        Raptor Forward Error Correction (FEC) Schemes for FECFRAME

Abstract

   This document describes Fully-Specified Forward Error Correction
   (FEC) Schemes for the Raptor and RaptorQ codes and their application
   to reliable delivery of media streams in the context of the FEC
   Framework. The Raptor and RaptorQ codes are systematic codes, where
   a number of repair symbols are generated from a set of source symbols
   and sent in one or more repair flows in addition to the source
   symbols that are sent to the receiver(s) within a source flow. The
   Raptor and RaptorQ codes offer close to optimal protection against
   arbitrary packet losses at a low computational complexity. Six FEC
   Schemes are defined: two for the protection of arbitrary packet
   flows, two that are optimized for small source blocks, and two for
   the protection of a single flow that already contains a sequence
   number. Repair data may be sent over arbitrary datagram transport
   (e.g., UDP) or using RTP.

Status of This Memo

   This is an Internet Standards Track document.

   This document is a product of the Internet Engineering Task Force
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   received public review and has been approved for publication by
   the Internet Engineering Steering Group (IESG). Further
   information on Internet Standards is available in Section 2 of
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   http://www.rfc-editor.org/info/rfc6681.

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1. Introduction

   The "Forward Error Correction (FEC) Framework" [RFC6363] describes a
   general framework for the use of Forward Error Correction in
   association with arbitrary packet flows. Modeled after the FEC
   Building Block developed by the IETF Reliable Multicast Transport
   working group [RFC5052], the FEC Framework defines the concept of FEC
   Schemes that provide specific Forward Error Correction Schemes. This
   document describes six FEC Schemes that make use of the Raptor and
   RaptorQ FEC codes as defined in [RFC5053] and [RFC6330].

   The FEC protection mechanism is independent of the type of source
   data that can be an arbitrary sequence of packets, for example audio
   or video data. In general, the operation of the protection mechanism
   is as follows:

   o The sender determines a set of source packets (a source block) to
      be protected together based on the FEC Framework Configuration
      Information.

   o The sender arranges the source packets into a set of source
      symbols, each of which is the same size.

   o The sender applies the Raptor/RaptorQ protection operation on the
      source symbols to generate the required number of repair symbols.

   o The sender packetizes the repair symbols and sends the repair
      packet(s) and the source packets to the receiver(s). Per the FEC
      Framework requirements, the sender MUST transmit the source and
      repair packets in different source and repair flows, or in the
      case Real-time Transport Protocol (RTP) transport is used for
      repair packets, in different RTP streams.

   o At the receiver side, if all of the source packets are
      successfully received, there is no need for FEC recovery and the
      repair packets are discarded. However, if there are missing
      source packets, the repair packets can be used to recover the
      missing information.

   The operation of the FEC mechanism requires that the receiver is able
   to identify the relationships between received source packets and
   repair packets, in particular, which source packets are missing. In
   many cases, data already exists in the source packets that can be
   used to refer to source packets and to identify which packets are
   missing. In this case, we assume it is possible to derive a
   "sequence number" directly or indirectly from the source packets, and
   this sequence number can be used within the FEC Scheme. This case is
   referred to as a "single sequenced flow". In this case, the FEC

Source Payload ID defined in [RFC6363] is empty and the source
packets are not modified by the application of FEC, with obvious
backwards compatibility advantages.

Otherwise, it is necessary to add data to the source packets for FEC
purposes in the form of a non-empty FEC Source Payload ID. This is
referred to as the "arbitrary packet flow" case. This document
defines six FEC Schemes, two for the case of a single sequenced flow
and four for the case of arbitrary packet flows.

2. Document Outline

   This document is organized as follows:

   o Section 5 defines general procedures applicable to the use of the
      Raptor and RaptorQ codes in the context of the FEC Framework.

   o Section 6 defines a FEC Scheme for the case of arbitrary source
      flows and follows the format defined for FEC Schemes in [RFC6363].
      When used with Raptor codes, this scheme is equivalent to that
      defined in 3GPP TS 26.346, "Multimedia Broadcast/Multicast Service
      (MBMS); Protocols and codecs" [MBMSTS].

   o Section 7 defines a FEC Scheme similar to that defined in Section
      6 but with optimizations for the case where only limited source
      block sizes are required. When used with Raptor codes, this
      scheme is equivalent to that defined in ETSI TS 102.034, "Digital
      Video Broadcasting (DVB); Transport of MPEG-2 Based DVB Services
      over IP Based Networks" [DVBTS] for arbitrary packet flows.

   o Section 8 defines a FEC Scheme for the case of a single flow,
      which is already provided with a source packet sequence number.
      When used with Raptor codes, this scheme is equivalent to that
      defined in [DVBTS] for the case of a single sequenced flow.

