This document defines new RTP payload formats for the Forward Error Correction (FEC) that is generated by the non-interleaved and interleaved parity codes from a source media encapsulated in RTP. These parity codes are systematic codes, 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 non-interleaved and interleaved parity codes offer a good protection against random and bursty packet losses.
respectively, at a cost of decent complexity. The RTP payload
formats that are defined in this document address the scalability
issues experienced with the earlier specifications including RFC
2733, RFC 5109 and SMPTE 2022-1, and offer several improvements. Due
to these changes, the new payload formats are not backward compatible
with the earlier specifications.

Table of Contents

1. Introduction ................................................. 4
   1.1. Use Cases for 1-D FEC Protection ...................... 6
   1.2. Use Cases for 2-D Parity FEC Protection ............... 8
   1.3. Overhead Computation .................................. 10
2. Requirements Notation ....................................... 10
3. Definitions, Notations and Abbreviations .................... 10
   3.1. Definitions ............................................. 10
   3.2. Notations ............................................... 11
   3.3. Abbreviations .......................................... 11
4. Packet Formats .............................................. 11
   4.1. Source Packets .......................................... 11
   4.2. Repair Packets ......................................... 12
5. Payload Format Parameters ................................... 14
   5.1. Media Type Registration ................................ 14
       5.1.1. Registration of audio/non-interleaved-parityfec .. 14
       5.1.2. Registration of video/non-interleaved-parityfec .. 16
       5.1.3. Registration of text/non-interleaved-parityfec ... 17
       5.1.4. Registration of application/non-interleaved-parityfec . 18
       5.1.5. Registration of audio/interleaved-parityfec ....... 19
       5.1.6. Registration of video/interleaved-parityfec ..... 20
       5.1.7. Registration of text/interleaved-parityfec ...... 21
       5.1.8. Registration of application/interleaved-parityfec .. 23
   5.2. Mapping to SDP Parameters ............................. 24
       5.2.1. Offer-Answer Model Considerations .................. 24
       5.2.2. Declarative Considerations .......................... 24
6. Protection and Recovery Procedures .......................... 24
   6.1. Overview ............................................... 25
   6.2. Repair Packet Construction ............................ 25
   6.3. Source Packet Reconstruction ........................... 26
       6.3.1. Associating the Source and Repair Packets ........ 26
       6.3.2. Recovering the RTP Header .......................... 27
       6.3.3. Recovering the RTP Payload ......................... 28
       6.3.4. Iterative Decoding Algorithm for the 2-D Parity
               FEC Protection .................................... 29
7. SDP Examples ............................................... 32
   7.1. Example SDP for 1-D Parity FEC Protection ............. 32
   7.2. Example SDP for 2-D Parity FEC Protection ............. 33
8. Congestion Control Considerations .......................... 34
9. Security Considerations ........................................ 34
10. IANA Considerations .......................................... 34
11. Acknowledgments .............................................. 35
12. Change Log .................................................... 35
   12.1. draft-ietf-fecframe-ld2d-parity-scheme-00 ................. 35
13. References ................................................... 35
   13.1. Normative References ................................... 35
   13.2. Informative References ................................ 35
Author’s Address ................................................. 36
Intellectual Property and Copyright Statements ................. 37
1. Introduction

This document defines new RTP payload formats for the FEC that is generated by the non-interleaved and interleaved parity codes from a source media encapsulated in RTP [RFC3550]. The type of the source media protected by these parity codes 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.

Both the non-interleaved and interleaved parity codes use 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 accommodate the receivers that do not support FEC (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.
In Figure 2, it is clear that the FEC packets have to be received by the receiver within a certain time to be useful in the FEC recovery process. In this document, we refer to the time that spans the source packets and the corresponding repair packets as the repair window. 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 depends on the source block size and the regime adopted for sending the repair packets.

Suppose that we have a group of D x L source packets that have sequence numbers starting from 1 running to D x L, and a repair packet is generated by applying the XOR operation to every L consecutive packets as sketched in Figure 3. This process is referred to as 1-D non-interleaved FEC protection. As a result of this process, D repair packets are generated, which we refer to as non-interleaved (or row) FEC packets.
Figure 3: Generating non-interleaved (row) FEC packets

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 4, 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.

