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RTP Payload Format for 1-D Interleaved Parity FEC
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Abstract

This document defines a new RTP payload format for the Forward Error Correction (FEC) that is generated by the 1-D interleaved parity code from a source media encapsulated in RTP. The 1-D interleaved parity code is a systematic code, where a number of repair symbols are generated from a set of source symbols and sent in a repair flow separate from the source flow that carries the source symbols. The 1-D interleaved parity code offers a good protection against bursty packet losses at a cost of decent complexity. The new payload format

defined in this document is compatible with and used as a part of the DVB Application-layer FEC Specification.

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1. Introduction

This document extends the Forward Error Correction (FEC) header defined in [RFC2733] and uses this new FEC header for the FEC that is generated by the 1-D interleaved parity code from a source media encapsulated in RTP [RFC3550]. The resulting new RTP payload format is registered by this document.

The type of the source media protected by the 1-D interleaved parity code can be audio, video, text or application. The FEC data are generated according to the media type parameters that are communicated through out-of-band means. The associations/ relationships between the source and repair flows are also communicated through out-of-band means.

The 1-D interleaved parity FEC uses the exclusive OR (XOR) operation to generate the repair symbols. In a nutshell, the following steps take place:

1. The sender determines a set of source packets to be protected together based on the media type parameters.

2. The sender applies the XOR operation on the source symbols to generate the required number of repair symbols.

3. The sender packetizes the repair symbols and sends the repair packet(s) along with the source packets to the receiver(s) (in different flows). The repair packets MAY be sent proactively or on-demand.

Note that the sender MUST transmit the source and repair packets in different source and repair flows, respectively to offer backward compatibility (See Section 4). 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. Block diagrams for the systematic parity FEC encoder and decoder are sketched in Figure 1 and Figure 2, respectively.

```
                              +------------+
+--+  +--+  +--+  +--+ --> | Systematic | --> +--+  +--+  +--+  +--+
+--+  +--+  +--+  +--+     | Parity FEC |     +--+  +--+  +--+  +--+
                              |  Encoder   |
                              |  (Sender)  | --> +==+  +==+
                              +------------+     +==+  +==+

Source Packet: +--+    Repair Packet: +==+
               +--+                   +==+
```

Figure 1: Block diagram for systematic parity FEC encoder

```
                              +------------+
+--+    X    X    +--+ --> | Systematic | --> +--+  +--+  +--+  +--+
+--+              +--+     | Parity FEC |     +--+  +--+  +--+  +--+
                              |  Decoder   |
            +==+  +==+ --> | (Receiver) |
            +==+  +==+     +------------+

Source Packet: +--+    Repair Packet: +==+    Lost Packet: X
               +--+                   +==+
```

Figure 2: Block diagram for systematic parity FEC decoder

Suppose that we have a group of D x L source packets that have sequence numbers starting from 1 running to D x L. If we apply the XOR operation to the group of the source packets whose sequence numbers are L apart from each other as sketched in Figure 3, we generate L repair packets. This process is referred to as 1-D interleaved FEC protection, and the resulting L repair packets are referred to as interleaved (or column) FEC packets.

```
+-------------+ +-------------+ +-------------+     +-------+
| S_1         | | S_2         | | S3          | ... | S_L   |
| S_L+1       | | S_L+2       | | S_L+3       | ... | S_2xL |
| .           | | .           | |             |     |       |
| .           | | .           | |             |     |       |
| .           | | .           | |             |     |       |
| S_(D-1)xL+1 | | S_(D-1)xL+2 | | S_(D-1)xL+3 | ... | S_DxL |
+-------------+ +-------------+ +-------------+     +-------+
       +               +               +                +
 -------------   -------------   -------------       -------
|     XOR     | |     XOR     | |     XOR     | ... |  XOR  |
 -------------   -------------   -------------       -------
       =               =               =                =
     +===+           +===+           +===+            +===+
     |C_1|           |C_2|           |C_3|      ...   |C_L|
     +===+           +===+           +===+            +===+
```

Figure 3: Generating interleaved (column) FEC packets

In Figure 3, S_n and C_m denote the source packet with a sequence number n and the interleaved (column) FEC packet with a sequence number m, respectively.

