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Raptor FEC Schemes for FECFRAME
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Status of this Memo

Abstract

This document describes Fully-Specified Forward Error Correction (FEC) Schemes for the Raptor code and its application to reliable delivery of media streams in the context of FEC Framework. The Raptor code is a systematic code, 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 code offers a close to optimal protection against arbitrary packet losses at a low computational complexity. Two FEC Schemes are defined, one for protection of arbitrary packet flows and another for 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. An RTP Payload Type is defined for this latter case.

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1. Introduction

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The FEC Framework [I-D.ietf-fecframe-framework] (Watson, M., “Forward Error Correction (FEC) Framework,” March 2010.) describes a framework for the application of Forward Error Correction to arbitrary packet flows. Modelled after the FEC Building Block developed by the IETF Reliable Multicast Transport working group ([RFC5052] (, “,” 2005.)), the FEC Framework defines the concept of FEC Schemes which provide specific Forward Error Correction schemes. This document describes two FEC Schemes which make use of the Raptor FEC code as defined in [RFC5053] (, “,” 2005.).

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

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

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

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

- The sender packetizes the repair symbols and sends the repair packet(s) along with 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, respectively. 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 can identify the relationships between received source packets and repair packets and in particular which source packets are missing. In many cases, data already exists in the source packets which 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 [I-D.ietf-fecframe-framework] (Watson, M., “Forward Error Correction

(FEC) Framework," March 2010.) 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 case if referred to as the "arbitrary packet flow" case. Accordingly, this document defines two FEC Schemes, one for the case of a single sequenced flow and another for the case of arbitrary packet flows.

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2. Document Outline

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This document is organised as follows:

> Section 5 (General procedures for Raptor FEC Schemes) defines general procedures applicable to the use of the Raptor code in the context of the FEC Framework.
>
> Section 6 (Raptor FEC Scheme for arbitrary packet flows)defines an FEC Scheme for the case of arbitrary source flows and follows the format defined for FEC Schemes in [I-D.ietf-fecframe-framework] (Watson, M., "Forward Error Correction (FEC) Framework," March 2010.). This scheme is equivalent to that defined in [3GPP MBMS Specification].
>
> Section 7 (Optimised Raptor FEC Scheme for arbitrary packet flows) defines an FEC Scheme similar to that defined in Section 6 (Raptor FEC Scheme for arbitrary packet flows)but with optimisations for the case where only limited source block sizes are required. This scheme is equivalent to that defined in [DVB AL-FEC specification] for arbitrary packet flows.
>
> Section 8 (Raptor FEC Scheme for a single sequenced flow) defines an FEC Scheme for the case of a single sequenced flow and follows the format defined for FEC Schemes in
>
> [I-D.ietf-fecframe-framework] (Watson, M., "Forward Error Correction (FEC) Framework," March 2010.). This scheme is equivalent to that defined in [DVB AL-FEC specification] for the case of a single sequenced flow.

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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] (Bradner, S., “Key words for use in RFCs to Indicate Requirement Levels,” March 1997.).

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4. Definitions and Abbreviations

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

4.1. Definitions

TOC

This document uses the following definitions. For further definitions that apply to FEC Framework in general, see [I-D.ietf-fecframe-framework] (Watson, M., “Forward Error Correction (FEC) Framework,” March 2010.).

Source Flow: The packet flow(s) carrying the source data and to which FEC protection is to be applied.

Repair Flow: The packet flow(s) carrying the repair data.

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

Source Symbol: The smallest unit of data used during the encoding process.

Repair Symbol: Repair symbols are generated from the source symbols.

Source Packet: Data packets that contain only source symbols.

Repair Packet: Data packets that contain only repair symbols.

Source Block: A block of source symbols that are considered together in the encoding process.

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

FEC Payload ID: Information that identifies the contents of a packet with respect to the FEC scheme.

Source FEC Payload ID: An FEC Payload ID specifically used with source packets.

Repair FEC Payload ID: An FEC Payload ID specifically used with repair packets.