Figure 4: Generating interleaved (column) FEC packets

1.1. Use Cases for 1-D FEC Protection

We generate one non-interleaved repair packet out of \( L \) consecutive source packets and one interleaved repair packet out of \( D \) non-consecutive source packets. Regardless of whether the repair packet is a non-interleaved or an interleaved one, it 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 non-interleaved FEC protection performs better when the source packets are randomly lost. However, if the packet losses occur in bursts, 1-D interleaved FEC protection performs better provided that \( L \) is chosen large enough, i.e., L-packet duration SHOULD NOT be shorter than the observed burst duration. The sender SHOULD monitor the occurrences of the loss events on the source packets and generate non-interleaved and interleaved FEC packets when the losses occur randomly and in bursts, respectively.

If the sender generates non-interleaved FEC packets and a burst loss hits the source packets, the repair operation fails. This is illustrated in Figure 5.

Figure 5: Example scenario where 1-D non-interleaved FEC protection fails 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 6. Note that it is possible that two burst losses may occur back-to-back, in which case interleaved FEC packets may still fail to recover the lost data.
1.2. Use Cases for 2-D Parity FEC Protection

In networks where the source packets are lost both randomly and in bursts, the sender may generate both non-interleaved and interleaved FEC packets. This type of FEC protection is known as 2-D parity FEC protection. At the expense of generating more FEC packets, thus increasing the FEC overhead, 2-D FEC provides a superior protection against mixed loss patterns. However, 2-D parity FEC protection is still not hitless and may fail to recover all of the lost source packets if a particular loss pattern hits the source packets. An example scenario is illustrated in Figure 7.

![Diagram showing an example scenario where 1-D interleaved FEC protection fails](image-url)
2-D parity FEC protection also fails when at least two rows are missing a source and the FEC packet and the missing source packets (in at least two rows) are aligned in the same column. An example loss pattern is sketched in Figure 8. Similarly, 2-D parity FEC protection cannot repair all missing source packets when at least two columns are missing a source and the FEC packet and the missing source packets (in at least two columns) are aligned in the same row.
1.3. 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.

Generally, repair packets are larger in size compared to the source packets. Also, not all the source packets are necessarily equal in size. However, if we assume that each repair packet carries an equal number of bytes carried by a source packet, we can compute the overhead for different FEC protection methods as follows:

- 1-D Non-interleaved FEC Protection: Overhead = 1/L
- 1-D Interleaved FEC Protection: Overhead = 1/D
- 2-D Parity FEC Protection: Overhead = 1/L + 1/D

where L and D are the number of columns and rows in the source block, respectively.

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.
Definition of Terms:

- **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.
- **ToP:** Type of protection.

### 3.3. Abbreviations

- **XOR:** Bitwise exclusive OR operation.
  - $0 \text{ XOR } 0 = 0$
  - $0 \text{ XOR } 1 = 1$
  - $1 \text{ XOR } 0 = 1$
  - $1 \text{ XOR } 1 = 0$

### 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 9.

\[
\begin{align*}
\text{+--------------------------+} \\
\text{| \hspace{1cm} IP Header \hspace{1cm}|} \\
\text{+--------------------------+} \\
\text{| \hspace{1cm} Transport Header \hspace{1cm}|} \\
\text{+--------------------------+} \\
\text{| \hspace{1cm} RTP Header \hspace{1cm}| \hspace{1cm}|} \\
\text{+--------------------------+} \\
\text{| \hspace{1cm} FEC Header \hspace{1cm}| \hspace{1cm}\backslash} \\
\text{+--------------------------+} \\
\text{| \hspace{1cm} Repair Symbols \hspace{1cm}| \hspace{1cm}\slash} \\
\text{+--------------------------+} \\
\text{> RTP Payload} \\
\end{align*}
\]

Figure 9: Format of repair packets

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

- **Marker (M) Bit:** This bit is not used for this payload type, and SHALL be set to 0.

- **Payload Type:** The (dynamic) payload type for the repair packets is determined through out-of-band means. Note that this document registers new payload formats 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, will discard the repair packet.