1.1. Use Cases

We generate one interleaved FEC packet out of D non-consecutive source packets. This repair packet can provide a full recovery of the missing information if there is only one packet missing among the corresponding source packets. This implies that 1-D interleaved FEC protection performs well under bursty loss conditions provided that L is chosen large enough, i.e., L-packet duration SHOULD NOT be shorter than the duration of the burst that is intended to be repaired.

For example, consider the scenario depicted in Figure 4 where the sender generates interleaved FEC packets and a bursty loss hits the source packets. Since the number of columns is larger than the number of packets lost due to the bursty loss, the repair operation succeeds.

```
                      +---+
                      | 1 |    X      X      X
                      +---+

                      +---+  +---+  +---+  +---+
                      | 5 |  | 6 |  | 7 |  | 8 |
                      +---+  +---+  +---+  +---+

                      +---+  +---+  +---+  +---+
                      | 9 |  | 10|  | 11|  | 12|
                      +---+  +---+  +---+  +---+

                      +===+  +===+  +===+  +===+
                      |C_1|  |C_2|  |C_3|  |C_4|
                      +===+  +===+  +===+  +===+
```

Figure 4: Example scenario where 1-D interleaved FEC protection succeeds error recovery

The sender may generate interleaved FEC packets to combat with the bursty packet losses. However, two or more random packet losses may hit the source and repair packets in the same column. In that case, the repair operation fails. This is illustrated in Figure 5. Note that it is possible that two or more bursty losses may occur in the same source block, in which case interleaved FEC packets may still fail to recover the lost data.

```
                      +---+         +---+  +---+
                      | 1 |    X    | 3 |  | 4 |
                      +---+         +---+  +---+

                      +---+         +---+  +---+
                      | 5 |    X    | 7 |  | 8 |
                      +---+         +---+  +---+

                      +---+  +---+  +---+  +---+
                      | 9 |  | 10|  | 11|  | 12|
                      +---+  +---+  +---+  +---+

                      +===+  +===+  +===+  +===+
                      |C_1|  |C_2|  |C_3|  |C_4|
                      +===+  +===+  +===+  +===+
```

Figure 5: Example scenario where 1-D interleaved FEC protection fails error recovery

1.2. Overhead Computation

The overhead is defined as the ratio of the number of bytes belonging to the repair packets to the number of bytes belonging to the protected source packets.

Assuming that each repair packet carries an equal number of bytes carried by a source packet, we can compute the overhead as follows:

Overhead = 1/D

where D is the number of rows in the source block.

1.3. Relation to Existing Specifications

This section discusses the relation of the current specification to other existing specifications.

1.3.1. RFC 2733 and RFC 3009

The current specification extends the FEC header defined in [RFC2733] and registers a new RTP payload format. This new payload format is not backward compatible with the payload format that was registered by [RFC3009].

1.3.2. SMPTE 2022-1

In 2007, the Society of Motion Picture and Television Engineers (SMPTE) - Technology Committee N26 on File Management and Networking Technology - decided to revise the Pro-MPEG Code of Practice (CoP) #3 Release 2 specification, which (was initially produced by the Pro-MPEG Forum in 2004) discussed the several aspects of the transmission of MPEG-2 transport streams over IP networks. The new SMPTE specification is referred to as [SMPTE2022-1].

The Pro-MPEG CoP #3 r2 document was originally based on [RFC2733]. SMPTE revised the document by extending the FEC header (by setting the E bit) proposed in [RFC2733]. This extended header offers some improvements.

For example, instead of utilizing the bitmap field used in [RFC2733], [SMPTE2022-1] introduces separate fields to convey the number of rows (D) and columns (L) of the source block as well as the type of the repair packet (i.e., whether the repair packet is an interleaved FEC packet computed over a column or a non-interleaved FEC packet computed over a row). These fields plus the base sequence number allow the receiver side to establish the associations between the source and repair packets. Note that although the bitmap field is

not utilized, the FEC header of [SMPTE2022-1] inherently carries over the bitmap field from [RFC2733].

