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Request for Comments: 3843   G. Pelletier
Category: Standards Track   Ericsson
                                                                June 2004

          RObust Header Compression (ROHC): A Compression Profile for IP

Abstract

   The original RObust Header Compression (ROHC) RFC (RFC 3095) defines
   a framework for header compression, along with compression protocols
   (profiles) for IP/UDP/RTP, IP/ESP (Encapsulating Security Payload),
   IP/UDP, and also a profile for uncompressed packet streams. However,
   no profile was defined for compression of IP only, which has been
   identified as a missing piece in RFC 3095. This document defines a
   ROHC compression profile for IP, similar to the IP/UDP profile
   defined by RFC 3095, but simplified to exclude UDP, and enhanced to
   compress IP header chains of arbitrary length.

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1. Introduction

   The original RObust Header Compression (ROHC) RFC [RFC-3095] defines
   a framework for header compression, along with compression protocols
   (profiles) for IP/UDP/RTP, IP/ESP (Encapsulating Security Payload),
   IP/UDP, and also a profile for uncompressed packet streams. The
   profile for uncompressed data was defined to provide a means to
   encapsulate all traffic over a link within ROHC packets. Through
   this profile, the lower layers do not have to provide multiplexing
   for different packet types, but instead ROHC can handle any packet
   stream, even if compression profiles for all kinds of packet streams
   have not yet been defined or implemented over the link.

   Although the profile without compression is simple and can tunnel
   arbitrary packets, it has of course a major weakness in that it does
   not compress the headers at all. When considering that normally all
   packets are expected to be IP [RFC-791, RFC-2460] packets, and that
   the IP header often represents a major part of the total header, a
   useful alternative to no compression would for most packets be
   compression of the IP header only. Unfortunately, such a profile was
   not defined in [RFC-3095], and this has thus been identified as an
   important missing piece in the ROHC toolbox.

   This document addresses this missing compression support and defines
   a ROHC compression profile for IP [RFC-791, RFC-2460] only, similar
   to the IP/UDP profile defined by [RFC-3095], but simplified to
   exclude UDP. Due to the similarities with the IP/UDP profile, the IP
   compression profile is described based on the IP/UDP profile, mainly
   covering differences. The most important differences are a different
   way of terminating the static header chain, and the capability of
   compressing IP header chains of arbitrary length.

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 [RFC-2119].

ROHC UDP

   "ROHC UDP" in this document refers to the IP/UDP profile (Profile
   0x0002) as defined in [RFC-3095].

3. ROHC IP Compression (Profile 0x0004)

   In general, there are no major differences between the ROHC UDP
   profile and the IP profile (ROHC IP) defined in this document, since
   the removal of UDP has no impact on the compression mechanisms in
   principle. As for ROHC UDP, the compressor generates a 16-bit
   sequence number which increases by one for each packet compressed in
   the packet stream, simply called SN below. The most important
   difference between this profile and ROHC UDP is about static chain
   termination and the handling of multiple IP headers. Unless stated
   explicitly below, mechanisms and formats are the same as for ROHC
   UDP.

3.1. Static Chain Termination

   One difference for IP-only compression, compared to IP/UDP
   compression, is related to the termination of the static chain in IR
   headers. For the UDP profile, the chain always ends with a UDP
   header part, which per definition provides the boundaries for the
   chain. The UDP header is also the last header in the uncompressed
   packet (except for a potential application header). For the IP-only
   profile, there is no single last header that per profile definition
   terminates the chain. Instead, the static chain is terminated if the
   "Next Header / Protocol" field of a static IP header part indicates
   anything but IP (IPinIP or IPv6). Alternatively, the compressor can
   choose to end the static chain at any IP header, and indicate this by
   setting the MSB of the IP version field to 1 (0xC for IPv4 or 0xE for
   IPv6). The decompressor must store this indication in the context
   for correct decompression of subsequent headers. Note that the IP
   version field in decompressed headers must be restored to its
   original value.

3.2. Handling Multiple Levels of IP Headers

   The ROHC IR and IR-DYN packets defined in [RFC-3095] are used to
   communicate static and/or dynamic parts of a context. For each of
   the compression profiles defined in [RFC-3095], there is a single
   last header in the header chain that clearly marks the termination of
   the static chain. The length of the dynamic chain is then inferred
   from the static chain in the IR header itself, or from the static
   chain in the context for the IR-DYN header. The length of both
   static and dynamic chains may thus be of arbitrary length and may, in
   theory, initialize a context with an arbitrary number of IP levels.