- **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. The initial value of the sequence number SHOULD be random (unpredictable) [RFC3550].

- **Timestamp (TS):** The timestamp SHALL be set to a time corresponding to the repair packet’s transmission time. Note that the timestamp value has no use in the actual FEC protection
process and is usually useful for jitter calculations.

- **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].

The FEC header is 12 octets (or 16 octets when the optional padding is used). The format of the FEC header is shown in Figure 10.

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|E|I|P|X|  CC   |M| PT recovery |            SN base            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          TS recovery                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        Length recovery        |            Padding            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Padding (optional)                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

**Figure 10: Format of the FEC header**

The FEC header consists of the following fields:

- **The E bit** is the extension flag reserved to indicate any future extension to this specification.

- **The I bit** is used to indicate the length of padding in the FEC header. The padding length SHOULD be selected based on the platform architecture and the impact of header length on the header processing performance.

- **The P, X, CC, M and PT recovery fields** are used to determine the corresponding fields of the recovered packets.

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

- **The TS recovery field** is used to determine the timestamp of the recovered packets.
The Length recovery field is used to determine the length of the recovered packets.

The Padding field is used to pad the FEC header to 12 bytes (integer multiples of 32 bits).

The second (optional) Padding field is used to pad the FEC header to 16 bytes (integer multiples of 64 bits).

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 ones specified in [RFC2733] and [RFC5109]) 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 similar to the one proposed in [SMPTE2022-1] is inherently more efficient. Yet, [SMPTE2022-1] carries the values of D and L in 8-bit fields. While this approach can support larger blocks compared to the mask-based approaches, 8-bit fields may still be limiting when a high-bitrate source flow (e.g., a flow carrying Ultra HD video) is to be protected or when network outages/lossy periods span more than 255 packets.

5. Payload Format Parameters

This section provides the media subtype registration for the non-interleaved and 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/non-interleaved-parityfec

Type name: audio

Subtype name: non-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.

o D: Number of rows of the source block. D is a positive integer.

o ToP: Type of the protection applied by the sender: 0 for 1-D interleaved FEC protection, 1 for 1-D non-interleaved FEC protection, and 2 for 2-D parity FEC protection. The ToP value of 3 is reserved for future uses.

o repair-window: The time that spans the source packets and the corresponding repair packets. 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/non-interleaved-parityfec

Type name: video

Subtype name: non-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.

- D: Number of rows of the source block. D is a positive integer.

- ToP: Type of the protection applied by the sender: 0 for 1-D interleaved FEC protection, 1 for 1-D non-interleaved FEC protection, and 2 for 2-D parity FEC protection. The ToP value of 3 is reserved for future uses.

- repair-window: The time that spans the source packets and the corresponding repair packets. 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.
5.1.3. Registration of text/non-interleaved-parityfec

Type name: text
Subtype name: non-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.

- **D**: Number of rows of the source block. D is a positive integer.

- **ToP**: Type of the protection applied by the sender: 0 for 1-D interleaved FEC protection, 1 for 1-D non-interleaved FEC protection, and 2 for 2-D parity FEC protection. The ToP value of 3 is reserved for future uses.

- **repair-window**: The time that spans the source packets and the corresponding repair packets. 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.
5.1.4. Registration of application/non-interleaved-parityfec

Type name: application

Subtype name: non-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.

- D: Number of rows of the source block. D is a positive integer.

- ToP: Type of the protection applied by the sender: 0 for 1-D interleaved FEC protection, 1 for 1-D non-interleaved FEC protection, and 2 for 2-D parity FEC protection. The ToP value of 3 is reserved for future uses.

- repair-window: The time that spans the source packets and the corresponding repair packets. 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.

5.1.5. Registration of audio/interleaved-parityfec

Type name: audio

Subtype name: 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.

- D: Number of rows of the source block. D is a positive integer.

- ToP: Type of the protection applied by the sender: 0 for 1-D interleaved FEC protection, 1 for 1-D non-interleaved FEC protection, and 2 for 2-D parity FEC protection. The ToP value of 3 is reserved for future uses.

- repair-window: The time that spans the source packets and the corresponding repair packets. 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.