On the other hand, some parts of [SMPTE2022-1] are not in compliant with RTP [RFC3550]. For example, [SMPTE2022-1] sets the SSRC field to zero and does not use the timestamp field in the RTP headers of the repair packets (Receivers ignore the timestamps of the repair packets). Furthermore, [SMPTE2022-1] also sets the CC field in the RTP header to zero and does not allow any Contributing Source (CSRC) entry in the RTP header.

The current document adopts the extended FEC header of [SMPTE2022-1] and registers a new RTP payload format. At the same time, this document fixes the parts of [SMPTE2022-1] that are not in compliant with RTP [RFC3550].

1.3.3. ETSI TS 102 034

In 2007, the Digital Video Broadcasting (DVB) consortium published a technical specification [ETSI-TS-102-034] through European Telecommunications Standards Institute (ETSI). This specification covers several areas related to the transmission of MPEG-2 transport stream-based services over IP networks.

The Annex E of [ETSI-TS-102-034] defines an optional protocol for Application-layer FEC (AL-FEC) protection of streaming media for DVB-IP services carried over RTP [RFC3550] transport. AL-FEC protocol uses two layers for protection: a base layer that is produced by a packet-based interleaved parity code, and an enhancement layer that is produced by a Raptor code. While the use of the enhancement layer is optional, the use of the base layer is mandatory wherever AL-FEC is used. The DVB AL-FEC protocol is also described in [I-D.begen-fecframe-dvb-al-fec].

The interleaved parity code that is used in the base layer is a subset of [SMPTE2022-1]. In particular, AL-FEC base layer uses the 1-D interleaved FEC protection only from [SMPTE2022-1]. The new RTP payload format that is defined and registered in this document is compatible with and used as the AL-FEC base layer.

2. 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].

3. Definitions, Notations and Abbreviations

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

3.1. Definitions

This document uses the following definitions:

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.

3.2. Notations

- L: Number of columns of the source block.
- D: Number of rows of the source block.

3.3. Abbreviations

- XOR: Bitwise exclusive OR operation.
  0 XOR 0 = 0
  0 XOR 1 = 1
  1 XOR 0 = 1
  1 XOR 1 = 0

4. Packet Formats

This section defines the formats of the source and repair packets.

4.1. Source Packets

The source packets MUST contain the information that identifies the source block and the position within the source block occupied by the packet. Since the source packets that are carried within an RTP stream already contain unique sequence numbers in their RTP headers [RFC3550], we can identify the source packets in a straightforward manner and there is no need to append additional field(s). The primary advantage of not modifying the source packets in any way is that it provides backward compatibility for the receivers that do not support FEC at all. In multicast scenarios, this backward compatibility becomes quite useful as it allows the non-FEC-capable and FEC-capable receivers to receive and interpret the same source packets sent in the same multicast session.

4.2. Repair Packets

The repair packets MUST contain information that identifies the source block they pertain to and the relationship between the contained repair symbols and the original source block. For this purpose, we use the RTP header of the repair packets as well as another header within the RTP payload, which we refer to as the FEC header, as shown in Figure 7.

```
+------------------------------+
|          IP Header           |
+------------------------------+
|       Transport Header       |
+------------------------------+
|          RTP Header          | __
+------------------------------+   |
|          FEC Header          |    \
+------------------------------+     > RTP Payload
|        Repair Symbols        |    /
+------------------------------+ __|
```

Figure 7: Format of repair packets

The RTP header is formatted according to [RFC3550] with some further clarifications listed below:

- o Version: The version field is set to 2.