3. Requirements Notation

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

4. Definitions and Abbreviations

   The definitions, notations, and abbreviations commonly used in this
   document are summarized in this section.

4.1. Definitions

   The FEC-specific terminology used in this document is defined in
   [RFC6363]. In this document, as in [RFC6363], the first letter of
   each FEC-specific term is capitalized along with the new terms
   defined here:

   Symbol: A unit of data. Its size, in octets, is referred to as the
      symbol size.

   FEC Framework Configuration Information: Information that controls
      the operation of the FEC Framework. Each FEC Framework instance
      has its own configuration information.

4.2. Abbreviations

   This document uses abbreviations that apply to the FEC Framework in
   general as defined in [RFC6363]. In addition, this document uses the
   following abbreviations

   FSSI: FEC-Scheme-Specific Information.

   ADU: Application Data Unit

   ADUI: Application Data Unit Information.

   SPI: Source Packet Information.

   MSBL: Maximum Source Block Length

5. General Procedures for Raptor FEC Schemes

   This section specifies general procedures that apply to all Raptor
   and RaptorQ FEC Schemes, specifically the construction of source
   symbols from a set of source transport payloads.

   For any field defined in this document, the octets are ordered in
   network byte order.

   As described in [RFC6363], for each Application Data Unit (ADU) in a
   source block, the FEC Scheme is provided with:

   o A description of the source data flow with which the ADU is
      associated and an integer identifier associated with that flow.

   o The ADU itself.

   o The length of the ADU.

For each ADU, we define the Application Data Unit Information (ADUI)
as follows:

Let

o n be the number of ADUs in the source block.

o T be the source symbol size in octets. Note: this information is
   provided by the FEC Scheme as defined below.

o i the index to the (i+1)-th ADU to be added to the source block,
   0 <= i < n.

o f[i] denote the integer identifier associated with the source data
   flow from which the i-th ADU was taken.

o F[i] denote a single octet representing the value of f[i].

o l[i] be a length indication associated with the i-th ADU -- the
   nature of the length indication is defined by the FEC Scheme.

o L[i] denote two octets representing the value of l[i] in network
   byte order (high order octet first) of the i-th ADU.

o R[i] denote the number of octets in the (i+1)-th ADU.

o s[i] be the smallest integer such that s[i]*T >= (l[i]+3). Note:
   s[i] is the length of SPI[i] in units of symbols of size T octets.

o P[i] denote s[i]*T-(l[i]+3) zero octets. Note: P[i] are padding
   octets to align the start of each UDP packet with the start of a
   symbol.

o ADUI[i] be the concatenation of F[i], L[i], R[i], and P[i].

Then, a source data block is constructed by concatenating ADUI[i] for
i = 0, 1, 2, ... n-1. The source data block size, S, is then given
by sum {s[i]*T, i=0, ..., n-1}. Symbols are allocated integer
encoding symbol IDs (ESI) consecutively starting from zero within the
source block. Each ADU is associated with the ESI of the first
symbol containing SPI for that packet. Thus, the encoding symbol ID
value associated with the j-th source packet, ESI[j], is given by
ESI[j] = 0, for j=0 and ESI[j] = sum{s[i], i=0,...,(j-1)}, for
0 < j < n.

Source blocks are identified by integer Source Block Numbers. This
specification does not specify how Source Block Numbers are allocated
to the source blocks. The Source FEC Packet Identification

Information consists of the identity of the source block and the
encoding symbol ID associated with the packet.

6. Raptor FEC Schemes for Arbitrary Packet Flows

6.1. Introduction

This section specifies a FEC Scheme for the application of the Raptor
and RaptorQ codes to arbitrary packet flows. This scheme is
recommended in scenarios where maximal generality is required.

When used with the Raptor codes specified in [RFC5053], this scheme
is equivalent to that specified in [MBMSTS].