5.1.6. Registration of video/interleaved-parityfec

Type name: video

Subtype name: 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.

- D: Number of rows of the source block. D is a positive integer.
ToP: Type of the protection applied by the sender: 0 for 1-D interleaved FEC protection, 1 for 1-D non-interleaved FEC protection, and 2 for 2-D parity FEC protection. The ToP value of 3 is reserved for future uses.

repair-window: The time that spans the source packets and the corresponding repair packets. 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.

5.1.7. Registration of text/interleaved-parityfec

Type name: text

Subtype name: 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.

- **D**: Number of rows of the source block. D is a positive integer.

- **ToP**: Type of the protection applied by the sender: 0 for 1-D interleaved FEC protection, 1 for 1-D non-interleaved FEC protection, and 2 for 2-D parity FEC protection. The ToP value of 3 is reserved for future uses.

- **repair-window**: The time that spans the source packets and the corresponding repair packets. 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.
5.1.8. Registration of application/interleaved-parityfec

Type name: application

Subtype name: 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.

- D: Number of rows of the source block. D is a positive integer.

- ToP: Type of the protection applied by the sender: 0 for 1-D interleaved FEC protection, 1 for 1-D non-interleaved FEC protection, and 2 for 2-D parity FEC protection. The ToP value of 3 is reserved for future uses.

- repair-window: The time that spans the source packets and the corresponding repair packets. 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.
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 subtypes registered by this document. 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 "non-interleaved-parityfec" and "interleaved-parityfec" and their parameters in SDP is as follows:

- The media type (e.g., "application") goes into the "m=" line as the media name.
- The media subtype 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 and 2-D
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 12 octets (or 16 octets when the optional padding is used). 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:

- The first 64 bits of the RTP header (64 bits).
- 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, extension header, RTP payload and RTP padding (16 bits).

By applying the parity operation on the bit strings produced from the source packets, we generate the FEC bit string. The FEC header is generated from the FEC bit string as follows:

- The first (most significant) 2 bits in the FEC bit string are skipped. The E bit in the FEC header is set to 0. The I bit in the FEC header is set to 0 if only 2-byte padding is used, or to 1 if 6-byte padding is used.
- The next bit in the FEC bit string is written into the P recovery bit in the FEC header.
- The next bit in the FEC bit string is written into the X recovery bit in the FEC header.
- The next 4 bits of the FEC bit string are written into the CC recovery field in the FEC header.
The next bit is written into the M recovery bit in the FEC header.

The next 7 bits of the FEC bit string are written into the PT recovery field in the FEC header.

The next 16 bits are skipped.

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.

The 2-byte padding field of the FEC header SHALL be set to 0.

If the I bit is set to 1, indicating that 6-byte padding is used, four more bytes SHALL be added to the FEC header and these bytes SHALL be set to 0.

As described in Section 4.2, the SN base field of the FEC header MUST be set to the lowest sequence number of the source packets protected by this repair packet. For the interleaved FEC packets, this corresponds to the lowest sequence number of the source packets that form the column. For the non-interleaved FEC packets, the SN base field MUST be set to the lowest sequence number of the source packets that form the row.

The repair packet payload consists of the bits that are generated by applying the XOR operation on the payloads of the source RTP packets. 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.

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.

Note that the same algorithms are used by the 1-D parity codes, regardless of whether the FEC protection is applied over a column or a row. The 2-D parity codes, on the other hand, usually require multiple iterations of the procedures described here. This iterative decoding algorithm is further explained in Section 6.3.4.

### 6.3.1. Associating the Source and Repair Packets

The first step is associating the source and repair packets. By virtue of the payload type field in the RTP header, each repair packet is indicated whether it is an interleaved or non-interleaved FEC packet. In addition, the SN base field in the FEC header shows the lowest sequence number of the source packets that form the particular column or row. Finally, the information of how many source packets are included in each column or 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:

\[
p*_\text{snb} + i \times X_1
\]

where \( p*_\text{snb} \) denotes the value in the SN base field of p*’s FEC header, \( X_1 \) is set to \( L \) and 1 for the interleaved and non-interleaved FEC packets, respectively, and

\[
0 \leq i < X_2
\]

where \( X_2 \) is set to \( D \) and \( L \) for the interleaved and non-interleaved FEC packets, respectively.