- o Padding (P) Bit: This bit is obtained by applying protection to the corresponding P bits from the RTP headers of the source packets protected by this repair packet. However, padding octets are never present in a repair packet, independent of the value of the P bit.

o Extension (X) Bit: This bit is obtained by applying protection to the corresponding X bits from the RTP headers of the source packets protected by this repair packet. However, an RTP header extension is never present in a repair packet, independent of the value of the X bit.

o CSRC Count (CC): This field is obtained by applying protection to the corresponding CC values from the RTP headers of the source packets protected by this repair packet. However, a CSRC list is never present in a repair packet, independent of the value of the CC field.

o Marker (M) Bit: This bit is obtained by applying protection to the corresponding M bits from the RTP headers of the source packets protected by this repair packet.

o Payload Type: The (dynamic) payload type for the repair packets is determined through out-of-band means. Note that this document registers a new payload format for the repair packets (Refer to Section 5 for details). According to [RFC3550], an RTP receiver that cannot recognize a payload type must discard it. This provides backward compatibility. The FEC mechanisms can then be used in a multicast group with mixed FEC-capable and non-FEC-capable receivers. If a non-FEC-capable receiver receives a repair packet, it will not recognize the payload type, and hence, discards the repair packet.

o Sequence Number (SN): The sequence number has the standard definition. It MUST be one higher than the sequence number in the previously transmitted repair packet.

o Timestamp (TS): The timestamp MUST be set to the timestamp of the source packet whose sequence number is the lowest among the source packets protected by this repair packet.

o Synchronization Source (SSRC): The SSRC value SHALL be randomly assigned as suggested by [RFC3550]. This allows the sender to multiplex the source and repair flows on the same port, or multiplex multiple repair flows on a single port. The repair flows SHOULD use the RTCP CNAME field to associate themselves with the source flow. Note that due to the randomness of the SSRC assignments, there is a possibility of SSRC collision. In such cases, the collisions MUST be resolved as described in [RFC3550].

Note that the P bit, X bit, CC field and M bit of the source packets are protected by the corresponding bits/fields in the RTP header of the repair packet. On the other hand, the payload of a repair packet protects the concatenation of (if present) the CSRC list, RTP

extension, payload and padding of the source RTP packets associated with this repair packet.