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4.2. Abbreviations

*FSSI: FEC-Scheme-Specific Information.

*SS-FSSI: Sender-Side FEC-Scheme-Specific Information.

*RS-FSSI: Receiver-Side FEC-Scheme-Specific Information.

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5. General procedures for Raptor FEC Schemes

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This section specifies general procedures which apply to all Raptor FEC Schemes, specifically the construction of source symbols from a set of source transport payloads. As described in [I-D.ietf-fecframe-framework] (Watson, M., “Forward Error Correction (FEC) Framework,” March 2010.) for each source transport payload in a source block, the FEC Scheme is provided with:

*A description of the source transport flow with which the transport payload is associated and an integer identifier associated with that flow.

*The source transport payload itself.

*The length of the source transport payload.

For each source transport payload, we define the Source Packet Information (SPI) as follows:
Let

> n be the number of source transport payloads in the source block.
>
> T be the source symbol size in bytes. Note: this information is provided by the FEC Scheme as defined below.
>
> i the index to the (i+1)-th source transport payload to be added to the source block, 0 <= i < n.
>
> R[i] denote the number of octets in the (i+1)-th source transport payload.
>
> l[i] be a length indication associated with the i-th UDP packet – the nature of the length indication is defined by the FEC Scheme.
>
> L[i] denote two octets representing the value of l[i] in network byte order (high order octet first) of the i-th UDP packet.

f[i] denote the integer identifier associated with the source transport payload from which the i-th source transport payload was taken.

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

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 bytes.

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.

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

Then, a source data block is constructed by concatenating SPI[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 consecutively starting from zero within the source block. Each source transport payload is associated with the Encoding Symbol ID 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 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.

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6. Raptor FEC Scheme for arbitrary packet flows

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6.1. Introduction

TOC

This section specifies an FEC Scheme for the application of the Raptor code to arbitary packet flows. This scheme is recommended in scenarios where maximal generality is required.
This scheme is equivalent to that specified in [3GPP MBMS Specification].

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6.2. Formats and Codes

6.2.1. FEC Framework Configuration Information

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6.2.1.1. FEC Scheme ID

TOC

The value of the FEC Scheme ID for the fully-specified FEC scheme defined in this section MUST be TBD as assigned by IANA.

6.2.1.2. Scheme-Specific Elements

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

> **Maximum Source Block Length** A non-negative integer less than 2^13, in units of symbols
>
> **Encoding Symbol Size** A non-negative integer less than 2^16, in units of bytes

An encoding format for this information in a 4 octet field is defined as follows:

```
                     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)         |  Max. Source Block Length     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1: FEC Scheme Specific Information

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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.

```
                     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

Source Block Number (SBN), (16 bits): An integer identifier for the source block that the source data within the packet relates to.
Encoding Symbol ID (ESI), (16 bits): The starting symbol index of the source packet in the source block.

6.2.3. Repair FEC Payload ID

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The structure of the Repair FEC Payload ID 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Source Block Number (SBN)   |   Encoding Symbol ID (ESI)    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Source Block Length (SBL)   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Repair FEC Payload ID

Source Block Number (SBN), (16 bits) An integer identifier for the source block that the repair symbols within the packet relate to.

Encoding Symbol ID (ESI), (16 bits) Integer identifier for the encoding symbols within the packet.

Source Block Length (SBL), (16 bits)

The number of source symbols in the source block.

The interpretation of the Source Block Number, Encoding Symbol Identifier and Source Block Length is defined by the FEC Code Specification.

6.3. Procedures

TOC

6.3.1. Source symbol construction

TOC

This FEC Scheme uses the procedures defined in Section 5 (General procedures for Raptor FEC Schemes) 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 2^16-1.
During the construction of the source block:

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

*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

TOC

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 given by the following formula:
ESI_repair = I_repair + SBL,
where I_repair is the index of the repair symbol in the sequence of repair symbols generated according to Section 6.4 (FEC Code Specification), where the first repair symbol has index 0, the second index 1 etc. and SBL is the Source Block Length. The Source Block Length field of the Repair FEC Payload ID field SHALL be set to the number of symbols included in the Source Packet Information of packets associated with the source block.