6.2. Formats and Codes

6.2.1. FEC Framework Configuration Information

6.2.1.1. FEC Scheme ID

The value of the FEC Scheme ID for the Fully-Specified FEC scheme
defined in this section is 1 when [RFC5053] is used and 2 when
[RFC6330] is used, as assigned by IANA.

6.2.1.2. Scheme-Specific Elements

The scheme-specific elements of the FEC Framework Configuration
information for this scheme are as follows:

MSBL: The maximum source block length. A non-negative integer less
   than 8192 for FEC Scheme 1 and less than 56403 for FEC Scheme 2,
   in units of symbols. The field type is unsigned integer.

T: The encoding symbol size. A non-negative integer less than 65536,
   in units of octets. The field type is unsigned integer.

P: The payload ID format indicator. The P bit shall be set to zero
   to indicate payload ID format A or to one to indicate payload ID
   format B. The field type is unsigned integer.

   An encoding format for the encoding symbol size, MSBL and payload ID
   format indicator is defined below.
                                  1   2   3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
     +-+
     | Symbol Size (T) | MSBL |
     +-+
     |P| Reserved |
     +-+-+-+-+-+-+-+-+
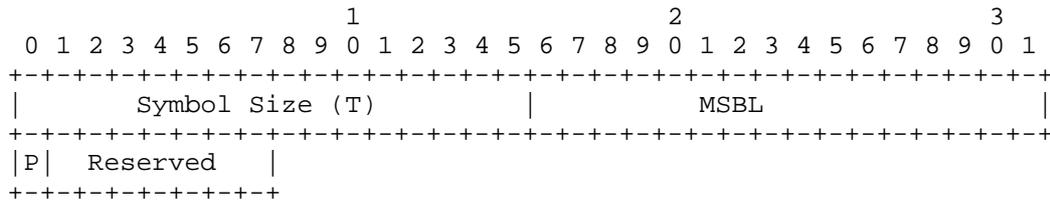
              Figure 1: FEC-Scheme-Specific Information

   The P bit shall be set to zero to indicate Payload ID format A or to
   one to indicate Payload ID format B. The last octet of FEC-Scheme-
   Specific Information SHOULD be omitted, indicating that Payload ID
   format A is in use. The payload ID format indicator defines which of
   the Source FEC Payload ID and Repair FEC Payload ID formats defined
   below shall be used. Payload ID format B SHALL NOT be used for FEC
   Scheme 1. The two formats enable different use cases. Format A is
   appropriate in case the stream has many typically smaller source
   blocks, and format B is applicable if the stream has fewer large
   source blocks, each with many encoding symbols.

6.2.2. Source FEC Payload ID

   This scheme makes use of an Explicit Source FEC Payload ID, which is
   appended to the end of the source packets. Two formats are defined
   for the Source FEC Payload ID, format A and format B. The format
   that is used is signaled as part of the FEC Framework Configuration
   Information.

   The Source FEC Payload ID for format A is provided in Figure 2.

                                  1   2   3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
     +-+
     | Source Block Number (SBN) | Encoding Symbol ID (ESI) |
     +-+

                 Figure 2: Source FEC Payload ID - Format A

   Source Block Number (SBN), (16 bits): Identifier for the source block
      that the source data within the packet relates. The field type is
      unsigned integer.

   Encoding Symbol ID (ESI), (16 bits): The starting symbol index of the
      source packet in the source block. The field type is unsigned
      integer.

The Source FEC Payload ID for format B is provided in Figure 3.

```
                    1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     SBN       |            Encoding Symbol ID (ESI)           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

             Figure 3: Source FEC Payload ID - Format B

Source Block Number (SBN), (8 bits): Identifier for the source block
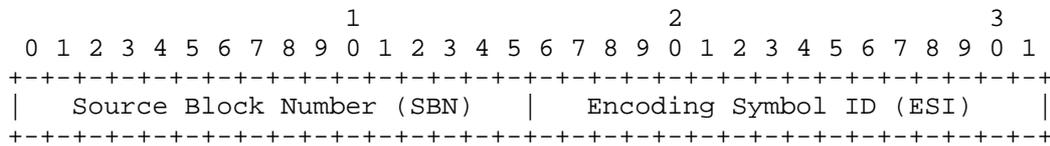   that the source data within the packet relates. The field type is
   unsigned integer.

Encoding Symbol ID (ESI), (24 bits): The starting symbol index of the
   source packet in the source block. The field type is unsigned
   integer.

6.2.3. Repair FEC Payload ID

Two formats for the Repair FEC Payload ID, format A and format B, are
defined below.

The Repair FEC Payload ID for format A is provided in Figure 4.