The FEC header is 16 octets. The format of the FEC header is shown in Figure 8.

```
 0                   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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          SN base low          |        Length recovery        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|E| PT recovery |                    Mask                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          TS recovery                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|N|D|Type |Index|     Offset    |       NA      |  SN base ext  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 8: Format of the FEC header

The FEC header consists of the following fields:

- o The SN base low field is used to indicate the lowest sequence number, taking wrap around into account, of those source packets protected by this repair packet.

- o The Length recovery field is used to determine the length of any recovered packets.

- o The E bit is the extension flag introduced in [RFC2733] and used to extend the [RFC2733] FEC header.

- o The PT recovery field is used to determine the payload type of the recovered packets.

- o The Mask field is not used.

- o The TS recovery field is used to determine the timestamp of the recovered packets.

- o The N bit is the extension flag that is reserved for future uses.

- o The D bit is not used.

- o The Type field indicates the type of the error-correcting code used. This document defines only one error-correcting code.

o The Index field is not used.

o The Offset and NA fields are used to indicate the number of columns (L) and rows (D) of the source block, respectively.

o The SN base ext field is not used.

The details on setting the fields in the FEC header are provided in Section 6.2.

It should be noted that a mask-based approach (similar to the one specified in [RFC2733]) may not be very efficient to indicate which source packets in the current source block are associated with a given repair packet. In particular, for the applications that would like to use large source block sizes, the size of the mask that is required to describe the source-repair packet associations may be prohibitively large. Instead, a systematic approach is inherently more efficient.

5. Payload Format Parameters

This section provides the media subtype registration for the 1-D interleaved parity FEC. The parameters that are required to configure the FEC encoding and decoding operations are also defined in this section.

5.1. Media Type Registration

This registration is done using the template defined in [RFC4288] and following the guidance provided in [RFC3555].

5.1.1. Registration of audio/1d-interleaved-parityfec

Type name: audio

Subtype name: 1d-interleaved-parityfec

Required parameters:

o rate: The RTP timestamp (clock) rate. The rate SHALL be larger than 1000 Hz to provide sufficient resolution to RTCP operations. However, it is RECOMMENDED to select the rate that matches the rate of the protected source RTP stream.

o L: Number of columns of the source block. L is a positive integer that is less than or equal to 255.

- D: Number of rows of the source block. D is a positive integer that is less than or equal to 255.

- repair-window: The time that spans the source packets and the corresponding repair packets. An FEC encoder processes a block of source packets and generates a number of repair packets, which are then transmitted within a certain duration. At the receiver, the FEC decoder tries to decode all the packets received within the repair window to recover the missing packets. Assuming that there is no issue of delay variation, the FEC decoder SHOULD NOT wait longer than the repair window since additional waiting would not help the recovery process. The size of the repair window is specified in microseconds.

Optional parameters: None.

Encoding considerations: This media type is framed (See Section 4.8 in the template document [RFC4288]) and contains binary data.

Security considerations: See Section 9 of this document.

Interoperability considerations: None.

Published specification: This document.

Applications that use this media type: Multimedia applications that want to improve resiliency against packet loss by sending redundant data in addition to the source media.

Additional information: None.

Person & email address to contact for further information: Ali Begen <abegen@cisco.com> and IETF Audio/Video Transport Working Group.

Intended usage: COMMON.

Restriction on usage: None.

Author: Ali Begen <abegen@cisco.com>.

Change controller: IETF Audio/Video Transport Working Group delegated from the IESG.

5.1.2. Registration of video/1d-interleaved-parityfec

Type name: video

Subtype name: 1d-interleaved-parityfec

Required parameters:

- rate: The RTP timestamp (clock) rate. The rate SHALL be larger than 1000 Hz to provide sufficient resolution to RTCP operations. However, it is RECOMMENDED to select the rate that matches the rate of the protected source RTP stream.

- L: Number of columns of the source block. L is a positive integer that is less than or equal to 255.

- D: Number of rows of the source block. D is a positive integer that is less than or equal to 255.

- repair-window: The time that spans the source packets and the corresponding repair packets. An FEC encoder processes a block of source packets and generates a number of repair packets, which are then transmitted within a certain duration. At the receiver, the FEC decoder tries to decode all the packets received within the repair window to recover the missing packets. Assuming that there is no issue of delay variation, the FEC decoder SHOULD NOT wait longer than the repair window since additional waiting would not help the recovery process. The size of the repair window is specified in microseconds.

Optional parameters: None.

Encoding considerations: This media type is framed (See Section 4.8 in the template document [RFC4288]) and contains binary data.

Security considerations: See Section 9 of this document.

Interoperability considerations: None.

Published specification: This document.

Applications that use this media type: Multimedia applications that want to improve resiliency against packet loss by sending redundant data in addition to the source media.

Additional information: None.

Person & email address to contact for further information: Ali Begen <abegen@cisco.com> and IETF Audio/Video Transport Working Group.

Intended usage: COMMON.

Restriction on usage: None.

Author: Ali Begen <abegen@cisco.com>.

Change controller: IETF Audio/Video Transport Working Group delegated from the IESG.

5.1.3. Registration of text/1d-interleaved-parityfec

Type name: text

Subtype name: 1d-interleaved-parityfec

Required parameters:

- o rate: The RTP timestamp (clock) rate. The rate SHALL be larger than 1000 Hz to provide sufficient resolution to RTCP operations. However, it is RECOMMENDED to select the rate that matches the rate of the protected source RTP stream.