6.4. FEC Code Specification

TOC

The Raptor FEC encoder defined in [RFC5053] (, “,” 2005.) SHALL be used. The source symbols passed to the Raptor FEC encoder SHALL consist of the source symbols constructed according to Section 6.3.1 (Source symbol construction). 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 signalled 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. Optimised Raptor FEC Scheme for arbitrary packet flows

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7.1. Introduction

TOC

This section specifies a slightly modified version of the FEC Scheme specified in Section 6 (Raptor FEC Scheme for arbitrary packet flows) which is applicable to scenarios in which only relatively small block sizes will be used. These modifications admit substantial optimisations to both sender and receiver implementations.
In outline, the modifications are:

> 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 signalled in the Maximum Source Block Size field of the scheme-specific information. This allows for efficient parallel encoding of multiple streams.
>
> A restricted set of possible source block sizes is specified. This allows explicit operation sequences for encoding the restricted set of block sizes to be pre-calculated and embedded in software or hardware.

This scheme is equivalent to that specified in [DVB AL-FEC Specification] for arbitrary packet flows.

7.2. Formats and Codes

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7.2.1. FEC Framework Configuration Information

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7.2.1.1. FEC Scheme ID

TOC

The value of the FEC Scheme ID for the fully-specified FEC scheme defined in this section MUST be TBD as assigned by IANA.

7.2.1.2. FEC Scheme specific information

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See . (Scheme-Specific Elements)

7.2.2. Source FEC Payload ID

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See . (Source FEC Payload ID)

7.2.3. Repair FEC Payload ID

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SeeSection 6.2.3 (Repair FEC Payload ID)

7.3. Procedures

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7.3.1. Source symbol construction

See Section 6.3.1 (Source symbol construction)

7.3.2. Repair packet construction

TOC

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 given by the following formula:
ESI_repair = I_repair + MSBL
Where I_repair is the index of the repair symbol in the sequence of repair symbols generated according to Section 6.4 (FEC Code Specification), where the first repair symbol has index 0, the second index 1 etc. and MSBL is the Maximum Source Block Length signalled in the FEC Scheme Specific Information. The Source Block Length field of the Repair FEC Payload ID field SHALL be set to the number of symbols included in the Source Packet Information of packets associated with the source block.

7.4. FEC Code Specification

TOC

The Raptor FEC encoder defined in [RFC5053] (, “,” 2005.) SHALL be used. The source symbols passed to the Raptor FEC encoder SHALL consist of the source symbols constructed according to Section 6.3.1 (Source symbol construction) extended with zero or more padding symbols such that the total number of symbols in the source block is equal to the Maximum Source Block Length signaled in the FEC Scheme Specific Information. Thus the value of the parameter K used by the FEC encoded is equal to the Maximum Source Block Length for all blocks of the stream. Padding symbols shall consist entirely of bytes set to the value zero. 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. The parameter T shall be set such that the number of source symbols in any source block is at most KMAX = 8192. The Maximum Source Block Length 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

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8. Raptor FEC Scheme for a single sequenced flow

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8.1. Formats and codes

TOC

8.1.1. FEC Framework Configuration Information

TOC

8.1.1.1. FEC Scheme ID

TOC

The value of the FEC Scheme ID for the fully-specified FEC scheme defined in this section MUST be TBD as assigned by IANA.

8.1.1.2. Scheme-specific elements

TOC

See Section 6.2.1.2 (Scheme-Specific Elements)

8.1.2. Source FEC Payload ID

TOC

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

TOC

The Repair FEC Payload ID format for this FEC Scheme is shown 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Initial Sequence Number    |      Encoding Symbol ID       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Source Block Length      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: Repair FEC Payload ID

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.

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.

Source Block Length (SBL) – 16 bits This field specifies the length of the source block in symbols.