```
                    1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Source Block Number (SBN)  |    Encoding Symbol ID (ESI)   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Source Block Length (SBL)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

             Figure 4: Repair FEC Payload ID - Format A

Source Block Number (SBN), (16 bits): Identifier for the source block
   that the repair symbols within the packet relate. For format A,
   it is of size 16 bits. The field type is unsigned integer.

Encoding Symbol ID (ESI), (16 bits): Identifier for the encoding
   symbols within the packet. The field type is unsigned integer.

Source Block Length (SBL), (16 bits): The number of source symbols in
   the source block. The field type is unsigned integer.

The Repair FEC Payload ID for format B is provided in Figure 5.

```
                        1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |     SBN       |              Encoding Symbol ID (ESI)         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    Source Block Length (SBL)   |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
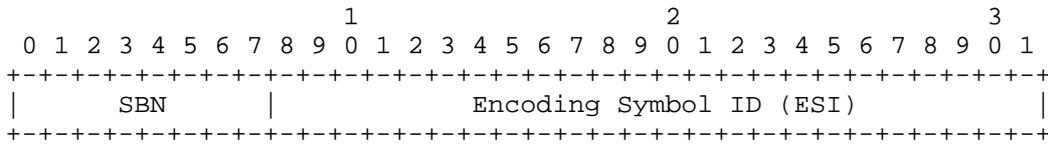
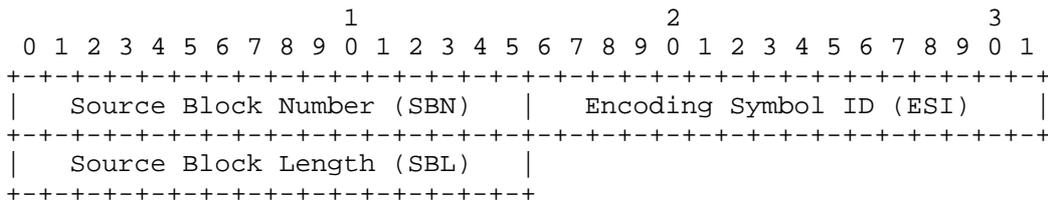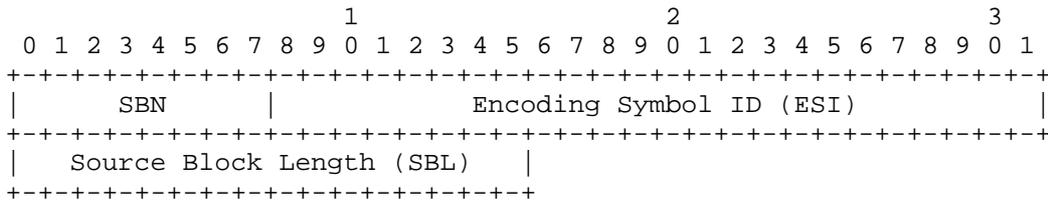   Figure 5: Repair FEC Payload ID - Format B

   Source Block Number (SBN), (8 bits): Identifier for the source block
      that the repair symbols within the packet relate. For format B,
      it is of size 8 bits. The field type is unsigned integer.

   Encoding Symbol ID (ESI), (24 bits): Identifier for the encoding
      symbols within the packet. The field type is unsigned integer.

   Source Block Length (SBL), (16 bits): The number of source symbols in
      the source block. The field type is unsigned integer.

   The interpretation of the Source Block Number, encoding symbol ID,
   and Source Block Length is defined by the FEC Code Specification in
   [RFC5053] for FEC Scheme 1 and [RFC6330] for FEC Scheme 2.

6.3. Procedures

6.3.1. Source Symbol Construction

   FEC Scheme 1 and FEC Scheme 2 use the procedures defined in Section 5
   to construct a set of source symbols to which the FEC Code can be
   applied. The sender MUST allocate Source Block Numbers to source
   blocks sequentially, wrapping around to zero after Source Block
   Number 65535 (format A) or 255 (format B).

   During the construction of the source block:

   o the length indication, l[i], included in the Source Packet
      Information for each packet shall be the transport payload length,
      i.e., the length of the ADU.

   o the value of s[i] in the construction of the Source Packet
      Information for each packet shall be the smallest integer such
      that s[i]*T >= (l[i]+3).

6.3.2. Repair Packet Construction

   For FEC Scheme 1 [RFC5053], the ESI value placed into a repair packet
   is calculated as specified in Section 5.3.2 of [RFC5053].

   For FEC Scheme 2 [RFC6330], the ESI value placed into a repair packet
   is calculated as specified in Section 4.4.2 of [RFC6330].

   In both cases, K is identical to SBL.

6.4. FEC Code Specification

   The FEC encoder defined in [RFC5053] SHALL be used for FEC Scheme 1
   and the FEC encoder defined in [RFC6330] SHALL be used for FEC Scheme
   2. For both FEC Scheme 1 and FEC Scheme 2, the source symbols passed
   to the FEC encoder SHALL consist of the source symbols constructed
   according to Section 6.3.1. Thus, the value of the parameter K used
   by the FEC encoder (equal to the Source Block Length) may vary
   amongst the blocks of the stream but SHALL NOT exceed the Maximum
   Source Block Length signaled in the FEC-Scheme-Specific Information.
   The symbol size, T, to be used for source block construction and the
   repair symbol construction is equal to the encoding symbol size
   signaled in the FEC-Scheme-Specific Information.

7. Optimized Raptor FEC Scheme for Arbitrary Packet Flows

7.1. Introduction

   This section specifies a slightly modified version of the FEC Scheme
   specified in Section 6 that is applicable to scenarios in which only
   relatively small block sizes will be used. These modifications admit
   substantial optimizations to both sender and receiver
   implementations.

   In outline, the modifications are:

   o All source blocks within a stream are encoded using the same
      source block size. Code shortening is used to encode blocks of
      different sizes. This is achieved by padding every block to the
      required size using zero symbols before encoding. The zero
      symbols are then discarded after decoding. The source block size
      to be used for a stream is signaled in the Maximum Source Block
      Length (MSBL) field of the scheme-specific information. The