- o L: Number of columns of the source block. L is a positive integer that is less than or equal to 255.

- o D: Number of rows of the source block. D is a positive integer that is less than or equal to 255.

- o repair-window: The time that spans the source packets and the corresponding repair packets. An FEC encoder processes a block of source packets and generates a number of repair packets, which are then transmitted within a certain duration. At the receiver, the FEC decoder tries to decode all the packets received within the repair window to recover the missing packets. Assuming that there is no issue of delay variation, the FEC decoder SHOULD NOT wait longer than the repair window since additional waiting would not help the recovery process. The size of the repair window is specified in microseconds.

Optional parameters: None.

Encoding considerations: This media type is framed (See Section 4.8 in the template document [RFC4288]) and contains binary data.

Security considerations: See Section 9 of this document.

Interoperability considerations: None.

Published specification: This document.

Applications that use this media type: Multimedia applications that want to improve resiliency against packet loss by sending redundant

data in addition to the source media.

Additional information: None.

Person & email address to contact for further information: Ali Begen <abegen@cisco.com> and IETF Audio/Video Transport Working Group.

Intended usage: COMMON.

Restriction on usage: None.

Author: Ali Begen <abegen@cisco.com>.

Change controller: IETF Audio/Video Transport Working Group delegated from the IESG.

5.1.4. Registration of application/1d-interleaved-parityfec

Type name: application

Subtype name: 1d-interleaved-parityfec

Required parameters:

o rate: The RTP timestamp (clock) rate. The rate SHALL be larger than 1000 Hz to provide sufficient resolution to RTCP operations. However, it is RECOMMENDED to select the rate that matches the rate of the protected source RTP stream.

o L: Number of columns of the source block. L is a positive integer that is less than or equal to 255.

o D: Number of rows of the source block. D is a positive integer that is less than or equal to 255.

o repair-window: The time that spans the source packets and the corresponding repair packets. An FEC encoder processes a block of source packets and generates a number of repair packets, which are then transmitted within a certain duration. At the receiver, the FEC decoder tries to decode all the packets received within the repair window to recover the missing packets. Assuming that there is no issue of delay variation, the FEC decoder SHOULD NOT wait longer than the repair window since additional waiting would not help the recovery process. The size of the repair window is specified in microseconds.

Optional parameters: None.

Encoding considerations: This media type is framed (See Section 4.8 in the template document [RFC4288]) and contains binary data.

Security considerations: See Section 9 of this document.

Interoperability considerations: None.

Published specification: This document.

Applications that use this media type: Multimedia applications that want to improve resiliency against packet loss by sending redundant data in addition to the source media.

Additional information: None.

Person & email address to contact for further information: Ali Begen <abegen@cisco.com> and IETF Audio/Video Transport Working Group.

Intended usage: COMMON.

Restriction on usage: None.

Author: Ali Begen <abegen@cisco.com>.

Change controller: IETF Audio/Video Transport Working Group delegated from the IESG.

5.2. Mapping to SDP Parameters

Applications that are using RTP transport commonly use Session Description Protocol (SDP) [RFC4566] to describe their RTP sessions. The information that is used to specify the media types in an RTP session has specific mappings to the fields in an SDP description. In this section, we provide these mappings for the media subtype registered by this document ("1d-interleaved-parityfec"). Note that if an application does not use SDP to describe the RTP sessions, an appropriate mapping must be defined and used to specify the media types and their parameters for the control/description protocol employed by the application.

The mapping of the media type specification for "1d-interleaved-parityfec" and its parameters in SDP is as follows:

- o The media type (e.g., "application") goes into the "m=" line as the media name.

- o The media subtype ("1d-interleaved-parityfec") goes into the "a=rtpmap" line as the encoding name. The RTP clock rate

parameter ("rate") also goes into the "a=rtpmap" line as the clock rate.

- The remaining required payload-format-specific parameters go into the "a=fmtp" line by copying them directly from the media type string as a semicolon-separated list of parameter=value pairs.

SDP examples are provided in Section 7.

5.2.1. Offer-Answer Model Considerations

TBC.

5.2.2. Declarative Considerations

TBC.

6. Protection and Recovery Procedures

This section provides a complete specification of the 1-D interleaved parity code.

6.1. Overview

The following sections specify the steps involved in generating the repair packets and reconstructing the missing source packets from the repair packets.

6.2. Repair Packet Construction

The RTP header of a repair packet is formed based on the guidelines given in Section 4.2.

The FEC header includes 16 octets. It is constructed by applying the XOR operation on the bit strings that are generated from the individual source packets protected by this particular repair packet. The set of the source packets that are associated with a given repair packet can be computed by the formula given in Section 6.3.1.

The bit string is formed for each source packet by concatenating the following fields together in the order specified:

- Padding bit (1 bit) (This is the most significant bit of the bit string)

- Extension bit (1 bit)

- o CC field (4 bits)
- o Marker bit (1 bit)
- o PT field (7 bits)
- o Timestamp (32 bits)
- o Unsigned network-ordered 16-bit representation of the source packet length in bytes minus 12 (for the fixed RTP header), i.e., the sum of the lengths of all the following if present: the CSRC list, header extension, RTP payload and RTP padding (16 bits)
- o If CC is nonzero, the CSRC list (variable length)
- o If X is 1, the header extension (variable length)
- o Payload (variable length)
- o Padding, if present (variable length)

Note that if the payload lengths of the source packets are not equal, each shorter packet MUST be padded to the length of the longest packet by adding octet 0's at the end. Due to this possible padding and mandatory FEC header, a repair packet usually has a larger size than the source packets it protects. This may cause problems if the resulting repair packet size exceeds the Maximum Transmission Unit (MTU) size of the path over which the repair flow is sent.

