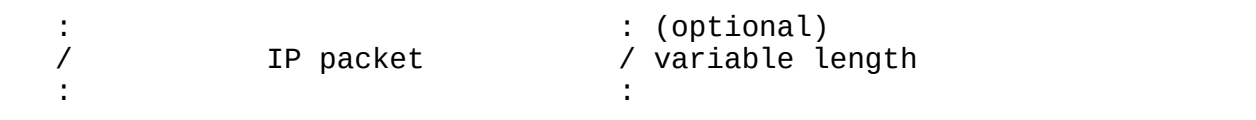


res: MUST be set to zero; otherwise, the decompressor MUST discard the packet.

Profile: 0x00

CRC: 8-bit CRC, computed using the polynomial of Section 5.3.1.1. The CRC covers the first octet of the IR Header through the Profile octet of the IR Header, i.e., it does not cover the CRC itself. Neither does it cover any preceding Padding or Feedback, nor the Payload.

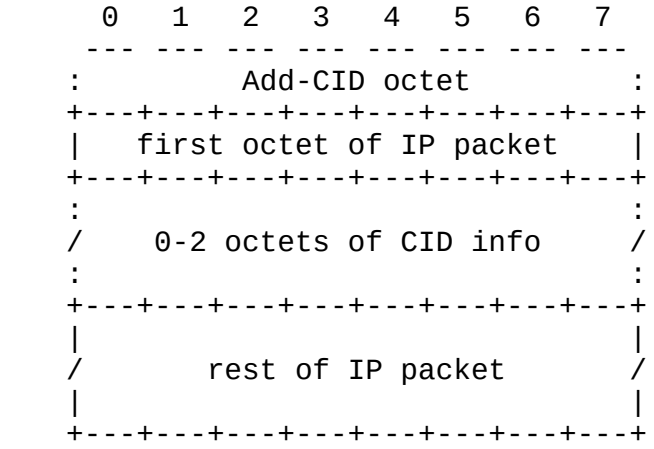
For the IR packet, Payload has the following format:



IP packet: An uncompressed IP packet may be included in the IR packet. The decompressor determines if the IP packet is present by considering the length of the IR packet.

5.4.2. Normal Packet

A Normal packet is a normal IP packet plus CID information. For the Normal Packet, the following format corresponds to the Header and Payload (as defined in Section 5.2.1):



Note that the first octet of the IP packet starts with the bit pattern 0100 (IPv4) or 0110 (IPv6). This does not conflict with any reserved packet types.

When the channel uses small CIDs, and profile 0x0000 is associated with a CID > 0, an Add-CID octet precedes the IP packet. When the channel uses large CIDs, the CID is placed so that it starts at the second octet of the combined Header/Payload format above.

A Normal Packet may carry Padding and/or Feedback as any other ROHC packet, preceding the combined Header/Payload.

5.4.3. Decompressor Operation

When an IR packet is received, the decompressor first validates its header using the 8-bit CRC.

- If the header fails validation, the decompressor MUST NOT deliver the IP packet to upper layers.

- If the header is successfully validated, the decompressor

  1) initializes the context if it has no valid context for the given CID already associated to the specified profile,

  2) delivers the IP packet to upper layers if present,

3) MAY send an ACK.

When any other packet is received while the decompressor has no context, it is discarded without further action.

When a Normal packet is received and the decompressor has a valid context, the IP packet is extracted and delivered to upper layers.

5.4.4. Feedback

The only kind of feedback defined by Profile 0x0000 is ACK, using the FEEDBACK-1 format of Section 5.2.4.1, where the value of the profile-specific octet in the FEEDBACK-1 is 0 (zero). The FEEDBACK-2 format is thus not defined for Profile 0x0000.

6. Overview of a ROHC Profile (Informative)

The ROHC protocol consists of a framework part and a profile part. The framework defines the mechanisms common to all profiles, while the profile defines the compression algorithm and profile specific packet formats.

Section 5 specifies the details of the ROHC framework. This section provides an informative overview of the elements that make a profile specification. The normative specification of individual profiles is outside the scope of this document.

A ROHC profile defines the elements that build up the compression protocol. A ROHC profile consists of:

Packet formats:

- Bits-on-the-wire

  The profile defines the layout of the bits for profile-specific packet types that it defines, and for the profile-specific parts of packet types common to all profiles (e.g., IR and IR-DYN).

- Field encodings

  Bits and groups of bits from the packet format layout, referred to as Compressed fields, represents the result of an encoding method specific for that compressed field within a specific packet format. The profile defines these encoding methods.

- Updating properties

  The profile-specific packet formats may update the state of the decompressor, and may do so in different ways. The profile defines how individual profile-specific fields, or entire profile-specific packet types, update the decompressor context.

- Verification

  Packets that update the state of the decompressor are verified to prevent incorrect updates to the decompressor context. The profile defines the mechanisms used to verify the decompression of a packet.

Context management:

- Robustness logic

  Packets may be lost or reordered between the compressor and the decompressor. The profile defines mechanism to minimize the impacts of such events and prevent damage propagation.

- Repair mechanism

  Despite the robustness logic, impairment events may still lead to decompression failure(s), and even to context damage at the decompressor. The profile defines context repair mechanisms, including feedback logic if used.

7. Security Considerations

Because encryption eliminates the redundancy that header compression schemes try to exploit, there is some inducement to forego encryption of headers in order to enable operation over low-bandwidth links.

A malfunctioning or malicious header compressor could cause the header decompressor to reconstitute packets that do not match the original packets but still have valid headers and possibly also valid transport checksums. Such corruption may be detected with end-to-end authentication and integrity mechanisms, which will not be affected by the compression. Moreover, the ROHC header compression scheme uses an internal checksum for verification of reconstructed headers, which reduces the probability of producing decompressed headers not matching the original ones without this being noticed.