However, the general compressed header formats defined in [RFC-3095, section 5.7.] specifies that at most two levels of IP headers (the 'Inner' and the 'Outer' level of IP headers) may be included in a compressed header. Specifically, the format defined for Extension 3 [RFC-3095, section 5.7.5.] can only carry one single 'Outer' IP header. In addition, while list compression may be used to compress other types of headers, it cannot be used to compress additional IP headers, as IP headers may not be part of an extension header chain in compressed headers [RFC-3095, section 5.8.].

For the compression profiles defined in [RFC-3095], the consequence is that at most two levels of IP headers can be compressed. In other words, the presence of additional IP headers at best partially disables header compression, as the compressor will only be allowed to send IR and IR-DYN packets in such cases.

For the compression of IP headers only, the additional IP headers would however not have to cause header compression to be disabled because there is no single packet type that ends the compressed chain. The excess IP headers could simply be left uncompressed by implicitly terminating the static and dynamic chains after at most two levels of IP headers.

The IP-only profile defined in this document goes one step further and supports compression of an arbitrary number of IP levels. This is achieved by adding a dynamic chain to the general format of compressed headers, to include the header part of each IP level in excess of the first two.

As explained above, the static chain within IR packets can be of arbitrary length, and the chain is terminated by the presence of a non-IP header (not IPinIP nor IPv6). Alternatively, the chain may be explicitly terminated with a special code value in the IP version field, as described in section 3.1. The dynamic chain is structured analogously.

For compressed headers, the information related to the initial two IP headers is carried as for the IP/UDP profile, and a chain of dynamic header information is added to the end of the compressed header for each and every additional IP header. Thus, this additional data structure is exactly the same as the one used in IR and IR-DYN packets. The length of the chain is inferred from the chain of static parameters in the context. While a dynamic chain carries dynamically changing parameters using an uncompressed representation, this ensures that flows with arbitrary levels of IP headers will not impair compression efficiency.

3.3. Constant IP-ID

   Most IPv4 stacks assign an IP-ID according to the value of a counter,
   increasing by one for each outgoing packet. ROHC UDP compresses the
   IP-ID field using offset IP-ID encoding based on the UDP SN [RFC-
   3095]. For stacks generating IP-ID values using a pseudo-random
   number generator, the field is not compressed and is sent as-is in
   its entirety as additional octets after the compressed header.

   Cases have also been found where an IPv4 stack uses a constant value
   for the IP Identifier. When the IP-ID field is constant, it cannot
   be compressed using offset IP-ID encoding and the field must be sent
   in its entirety. This overhead can be avoided with the addition of a
   flag within the dynamic part of the chain used to initialize the IPv4
   header, as follow:

   Dynamic part:

```
       +---+---+---+---+---+---+---+---+
       |          Type of Service      |
       +---+---+---+---+---+---+---+---+
       |           Time to Live        |
       +---+---+---+---+---+---+---+---+
       /          Identification       /    2 octets
       +---+---+---+---+---+---+---+---+
       | DF|RND|NBO|SID|       0       |
       +---+---+---+---+---+---+---+---+
       / Generic extension header list /  variable length
       +---+---+---+---+---+---+---+---+
```
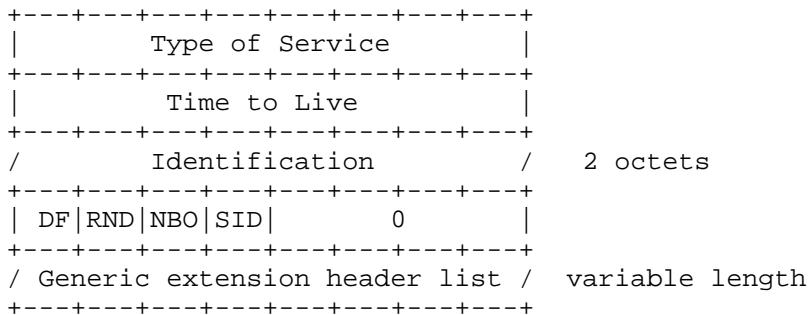
   SID: Static IP Identifier.

      For IR and IR-DYN packets, the logic is the same as for ROHC UDP
      with the addition that field(SID) must be kept in the context.