By applying the parity operation on the bit strings produced from the source packets, we generate the FEC bit string. Some parts of the RTP header and the FEC header of the repair packet are generated from the FEC bit string as follows:

- o The first (most significant) bit in the FEC bit string is written into the Padding bit in the RTP header of the repair packet.
- o The next bit in the FEC bit string is written into the Extension bit in the RTP header of the repair packet.
- o The next 4 bits of the FEC bit string are written into the CC field in the RTP header of the repair packet.
- o The next bit of the FEC bit string is written into the Marker bit in the RTP header of the repair packet.
- o The next 7 bits of the FEC bit string are written into the PT recovery field in the FEC header.

- The next 32 bits of the FEC bit string are written into the TS recovery field in the FEC header.

- The next 16 bits are written into the Length recovery field in the FEC header. This allows the FEC procedure to be applied even when the lengths of the protected source packets are not identical.

- The remaining bits are set to be the payload of the repair packet.

The remaining parts of the FEC header are set as follows:

- The SN base low field MUST be set to the lowest sequence number, taking wrap around into account, of those source packets protected by this repair packet.

- The E bit MUST be set to 1 to extend the [RFC2733] FEC header.

- The Mask field SHALL be set to 0 and ignored by the receiver.

- The N bit SHALL be set to 0 and ignored by the receiver.

- The D bit SHALL be set to 0 and ignored by the receiver.

- The Type field MUST be set to 0.

- The Index field SHALL be set to 0 and ignored by the receiver.

- The Offset field MUST be set to the number of columns of the source block (L).

- The NA field MUST be set to the number of rows of the source block (D).

- The SN base ext field SHALL be set to 0 and ignored by the receiver.

6.3. Source Packet Reconstruction

This section describes the recovery procedures that are required to reconstruct the missing packets. The recovery process has two steps. In the first step, the FEC decoder determines which source and repair packets should be used in order to recover a missing packet. In the second step, the decoder recovers the missing packet, which consists of an RTP header and RTP payload.

In the following, we describe the RECOMMENDED algorithms for the first and second steps. Based on the implementation, different algorithms MAY be adopted. However, the end result MUST be identical

to the one produced by the algorithms described below.

6.3.1. Associating the Source and Repair Packets

The first step is to associate the source and repair packets. The SN base low field in the FEC header shows the lowest sequence number of the source packets that form the particular column. In addition, the information of how many source packets are available in each column and row is available from the media type parameters specified in the SDP description. This set of information uniquely identifies all of the source packets associated with a given repair packet.

Mathematically, for any received repair packet, p*, we can determine the sequence numbers of the source packets that are protected by this repair packet as follows:

p*_snb + i * L

where p*_snb denotes the value in the SN base low field of p*'s FEC header, L is the number of columns of the source block and

0 <= i < D

where D is the number of rows of the source block.

We denote the set of the source packets associated with repair packet p* by set T(p*). Note that in a source block whose size is L columns by D rows, set T includes D source packets. Recall that 1-D interleaved FEC protection can fully recover the missing information if there is only one source packet is missing in set T. If the repair packet that protects the source packets in set T is missing, or the repair packet is available but two or more source packets are missing, then missing source packets in set T cannot be recovered by 1-D interleaved FEC protection.

6.3.2. Recovering the RTP Header and Payload

For a given set T, the procedure for the recovery of the RTP header of the missing packet, whose sequence number is denoted by SEQNUM, is as follows:

1. For each of the source packets that are successfully received in set T, compute the bit string as described in Section 6.2.

2. For the repair packet associated with set T, compute the bit string in the same fashion except use the PT recovery field instead of the PT field and TS recovery field instead of the Timestamp field, and set the CSRC list, header extension and

padding to null regardless of the values of the CC field, X bit and P bit.

3. If any of the bit strings generated from the source packets are shorter than the bit string generated from the repair packet, pad them to be the same length as the bit string generated from the repair packet. For padding, the padding of octet 0 MUST be added at the end of the bit string.

4. Calculate the recovered bit string as the XOR of the bit strings generated from all source packets in set T and the FEC bit string generated from the repair packet associated with set T.

5. Create a new packet with the standard 12-byte RTP header and no payload.

6. Set the version of the new packet to 2.

7. Set the Padding bit in the new packet to the first bit in the recovered bit string.

8. Set the Extension bit in the new packet to the next bit in the recovered bit string.

9. Set the CC field to the next 4 bits in the recovered bit string.

10. Set the Marker bit in the new packet to the next bit in the recovered bit string.

11. Set the Payload type in the new packet to the next 7 bits in the recovered bit string.

12. Set the SN field in the new packet to SEQNUM.

13. Set the TS field in the new packet to the next 32 bits in the recovered bit string.

14. Take the next 16 bits of the recovered bit string and set Y to whatever unsigned integer this represents (assuming network-order). Take Y bytes from the recovered bit string and append them to the new packet. Y represents the length of the new packet in bytes minus 12 (for the fixed RTP header), i.e., the sum of the lengths of all the following if present: the CSRC list, header extension, RTP payload and RTP padding.

15. Set the SSRC of the new packet to the SSRC of the source RTP stream.

This procedure completely recovers both the header and payload of an RTP packet.

7. Session Description Protocol (SDP) Signaling

This section provides an SDP [RFC4566] example. The following example uses the FEC grouping semantics [RFC4756].

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.example.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=mid:S1
m=application 30000 RTP/AVP 110
c=IN IP4 224.1.2.1/127
a=rtpmap:110 1d-interleaved-parityfec/90000
a=fmtp:110 L:5; D:10; repair-window: 200000
a=mid:R1
```