Denial-of-service attacks are possible if an intruder can introduce, for example, bogus IR, IR-DYN, or FEEDBACK packets onto the link and thereby cause compression efficiency to be reduced. However, an

intruder having the ability to inject arbitrary packets at the link layer in this manner raises additional security issues that dwarf those related to the use of header compression.

8. IANA Considerations

An IANA registry for "RObust Header Compression (ROHC) Profile Identifiers" [21] was created by RFC 3095 [3]. The assignment policy, as outlined by RFC 3095, is the following:

The ROHC profile identifier is a non-negative integer. In many negotiation protocols, it will be represented as a 16-bit value. Due to the way the profile identifier is abbreviated in ROHC packets, the 8 least significant bits of the profile identifier have a special significance: Two profile identifiers with identical 8 LSBs should be assigned only if the higher-numbered one is intended to supersede the lower-numbered one. To highlight this relationship, profile identifiers should be given in hexadecimal (as in 0x1234, which would for example supersede 0x0A34).

Following the policies outlined in [22], the IANA policy for assigning new values for the profile identifier shall be Specification Required: values and their meanings must be documented in an RFC or in some other permanent and readily available reference, in sufficient detail that interoperability between independent implementations is possible. In the 8 LSBs, the range 0 to 127 is reserved for IETF standard-track specifications; the range 128 to 254 is available for other specifications that meet this requirement (such as Informational RFCs). The LSB value 255 is reserved for future extensibility of the present specification.

The following profile identifiers have so far been allocated:

Profile Identifier	Usage	Reference
0x0000	ROHC uncompressed	RFC 4995
0x0001	ROHC RTP	RFC 3095
0x0002	ROHC UDP	RFC 3095
0x0003	ROHC ESP	RFC 3095
0x0004	ROHC IP	RFC 3843
0x0005	ROHC LLA	RFC 3242
0x0105	ROHC LLA with R-mode	RFC 3408
0x0006	ROHC TCP	RFC 4996
0x0007	ROHC RTP/UDP-Lite	RFC 4019
0x0008	ROHC UDP-Lite	RFC 4019

New profiles will need new identifiers to be assigned by the IANA, but this document does not require any additional IANA action.

9. Acknowledgments

The authors would like to acknowledge all who have contributed to previous ROHC work, and especially to the authors of RFC 3095 [3], which is the technical basis for this document. Thanks also to the various individuals who contributed to the RFC 3095 corrections and clarifications document [6], from which technical contents, when applicable, have been incorporated into this document. Committed WG document reviewers were Carl Knutsson and Biplab Sarkar, who reviewed the document during working group last-call.

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[21] IANA registry, "RObust Header Compression (ROHC) Profile Identifiers", http://www.iana.org/assignments/rohc-pro-ids

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Appendix A. CRC Algorithm

```
#!/usr/bin/perl -w
use strict;
#================================
#
# ROHC CRC demo - Carsten Bormann cabo@tzi.org 2001-08-02
#
# This little demo shows the four types of CRC in use in RFC 3095,
# the specification for robust header compression.  Type your data in
# hexadecimal form and then press Control+D.
#
#--------------------------------
#
# utility
#
sub dump_bytes($) {
    my $x = shift;
    my $i;
    for ($i = 0; $i < length($x); ) {
  printf("%02x ", ord(substr($x, $i, 1)));
  printf("\n") if (++$i % 16 == 0);
    }
    printf("\n") if ($i % 16 != 0);
}

#--------------------------------
#
# The CRC calculation algorithm.
#
sub do_crc($$$) {
    my $nbits = shift;
    my $poly = shift;
    my $string = shift;

    my $crc = ($nbits == 32 ? 0xffffffff : (1 << $nbits) - 1);
    for (my $i = 0; $i < length($string); ++$i) {
      my $byte = ord(substr($string, $i, 1));
      for( my $b = 0; $b < 8; $b++ ) {
        if (($crc & 1) ^ ($byte & 1)) {
          $crc >>= 1;
          $crc ^= $poly;
        } else {
        $crc >>= 1;
        }
        $byte >>= 1;
      }
    }
```

```
    printf "%2d bits, ", $nbits;
    printf "CRC: %02x\n", $crc;
}

#---------------------------------
#
# Test harness
#
$/ = undef;
$_ = <>;         # read until EOF
my $string = ""; # extract all that looks hex:
s/([0-9a-fA-F][0-9a-fA-F])/$string .= chr(hex($1)), ""/eg;
dump_bytes($string);

#---------------------------------
#
# 32-bit segmentation CRC
# Note that the text implies this is complemented like for PPP
# (this differs from 8, 7, and 3-bit CRC)
#
#      C(x) = x^0 + x^1 + x^2 + x^4 + x^5 + x^7 + x^8 + x^10 +
#             x^11 + x^12 + x^16 + x^22 + x^23 + x^26 + x^32
#
do_crc(32, 0xedb88320, $string);

#---------------------------------
#
# 8-bit IR/IR-DYN CRC
#
#      C(x) = x^0 + x^1 + x^2 + x^8
#
do_crc(8, 0xe0, $string);

#---------------------------------
#
# 7-bit FO/SO CRC
#
#      C(x) = x^0 + x^1 + x^2 + x^3 + x^6 + x^7
#
do_crc(7, 0x79, $string);

#---------------------------------
#
# 3-bit FO/SO CRC
#
#      C(x) = x^0 + x^1 + x^3
#
do_crc(3, 0x6, $string);
```

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