      For compressed headers other than IR and IR-DYN:

         If value(RND) = 0 and context(SID) = 0, hdr(IP-ID) is
         compressed using Offset IP-ID encoding (see [RFC-3095 section
         4.5.5]) using p = 0 and default-slope(IP-ID offset) = 0.

         If value(RND) = 0 and context(SID) = 1, hdr(IP-ID) is constant
         and compressed away; hdr(IP-ID) is the value of context(IP-ID).

         If value(RND) = 1, IP-ID is the uncompressed hdr(IP-ID). IP-ID
         is then passed as additional octets at the end of the
         compressed header, after any extensions.

   Note: Only IR and IR-DYN packets can update context(SID).

   Note: All other fields are the same as for ROHC UDP [RFC-3095].

3.4. Additional Mode Transition Logic

   The profiles defined in [RFC-3095] operate using different modes of
   compression. A mode transition can be requested once a packet has
   reached the decompressor by sending feedback indicating the desired
   mode. As per the specifications found in [RFC-3095], the compressor
   is compelled to honor such requests.

   For the IP profile defined in this document, the Mode parameter for
   the value mode = 0 (packet types UOR-2, IR and IR-DYN) is redefined
   to allow the compressor to decline a mode transition requested by the
   decompressor:

      Mode: Compression mode. 0 = (C)ancel Mode Transition

   Upon receiving the Mode parameter set to '0', the decompressor MUST
   stay in its current mode of operation and SHOULD refrain from sending
   further mode transition requests for the declined mode for a certain
   amount of time.

   More specifically, with reference to the parameters C_TRANS, C_MODE,
   D_TRANS, and D_MODE defined in [RFC-3095, section 5.6.1.], the
   following modifications apply when the compressor cancels a mode
   transition:

      Parameters for the compressor side:

      - C_MODE:

         This value must not be changed when sending mode information
         within packets if the mode parameter is set to '0' (as a
         response to a mode transition request from the decompressor).

      - C_TRANS:

         C_TRANS is (P)ending when receiving a mode transition request
         from the decompressor. C_TRANS is set to (D)one when the
         compressor receives an ACK for a UOR-2, IR-DYN, or IR packet
         sent with the mode parameter set to the mode in use at the time
         the mode transition request was initiated.

Parameters for the decompressor side:

- D_MODE:

  D_MODE MUST remain unchanged when receiving a UOR-2, an IR-DYN,
  or an IR packet sent with the mode parameter set to '0'.

- D_TRANS:

  D_TRANS is (P)ending when a UOR-2, IR-DYN, or IR packet sent
  with the mode parameter set to '0' is received. It is set to
  (D)one when a packet of type 1 or 0 corresponding to the
  unchanged mode is received.

The resulting mode transition procedure is described below:

```
            Compressor                         Decompressor
            ---------------------------------------------
C_MODE = X          |                               |   D_MODE = X
                    |        Mode Request(Y) +-<-<-<-|   D_TRANS = I
                    |        +-<-<-<-<-<-<-+         |
C_TRANS = P         |-<-<-<-+                        |
C_MODE = X          |                               |
                    |->->->-+ IR/IR-DYN/UOR-2(SN,C)  |
                    |       +->->->->->->->-+        |
                    |->-..                  +->->->-|    D_TRANS = P
                    |->-..                          |   D_MODE = X
                    |          ACK(SN,X)    +-<-<-<-|
                    |       +-<-<-<-<-<-<-+         |
C_TRANS = D         |-<-<-<-+                        |
                    |                               |
                    |->->->-+   X-0, X-1*            |
                    |       +->->->->->->->-+        |
                    |                       +->->->-|    D_TRANS = D
                    |                               |
```

        where X: mode in use before the mode transition was initiated
              Y: mode requested by the decompressor
              C: (C)ancel mode transition

3.5. Initialization

   The static context for ROHC IP compression can be initialized in
   either of two ways:

   1) By using an IR packet as in ROHC UDP, where the profile is 0x0004,
      and the static chain ends with the static part of an IP header,
      where the Next Header/Protocol field has any value but IPinIP (4)
      or IPv6 (41) [PROTOCOL], or where the IP version field indicates
      termination (see section 3.1). At the compressor, SN is
      initialized to a random value when the first IR packet is sent.