8. Congestion Control Considerations

FEC is an effective approach to provide applications resiliency against packet losses. However, in networks where the congestion is a major contributor to the packet loss, the potential impacts of using FEC SHOULD be considered carefully before injecting the repair flows into the network. In particular, in bandwidth-limited networks, FEC repair flows may consume most or all of the available bandwidth and consequently may congest the network. In such cases, the applications MUST NOT arbitrarily increase the amount of FEC protection since doing so may lead to a congestion collapse. If desired, stronger FEC protection MAY be applied only after the source rate has been reduced.

In a network-friendly implementation, an application SHOULD NOT send/receive FEC repair flows if it knows that sending/receiving those FEC repair flows would not help at all in recovering the missing packets. Such a practice helps reduce the amount of wasted bandwidth. It is

RECOMMENDED that the amount of FEC protection is adjusted dynamically based on the packet loss rate observed by the applications.

In multicast scenarios, it may be difficult to optimize the FEC protection per receiver. If there is a large variation among the levels of FEC protection needed by different receivers, it is RECOMMENDED that the sender offers multiple repair flows with different levels of FEC protection and the receivers join the corresponding multicast sessions to receive the repair flow(s) that is best for them.

9. Security Considerations

TBC.

10. IANA Considerations

New media subtypes are subject to IANA registration. For the registration of the payload format and its parameters introduced in this document, refer to Section 5.

11. Acknowledgments

A major part of this document is borrowed from [RFC2733] and [SMPTE2022-1]. Thus, the author would like to thank the authors and editors of these earlier specifications. The author also thanks Colin Perkins for his constructive suggestions for this document.

12. Change Log

12.1. draft-ietf-fecframe-interleaved-fec-scheme-00

This is the initial version, which is based on an earlier individual submission. The following are the major changes compared to that document:

- Per the discussion in the WG, references to the FEC Framework have been removed and the document has been turned into a pure RTP payload format specification.

- A new section is added for congestion control considerations.

- Editorial changes to clarify a few points.

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