8.2. Procedures

TOC

8.2.1. Source symbol construction

TOC

This FEC Scheme uses the procedures defined in Section 5 (General procedures for Raptor FEC Schemes) 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 2^16-1.
During the construction of the source block:

* 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.

*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

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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 bytes) for source packets within a source block is equal to 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 Source Packet Information Length (SPIL) 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 which are included in the source block is determined from the Initial Sequence Number (ISN) and Source Block Length (SBL) as follows:
Let,

> I be the Initial Sequence Number of the source block
>
> LP be the Source Packet Information Length in symbols
>
> 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.
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:

> The sequence number, Ns, of the packet
>
> The Source Packet Information Length for the source block, LP
>
> The Initial Sequence Number of the source block, I

Then the Encoding Symbol ID for packet with sequence number Ns is determined by the following formula:

```
ESI = ( Ns - I ) * LP
```

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

8.2.3. Repair packet construction

TOC

See Section 7.3.2 (Repair packet construction)

8.2.4. Procedures for RTP source flows

TOC

In the specific case of RTP source packet flows, then the RTP Sequence Number field SHALL be used as the sequence number in the procedures described above. The length indication included in the Source Packet Information SHALL be the RTP payload length plus the length of the CSRCs, if any, and the RTP padding bytes, if any. Note that this length is always equal to the UDP payload length of the packet, minus 12.

8.3. FEC Code Specification

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See Section 7.4 (FEC Code Specification)

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9. Security Considerations

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For the general security considerations related to the use of FEC, refer to [I-D.ietf-fecframe-framework] (Watson, M., "Forward Error Correction (FEC) Framework," March 2010.).

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10. Session Description Protocol (SDP) Signaling

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This section provides an SDP [RFC4566] (Handley, M., Jacobson, V., and C. Perkins, "SDP: Session Description Protocol," July 2006.) example. The following example uses the SDP elements for FEC Framework, which were introduced in [I-D.ietf-fecframe-sdp-elements] (Begen, A., “SDP Elements for FEC Framework,” April 2010.), and the FEC grouping semantics [RFC4756] (Li, A., “Forward Error Correction Grouping Semantics in Session Description Protocol,” November 2006.). In this example, 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 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.rocks.com
s=Interleaved Parity FEC Example
t=0 0
a=group:FEC S1 R1
m=video 30000 RTP/AVP 100
c=IN IP4 224.1.1.1/127
a=rtpmap:100 MP2T/90000
a=fec-source-flow: id=0
a=mid:S1
m=application 30000 udp/fec
c=IN IP4 224.1.2.1/127
a=fec-repair-flow: scheme-id=0; ss-fssi=5hu=
a=repair-window: 200
a=mid:R1
```

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11. Congestion Control Considerations

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For the general congestion control considerations related to the use of FEC, refer to [I-D.ietf-fecframe-framework] (Watson, M., “Forward Error Correction (FEC) Framework,” March 2010.).

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12. IANA Considerations

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12.1. Registration of FEC Scheme IDs

TOC

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 [I-D.ietf-fecframe-framework] (Watson, M., “Forward Error Correction (FEC) Framework,” March 2010.).

13. Normative References

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[I-D.ietf-fecframe-framework]	Watson, M., "Forward Error Correction (FEC) Framework," draft-ietf-fecframe-framework-07 (work in progress), March 2010 (TXT).
[RFC5052]	"," 2005.
[RFC5053]	"," 2005.
[I-D.ietf-fecframe-sdp-elements]	Begen, A., "SDP Elements for FEC Framework," draft-ietf-fecframe-sdp-elements-06 (work in progress), April 2010 (TXT).
[RFC2119]	Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels," BCP 14, RFC 2119, March 1997 (TXT, HTML, XML).
[RFC4566]	Handley, M., Jacobson, V., and C. Perkins, "SDP: Session Description Protocol," RFC 4566, July 2006 (TXT).
[RFC4756]	Li, A., "Forward Error Correction Grouping Semantics in Session Description Protocol," RFC 4756, November 2006 (TXT).

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