      extended source block is constructed by adding zero or more
      padding symbols such that the total number of symbols, MSBL, is
      one of the values listed in Section 7.4. Each padding symbol
      consists of T octets where the value of each octet is zero. MSBL

      MUST be selected as the smallest value of the possible values in
      Section 7.4 that is greater than or equal to K.

   o The possible choices of the MSBL for a stream is restricted to a
      small specified set. This allows explicit operation sequences for
      encoding and decoding the restricted set of source block lengths
      to be pre-calculated and embedded in software or hardware.

   When used with the Raptor codes specified in [RFC5053], this scheme
   is equivalent to that specified in [DVBTS] for arbitrary packet
   flows.

7.2. Formats and Codes

7.2.1. FEC Framework Configuration Information

7.2.1.1. FEC Scheme ID

   The value of the FEC Scheme ID for the Fully-Specified FEC scheme
   defined in this section is 3 when [RFC5053] is used and 4 when
   [RFC6330] is used, as assigned by IANA.

7.2.1.2. FEC-Scheme-Specific Information

   The elements for FEC Scheme 3 are the same as specified for FEC
   Scheme 1, and the elements specified for FEC Scheme 4 are the same as
   specified for FEC 2, as specified in Section 6.2.1.2, except that the
   MSBL value is as defined in Section 7.4.

7.2.2. Source FEC Payload ID

   The elements for FEC Scheme 3 are the same as specified for FEC
   Scheme 1, and the elements specified for FEC Scheme 4 are the same as
   specified for FEC 2, as specified in Section 6.2.2.

7.2.3. Repair FEC Payload ID

   The elements for FEC Scheme 3 are the same as specified for FEC
   Scheme 1, and the elements specified for FEC Scheme 4 are the same as
   specified for FEC 2, as specified in Section 6.2.3.

7.3. Procedures

7.3.1. Source Symbol Construction

   See Section 6.3.1.

7.3.2. Repair Packet Construction

   The number of repair symbols contained within a repair packet is
   computed from the packet length. The ESI value placed into a repair
   packet is calculated as X + MSBL - SBL, where X would be the ESI
   value of the repair packet if the ESI were calculated as specified in
   Section 5.3.2 of [RFC5053] for FEC Scheme 3 and as specified in
   Section 4.4.2 of [RFC6330] for FEC Scheme 4, where K=SBL. The value
   of SBL SHALL be, at most, the value of MSBL.

7.4. FEC Code Specification

   The FEC encoder defined in [RFC5053] SHALL be used for FEC Scheme 3
   and the FEC encoder defined in [RFC6330] SHALL be used for FEC Scheme
   4. The source symbols passed to the FEC encoder SHALL consist of the
   source symbols constructed according to Section 6.3.1 extended with
   zero or more padding symbols. The extension SHALL be such that the
   total number of symbols in the source block is equal to the MSBL
   signaled in the FEC-Scheme-Specific Information. Thus, the value of
   the parameter K used by the FEC encoder is equal to the MSBL for all
   blocks of the stream. Padding symbols shall consist entirely of
   octets set to the value zero. The symbol size, T, to be used for the
   source block construction and the repair symbol construction, is
   equal to the encoding symbol size signaled in the FEC-Scheme-Specific
   Information.

   For FEC Scheme 3, the parameter T SHALL be set such that the number
   of source symbols in any source block is, at most, 8192. The MSBL
   parameter, and hence the number of symbols used in the FEC Encoding
   and Decoding operations, SHALL be set to one of the following values:

      101, 120, 148, 164, 212, 237, 297, 371, 450, 560, 680, 842, 1031,
      1139, 1281

   For FEC Scheme 4, the parameter T SHALL be set such that the number
   of source symbols in any source block is less than 56403. The MSBL
   parameter SHALL be set to one of the supported values for K' defined
   in Section 5.6 of [RFC6330].

8. Raptor FEC Scheme for a Single Sequenced Flow

8.1. Formats and Codes

8.1.1. FEC Framework Configuration Information

8.1.1.1. FEC Scheme ID

   The value of the FEC Scheme ID for the Fully-Specified FEC scheme
   defined in this section is 5 when [RFC5053] is used and 6 when
   [RFC6330] is used, as assigned by IANA.

8.1.1.2. Scheme-Specific Elements

   The elements for FEC Scheme 5 are the same as specified for FEC
   Scheme 1, and the elements specified for FEC Scheme 6 are the same as
   specified for FEC 2, as specified in Section 6.2.1.2.

8.1.2. Source FEC Payload ID

   The Source FEC Payload ID field is not used by this FEC Scheme.
   Source packets are not modified by this FEC Scheme.

8.1.3. Repair FEC Payload ID

   Two formats for the Repair FEC Payload ID are defined, format A and
   format B.