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 plus one repair packet for the FEC protection applied over a column, and \( L \) source packets plus one repair packet for the FEC protection applied over a row. Recall that 1-D interleaved and non-interleaved FEC protection can fully recover the missing information if there is only source packet is missing in set \( T \). If there are more than one source packets missing in set \( T \), 1-D FEC protection will not work.
6.3.2. Recovering the RTP Header

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 T, compute the 80-bit string by concatenating the first 64 bits of their RTP header and the unsigned network-ordered 16-bit representation of their length in bytes minus 12.

2. For the repair packet in T, compute the FEC bit string from the first 80 bits of the FEC header.

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

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

5. Set the version of the new packet to 2. Skip the first 2 bits in the recovered bit string.

6. Set the Padding bit in the new packet to the next bit in the recovered bit string.

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

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

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

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

11. Set the SN field in the new packet to SEQNUM. Skip the next 16 bits in the recovered bit string.

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

13. Take the next 16 bits of the recovered bit string and set Y to whatever unsigned integer this represents (assuming network-order). Y represents the length of the new packet in bytes minus 12 (for the fixed RTP header), i.e., the sum of the
6.3.3. Recovering the RTP Payload

Following the recovery of the RTP header, the procedure for the recovery of the RTP payload is as follows:

1. Append Y bytes to the new packet.

2. For each of the source packets that are successfully received in T, compute the bit string from the Y octets of data starting with the 13th octet of the packet. If any of the bit strings generated from the source packets has a length shorter than Y, pad them to that length. The padding of octet 0 MUST be added at the end of the bit string. Note that the information of the first 8 octets are protected by the FEC header.

3. For the repair packet in T, compute the FEC bit string from the repair packet payload, i.e., the Y octets of data following the FEC header. Note that the FEC header may be 12 octets or 16 octets depending on whether the optional padding is used or not.

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

5. Append the recovered bit string (Y octets) to the new packet generated in Section 6.3.2.

6.3.4. Iterative Decoding Algorithm for the 2-D Parity FEC Protection

In 2-D parity FEC protection, the sender generates both non-interleaved and interleaved FEC packets to combat with the mixed loss patterns (random and bursty). At the receiver side, these FEC packets are used iteratively to overcome the shortcomings of the 1-D non-interleaved/interleaved FEC protection and improve the chances of full error recovery.

The iterative decoding algorithm runs as follows:
1. Set num_recovered_until_this_iteration to zero

2. Set num_recovered_so_far to zero

3. Recover as many source packets as possible by using the non-interleaved FEC packets as outlined in Section 6.3.2 and Section 6.3.3, and increase the value of num_recovered_so_far by the number of recovered source packets.

4. Recover as many source packets as possible by using the interleaved FEC packets as outlined in Section 6.3.2 and Section 6.3.3, and increase the value of num_recovered_so_far by the number of recovered source packets.

5. If num_recovered_so_far > num_recovered_until_this_iteration
   ---num_recovered_until_this_iteration = num_recovered_so_far
   ---Go to step 3
Else
   ---Terminate

The algorithm terminates either when all missing source packets are fully recovered or when there are still remaining missing source packets but the FEC packets are not able to recover any more source packets. For the example scenarios when the 2-D parity FEC protection fails full recovery, refer to Section 1.2. Upon termination, variable num_recovered_so_far has a value equal to the total number of recovered source packets.

Example:

Suppose that the receiver experienced the loss pattern sketched in Figure 13.
The receiver executes the iterative decoding algorithm and recovers source packets #1 and #11 in the first iteration. The resulting pattern is sketched in Figure 14.

```
+---+         +---+  +---+  +---+ 
| 1 |    X    | 3 | 4 | R_1 | 
+---+         +---+  +---+  +---+ 
| 5 | 6 | 7 | 8 | R_2 | 
+---+         +---+  +---+  +---+ 
| 9 | X X | 12 | R_3 | 
+---+         +---+  +---+  +---+ 
| C_1 | C_2 | C_3 | C_4 | 
+---+         +---+  +---+  +---+ 
```

Figure 14: The resulting pattern after the first iteration

Since the if condition holds true, the receiver runs a new iteration. In the second iteration, source packets #2 and #10 are recovered, resulting in a full recovery as sketched in Figure 15.
7. SDP Examples

This section provides two SDP [RFC4566] examples. The examples use the FEC grouping semantics defined in [RFC4756].