   2) By reusing an existing context. This is done with an IR-DYN
      packet, identifying profile 0x0004, where the dynamic chain
      corresponds to the prefix of the existing static chain, ending
      with an IP header where the Next Header/Protocol field has any
      value but IPinIP (4) or IPv6 (41) [PROTOCOL], or where the IP
      version field indicates termination (see section 3.1). At the
      compressor, SN is initialized to a random value when the first
      IR-DYN packet is sent.

   For ROHC IP, the dynamic part of an IR or IR-DYN packet is similar to
   the one for ROHC UDP, with a two-octet field containing the SN
   present at the end of the dynamic chain in IR and IR-DYN packets. It
   should be noted that the static and dynamic chains have an arbitrary
   length, and the SN is added only once, at the end of the dynamic
   chain in IR and IR-DYN packets.

3.6. Packet Types

   Except for one new feedback option (see section 3.7), the only packet
   format that differs from ROHC UDP is the general format for
   compressed packets, which has no UDP checksum in the end. Instead,
   it ends with a list of dynamic header portions, one for each IP
   header above the initial two (if any, as indicated by the presence of
   corresponding header portions in the static chain).

The general format for a compressed header is thus as follows:

```
      0   1   2   3   4   5   6   7
    --- --- --- --- --- --- --- ---
    :           Add-CID octet       :                             |
    +---+---+---+---+---+---+---+---+                              |
    |   first octet of base header  |                             |
    +---+---+---+---+---+---+---+---+                              |
    :                               :                             |
    /   0, 1, or 2 octets of CID    /                             |
    :                               :                             |
    +---+---+---+---+---+---+---+---+                              |
    /   remainder of base header    /                             |