```
                        1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |      Initial Sequence Number      |      Source Block Length      |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |        Encoding Symbol ID         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                 Figure 6: Repair FEC Payload ID - Format A

   Initial Sequence Number (Flow i ISN), (16 bits): This field specifies
      the lowest 16 bits of the sequence number of the first packet to
      be included in this sub-block. If the sequence numbers are
      shorter than 16 bits, then the received Sequence Number SHALL be
      logically padded with zero bits to become 16 bits in length,
      respectively. The field type is unsigned integer.

   Source Block Length (SBL), (16 bits): This field specifies the length
      of the source block in symbols. The field type is unsigned
      integer.

   Encoding Symbol ID (ESI), (16 bits): This field indicates which
      repair symbols are contained within this repair packet. The ESI
      provided is the ESI of the first repair symbol in the packet. The
      field type is unsigned integer.

```
                         1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |    Initial Sequence Number    |      Source Block Length      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    Encoding Symbol ID         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
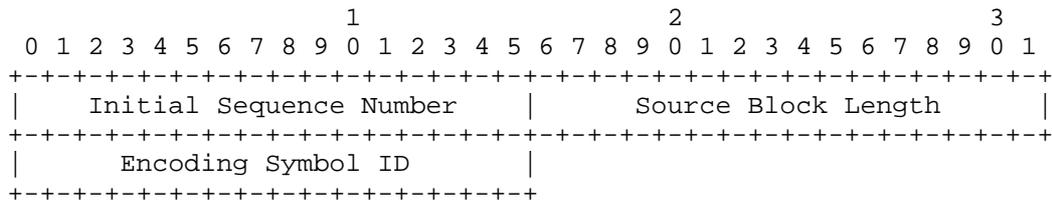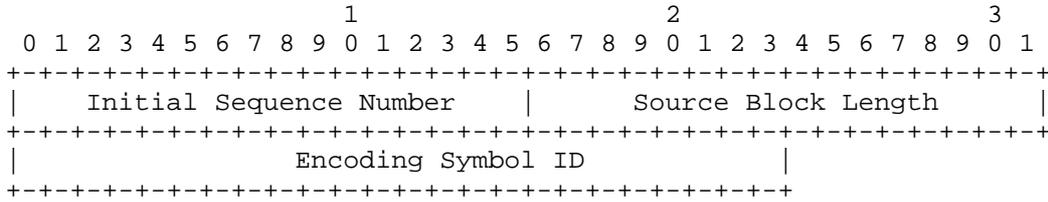
              Figure 7: Repair FEC Payload ID - Format B

   Initial Sequence Number (Flow i ISN), (16 bits): This field specifies
      the lowest 16 bits of the sequence number in the first packet to
      be included in this sub-block. If the sequence numbers are
      shorter than 16 bits, then the received Sequence Number SHALL be
      logically padded with zero bits to become 16 bits in length,
      respectively. The field type is unsigned integer.

   Source Block Length (SBL), (16 bits): This field specifies the length
      of the source block in symbols. The field type is unsigned
      integer.

   Encoding Symbol ID (ESI); (24 bits): This field indicates which
      repair symbols are contained within this repair packet. The ESI
      provided is the ESI of the first repair symbol in the packet. The
      field type is unsigned integer.

8.2. Procedures

8.2.1. Source Symbol Construction

   FEC Scheme 5 and FEC Scheme 6 use the procedures defined in Section 5
   to construct a set of source symbols to which the FEC code can be
   applied.

   During the construction of the source block:

   o the length indication, l[i], included in the Source Packet
      Information for each packet shall be dependent on the protocol
      carried within the transport payload. Rules for RTP are specified
      below.

   o the value of s[i] in the construction of the Source Packet
      Information for each packet shall be the smallest integer such
      that s[i]*T >= (l[i]+3)

8.2.2. Derivation of Source FEC Packet Identification Information

   The Source FEC Packet Identification Information for a source packet
   is derived from the sequence number of the packet and information
   received in any repair FEC packet belonging to this source block.
   Source blocks are identified by the sequence number of the first
   source packet in the block. This information is signaled in all
   repair FEC packets associated with the source block in the Initial
   Sequence Number field.

   The length of the Source Packet Information (in octets) for source
   packets within a source block is equal to the length of the payload