Editor’s note: MMUSIC WG is currently working on new grouping semantics (See [I-D.begen-mmusic-fec-grouping-issues] for details). The examples provided here can be updated once and if new semantics are introduced.

7.1. Example SDP for 1-D Parity FEC Protection

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.
### 7.2. Example SDP for 2-D Parity FEC Protection

In this example, we have one source video stream (mid:S1) and two FEC repair streams (mid:R1 and mid:R2). We form one FEC group with the "a=group:FEC S1 R1 R2" 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 1222334455 1222334466 IN IP4 fec.example.com
s=2-D Parity FEC Example
t=0 0
a=group:FEC S1 R1 R2
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 interleaved-parityfec/90000
a=fmtp:110 L:5; D:10; ToP:0; repair-window: 200000
a=mid:R1
```

```c=IN IP4 224.1.1.2/127
a=rtpmap:110 interleaved-parityfec/90000
a=fmtp:110 L:5; D:10; ToP:2; repair-window: 200000
a=mid:R2
```

Note that the sender might be generating two repair flows carrying non-interleaved and interleaved FEC packets, however the receiver might be interested only in the interleaved FEC packets. The receiver can identify the repair flow carrying the desired repair data by checking the payload types associated with each repair flow.
described in the SDP description.

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.

Editor’s note: Additional congestion control considerations regarding the use of 2-D parity codes should be added here.

9. Security Considerations

TBC.

10. IANA Considerations

New media subtypes are subject to IANA registration. For the registration of the payload formats and their parameters introduced in this document, refer to Section 5.
11. Acknowledgments

A major part of this document is borrowed from [RFC5109]. Thus, the author would like to thank the editor of [RFC5109] and those who contributed to [RFC5109].

The author would also like to thank the FEC Framework Design Team for their inputs, suggestions and contributions.

12. Change Log

12.1. draft-ietf-fecframe-1d2d-parity-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:

- The timestamp field definition has changed.

13. References

13.1. Normative References


13.2. Informative References


[ SMPTE2022-1 ]


Author’s Address

Ali Begen
Cisco Systems
170 West Tasman Drive
San Jose, CA  95134
USA

Email:  abegen@cisco.com
Full Copyright Statement

Copyright (C) The IETF Trust (2008).

This document is subject to the rights, licenses and restrictions contained in BCP 78, and except as set forth therein, the authors retain all their rights.

This document and the information contained herein are provided on an "AS IS" basis and THE CONTRIBUTOR, THE ORGANIZATION HE/SHE REPRESENTS OR IS SPONSORED BY (IF ANY), THE INTERNET SOCIETY, THE IETF TRUST AND THE INTERNET ENGINEERING TASK FORCE DISCLAIM ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO ANY WARRANTY THAT THE USE OF THE INFORMATION HEREIN WILL NOT INFRINGE ANY RIGHTS OR ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

Intellectual Property

The IETF takes no position regarding the validity or scope of any Intellectual Property Rights or other rights that might be claimed to pertain to the implementation or use of the technology described in this document or the extent to which any license under such rights might or might not be available; nor does it represent that it has made any independent effort to identify any such rights. Information on the procedures with respect to rights in RFC documents can be found in BCP 78 and BCP 79.

Copies of IPR disclosures made to the IETF Secretariat and any assurances of licenses to be made available, or the result of an attempt made to obtain a general license or permission for the use of such proprietary rights by implementers or users of this specification can be obtained from the IETF on-line IPR repository at http://www.ietf.org/ipr.

The IETF invites any interested party to bring to its attention any copyrights, patents or patent applications, or other proprietary rights that may cover technology that may be required to implement this standard. Please address the information to the IETF at ietf-ipr@ietf.org.

Acknowledgment

Funding for the RFC Editor function is provided by the IETF Administrative Support Activity (IASA).