    +---+---+---+---+---+---+---+---+                              |
    :                               :                             |
    /           Extension           /                             |
    :                               :                             |
    --- --- --- --- --- --- --- ---                               |
    :                               :                             |
    +   IP-ID of outer IPv4 header  +                             |
    :                               :    (see section 5.7 of [RFC-3095])
    --- --- --- --- --- --- --- ---                               |
    /   AH data for outer list      /                             |
    --- --- --- --- --- --- --- ---                               |
    :                               :                             |
    +           GRE checksum        +                             |
    :                               :                             |
    --- --- --- --- --- --- --- ---                               |
    :                               :                             |
    +   IP-ID of inner IPv4 header  +                             |
    :                               :                             |
    --- --- --- --- --- --- --- ---                               |
    /   AH data for inner list      /                             |
    --- --- --- --- --- --- --- ---                               |
    :                               :                             |
    +           GRE checksum        +                             |
    :                               :                             |
    --- --- --- --- --- --- --- ---
    :              List of          :
    /         Dynamic chains        /    variable, given by static chain
    :    for additional IP headers  :            (includes no SN)
    --- --- --- --- --- --- --- ---
```
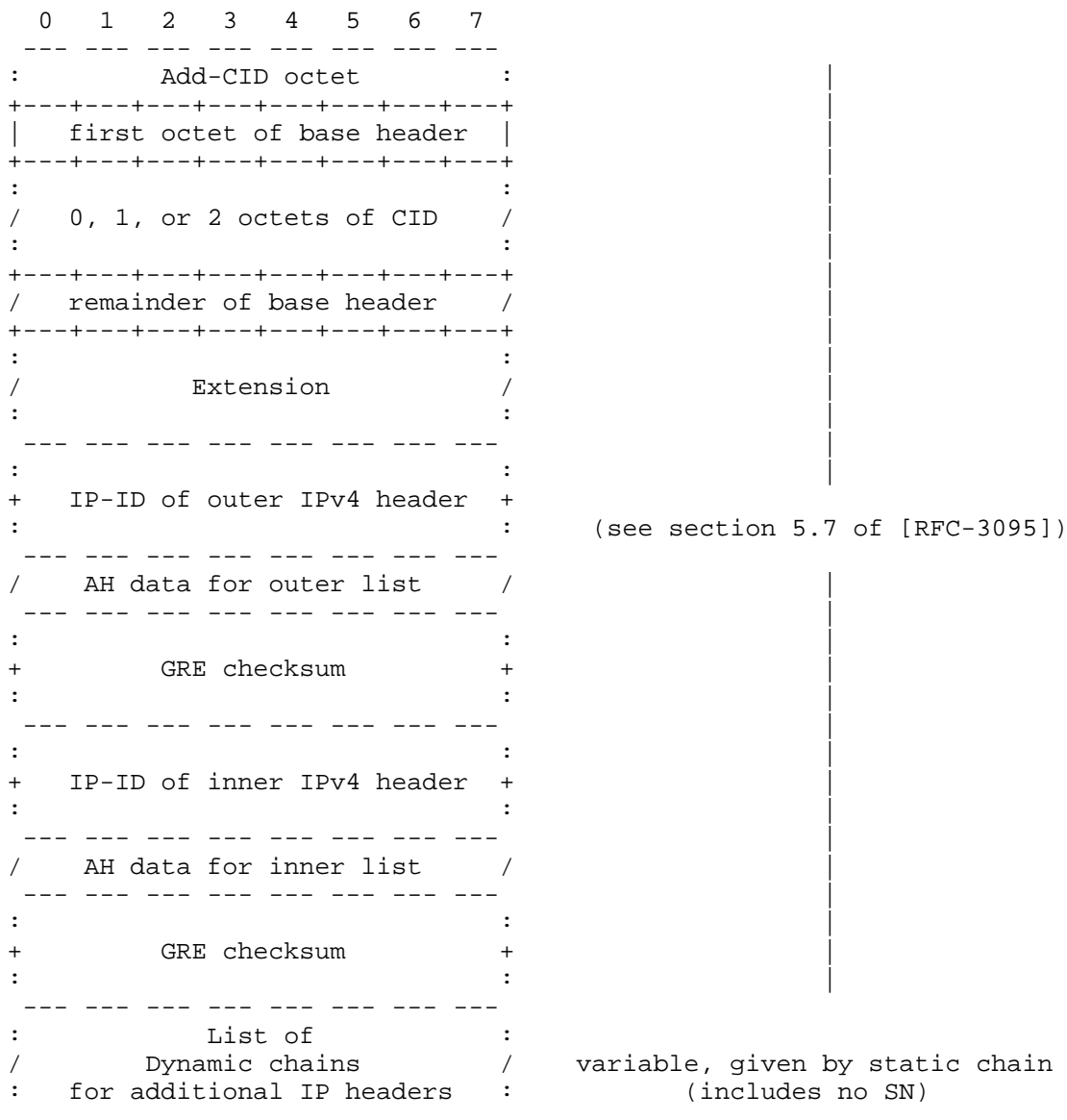
Note that the list of dynamic chains for the additional IP headers in
compressed packets do not have a sequence number at the end of the
chain, as SN is present within compressed base headers.