   containing encoding symbols of the repair packets (i.e., not
   including the Repair FEC Payload ID) for that block, which MUST be
   the same for all repair packets. The Application Data Unit
   Information Length (ADUIL) in symbols is equal to this length divided
   by the encoding symbol size (which is signaled in the FEC Framework
   Configuration Information). The set of source packets included in
   the source block is determined by the Initial Sequence Number (ISN)
   and Source Block Length (SBL) as follows:

   Let,

   o I be the Initial Sequence Number of the source block

   o LP be the Source Packet Information Length in symbols

   o LB be the Source Block Length in symbols

   Then, source packets with sequence numbers from I to I +(LB/LP)-1
   inclusive are included in the source block. The Source Block Length,
   LB, MUST be chosen such that it is at least as large as the largest
   Source Packet Information Length LP.

   Note that if no FEC repair packets are received, then no FEC decoding
   is possible, and it is unnecessary for the receiver to identify the
   Source FEC Packet Identification Information for the source packets.

   The encoding symbol ID for a packet is derived from the following
   information:

   o The sequence number, Ns, of the packet

   o The Source Packet Information Length for the source block, LP

   o The Initial Sequence Number of the source block, I

   Then, the encoding symbol ID for the packet with sequence number Ns
   is determined by the following formula:

      ESI = (Ns – I) * LP

   Note that all repair packets associated to a given source block MUST
   contain the same Source Block Length and Initial Sequence Number.

   Note also that the source packet flow processed by the FEC encoder
   MUST have consecutive sequence numbers. In case the incoming source
   packet flow has a gap in the sequence numbers, then implementors
   SHOULD insert an ADU in the source block that complies to the format
   of the source packet flow, but is ignored at the application with
   high probability. For additional guidelines, refer to [RFC6363],
   Section 10.2, paragraph 5.

8.2.3. Repair Packet Construction

   See Section 7.3.2

8.2.4. Procedures for RTP Source Flows

   In the specific case of RTP source packet flows, the RTP Sequence
   Number field SHALL be used as the sequence number in the procedures
   described above. The length indication included in the Application
   Data Unit Information SHALL be the RTP payload length plus the length
   of the contributing sources (CSRCs), if any, the RTP Header
   Extension, if present, and the RTP padding octets, if any. Note that
   this length is always equal to the UDP payload length of the packet
   minus 12.

8.3. FEC Code Specification

   The elements for FEC Scheme 5 are the same as specified for FEC
   Scheme 3, and the elements specified for FEC Scheme 6 are the same as
   specified for FEC 4, as specified in Section 7.4.

9. Security Considerations

   For the general security considerations related to the use of FEC,
   refer to [RFC6363]. Also consider relevant security considerations
   in [RFC5053] and [RFC6330]. No security vulnerabilities specific to
   this document have been identified.

10. Session Description Protocol (SDP) Signaling

   This section provides an SDP [RFC4566] example. The syntax follows
   the definition in [RFC6364]. Assume we have one source video stream
   (mid:S1) and one FEC repair stream (mid:R1). We form one FEC group
   with the "a=group:FEC-FR S1 R1" line. The source and repair streams
   are sent to the same port on different multicast groups. The repair
   window is set to 200 ms.

```
      v=0
      o=ali 1122334455 1122334466 IN IP4 fec.example.com
      s=Raptor FEC Example
      t=0 0
      a=group:FEC-FR S1 R1
      m=video 30000 RTP/AVP 100
      c=IN IP4 233.252.0.1/127
      a=rtpmap:100 MP2T/90000
      a=fec-source-flow: id=0
      a=mid:S1
      m=application 30000 UDP/FEC
      c=IN IP4 233.252.0.2/127
      a=fec-repair-flow: encoding-id=6; fssi=Kmax:8192,T:128,P:A
      a=repair-window:200ms
      a=mid:R1
```

11. Congestion Control Considerations

   For the general congestion control considerations related to the use
   of FEC, refer to [RFC6363].

12. IANA Considerations

12.1. Registration of FEC Scheme IDs

   The value of FEC Scheme IDs is subject to IANA registration. For
   general guidelines on IANA considerations as they apply to this
   document, refer to [RFC6363].

   This document registers six values in the "FEC Framework (FECFRAME)
   FEC Encoding IDs" registry (http://www.iana.org/assignments/
   rmt-fec-parameters/) as provided in Table 1. Each value refers to a
   Fully-Specified FEC scheme.

FEC Encoding ID	FEC Scheme Description	Reference
1	Raptor FEC Scheme for Arbitrary Packet Flows	Section 6 in this document using [RFC5053]
2	RaptorQ FEC Scheme for Arbitrary Packet Flows	Section 6 in this document using [RFC6330].
3	Raptor FEC Scheme Optimized for Arbitrary Packet Flows	Section 7 in this document using Raptor [RFC5053].
4	RaptorQ FEC Scheme Optimized for Arbitrary Packet Flows	Section 7 in this document using RaptorQ [RFC6330].
5	Raptor FEC Scheme for a Single Sequence Flow	Section 8 in this document using Raptor [RFC5053].
6	RaptorQ FEC Scheme for a Single Sequence Flow	Section 8 in this document using RaptorQ [RFC6330].

Table 1: FEC Framework (FECFRAME) FEC Encoding IDs

13. Acknowledgements

   Thanks are due to Ali C. Begen and David Harrington for thorough
   review of earlier draft versions of this document.

14. References

14.1. Normative References

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              "Raptor Forward Error Correction Scheme for Object
              Delivery", RFC 5053, October 2007.

   [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate
              Requirement Levels", BCP 14, RFC 2119, March 1997.

   [RFC6330] Luby, M., Shokrollahi, A., Watson, M., Stockhammer, T.,
              and L. Minder, "RaptorQ Forward Error Correction Scheme
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14.2. Informative References

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