3.7. The CONTEXT_MEMORY Feedback Option

   The CONTEXT_MEMORY option informs the compressor that the
   decompressor does not have sufficient memory resources to handle the
   context of the packet stream, as the stream is currently compressed.

```
     0   1   2   3   4   5   6   7
   +---+---+---+---+---+---+---+---+
   |  Opt Type = 9 |  Opt Len = 0  |
   +---+---+---+---+---+---+---+---+
```

   When receiving a CONTEXT_MEMORY option, the compressor SHOULD take
   actions to compress the packet stream in a way that requires less
   decompressor memory resources, or stop compressing the packet stream.

4. Security Considerations

   The security considerations of [RFC-3095] apply equally to this
   document, without exceptions or additions.

5. IANA Considerations

   ROHC profile identifier 0x0004 has been reserved by the IANA for the
   profile defined in this document.

6. Acknowledgements

   The authors would like to thank Carsten Bormann, Fredrik Lindstrom,
   Tommy Lundemo, and especially the committed document reviewers
   Kristofer Sandlund and Mark West, for valuable input and review.

7. Normative References

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                H., Hannu, H., Jonsson, L-E., Hakenberg, R., Koren, T.,
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   [PROTOCOL]   "Assigned Internet Protocol Numbers", IANA registry at:
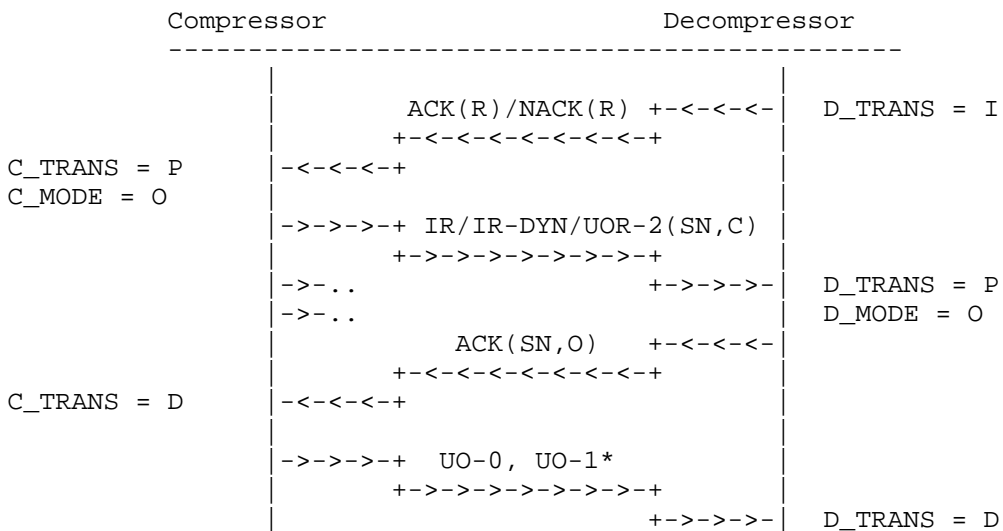   http://www.iana.org/assignments/protocol-numbers

Appendix A. Detailed Procedures for Canceling Mode Transitions

   The profiles defined in [RFC-3095] operate using different modes of
   compression: Unidirectional (U-Mode), Bi-directional Optimistic
   (O-Mode), and Bi-directional Reliable (R-Mode). Compression always
   starts in the U-Mode, and mode transitions can only be initiated by
   the decompressor [RFC-3095, section 5.6.]. A mode transition can be
   requested once a packet has reached the decompressor by sending
   feedback indicating the desired mode.

   With reference to the parameters C_TRANS, C_MODE, D_TRANS, and D_MODE
   defined in [RFC-3095, section 5.6.1.], the following sub-sections
   describe the resulting procedures when a compressor declines a mode
   transition request from the decompressor as described in section 3.4.

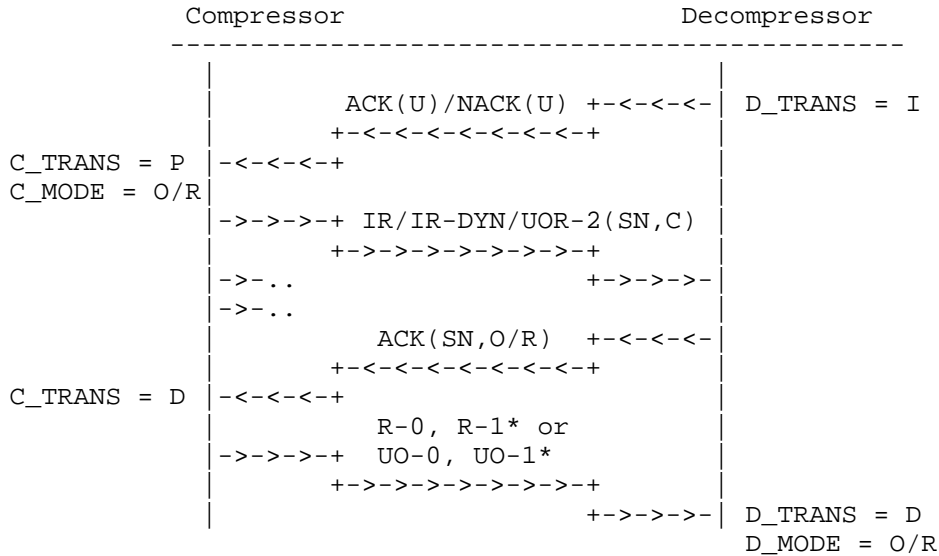A.1. Transition from Optimistic to Reliable Mode

   When the decompressor initiates a mode transition from Optimistic to
   Reliable mode, the cancellation of the transition procedure is as
   follows:

```
              Compressor                    Decompressor
              ---------------------------------------------
                    |                           |
                    |         ACK(R)/NACK(R) +-<-<-<-|  D_TRANS = I
                    |         +-<-<-<-<-<-<-+       |
  C_TRANS = P       |-<-<-<-+                       |
  C_MODE = O        |                               |
                    |->->->-+ IR/IR-DYN/UOR-2(SN,C) |
                    |       +->->->->->->->-+       |
                    |->-..                 +->->->-|  D_TRANS = P
                    |->-..                         |  D_MODE = O
                    |          ACK(SN,O)   +-<-<-<-|
                    |       +-<-<-<-<-<-<-+         |
  C_TRANS = D       |-<-<-<-+                       |
                    |                               |
                    |->->->-+  UO-0, UO-1*          |
                    |       +->->->->->->->-+       |
                    |                       +->->->-|  D_TRANS = D
```

   The compressor must not send packet types 1 or 0 when C_TRANS is P,
   i.e., not until it has received an ACK for a UOR-2, IR-DYN, or IR
   packet sent with the mode transition parameter set to C. When the
   decompressor receives a UOR-2, IR-DYN, or IR packet sent with the
   mode transition parameter set to C, it must keep the value D_MODE as
   O and set D_TRANS to P. When the decompressor receives packet types
   0 or 1, after having ACKed a UOR-2, IR-DYN, or IR packet, it sets
   D_TRANS to D.

A.2. Transition from Unidirectional to Reliable Mode

   The cancellation of a transition from Unidirectional to Reliable mode
   follows the same procedure as defined in section 4.2 above.

A.3. Transition from Reliable to Optimistic Mode

   When the decompressor initiates a mode transition from Reliable to
   Optimistic mode, the cancellation of the transition procedure is
   described as follows:

```
              Compressor                      Decompressor
           ---------------------------------------------
                  |                           |
                  |         ACK(O)/NACK(O) +-<-<-<-|  D_TRANS = I
                  |         +-<-<-<-<-<-<-<-+      |
 C_TRANS = P      |-<-<-<-+                        |
 C_MODE = R       |                               |
                  |->->->-+ IR/IR-DYN/UOR-2(SN,C) |
                  |       +->->->->->->->-+        |
                  |->-..                  +->->->-|  D_MODE = R
                  |->-..                           |
                  |         ACK(SN,R)    +-<-<-<-|
                  |         +-<-<-<-<-<-<-<-+      |
 C_TRANS = D      |-<-<-<-+                        |
                  |                               |
                  |->->->-+   R-0, R-1*           |
                  |       +->->->->->->->-+        |
                  |                       +->->->-|  D_TRANS = D
                  |                           |
```

   The compressor must not send packet types 1 or 0 when C_TRANS is P,
   i.e., not until it has received an ACK for a UOR-2, IR-DYN, or IR
   packet sent with the mode transition parameter set to C. When the
   decompressor receives a UOR-2, IR-DYN, or IR packet sent with the
   mode transition parameter set to C, it must keep the value D_MODE as
   R. When the decompressor receives packet types 0 or 1, after having
   ACKed a UOR-2, IR-DYN, or IR packet, it sets D_TRANS to D.

A.4. Transition Back to Unidirectional Mode

   When the decompressor initiates a mode transition from Reliable or
   Optimistic mode back to Unidirectional mode, the cancellation of the
   transition procedure is as follows:

```
                Compressor                       Decompressor
                -----------------------------------------------
                   |                            |
                   |       ACK(U)/NACK(U) +-<-<-<-| D_TRANS = I
                   |       +-<-<-<-<-<-<-<-+      |
  C_TRANS = P  |-<-<-<-+                          |
  C_MODE = O/R |                                  |
                   |->->->-+ IR/IR-DYN/UOR-2(SN,C) |
                   |       +->->->->->->->-+      |
                   |->-..                +->->->-|
                   |->-..                         |
                   |           ACK(SN,O/R)   +-<-<-<-|
                   |       +-<-<-<-<-<-<-<-+      |
  C_TRANS = D  |-<-<-<-+                          |
                   |           R-0, R-1* or       |
                   |->->->-+  UO-0, UO-1*          |
                   |       +->->->->->->->-+      |
                   |                     +->->->-| D_TRANS = D
                                                    D_MODE = O/R
```

   When the decompressor receives a UOR-2, IR-DYN, or IR packet sent
   with the mode transition parameter set to C, it must keep the value
   D_MODE to the bi-directional mode already in use (either O- or R-
   mode). After ACKing the first UOR-2(C), IR-DYN(C), or IR(C), the
   decompressor MUST continue to send feedback with the Mode parameter
   set to the bi-directional mode in use (either O- or R-mode) until it
   receives packet types 0 or 1. When the decompressor receives packet
   types 0 or 1, after having ACKed a UOR-2, IR-DYN, or IR packet, it
   sets D_TRANS to D.

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