SMPTE 2022-1-2007

# SMPTE STANDARD

# Forward Error Correction for Real-Time Video/Audio Transport Over IP Networks



## Table of Contents

Page




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## Foreword

SMPTE (the Society of Motion Picture and Television Engineers) is an internationally-recognized standards developing organization. Headquartered and incorporated in the United States of America, SMPTE has members in over 80 countries on six continents. SMPTE's Engineering Documents, including Standards, Recommended Practices and Engineering Guidelines, are prepared by SMPTE's Technology Committees. Participation in these Committees is open to all with a bona fide interest in their work. SMPTE cooperates closely with other standards-developing organizations, including ISO, IEC and ITU.

SMPTE Engineering Documents are drafted in accordance with the rules given in Part XIII of its Administrative Practices.

SMPTE 2022-1 was prepared by Technology Committee N26 on File Management and Networking Techology.

## Introduction

This section is entirely informative and does not form an integral part of this document.

IP-based networks have become increasingly important for delivery of compressed content as MPEG-2 Transport Streams. However, existing transport protocols do not fully meet the user requirements, especially for a standardized forward error correction technique required for interoperability between different manufacturers. This standard defines a forward error correction technique to be used to correct for errors induced when video/audio payloads are transported over IP networks.

This document defines a structured mechanism for FEC. Nothing in this standard defines when this FEC mechanism should be used. It is up to the implementer to determine whether FEC is required over the IP network in use, and whether the mechanism presented here meets their application requirements.

This standard is intended for real-time audio/video applications such as contribution, distribution, and "e-cinema". The applications addressed by this standard may employ any transport scheme that is supported by the video/audio transport Standards. This standard defines two levels of FEC – Level A and Level B. Level A uses one FEC stream and Level B uses two FEC streams.

## 1 Scope

This standard defines a forward error correction technique for the carriage of real-time Video/Audio content over IP networks.

## 2 Conformance Notation

Normative text is text that describes elements of the design that are indispensable or contains the conformance language keywords: "shall", "should", or "may". Informative text is text that is potentially helpful to the user, but not indispensable, and can be removed, changed, or added editorially without affecting interoperability. Informative text does not contain any conformance keywords.

All text in this document is, by default, normative, except: the Introduction, any section explicitly labeled as "Informative" or individual paragraphs that start with "Note:"

The keywords "shall" and "shall not" indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

The keywords, "should" and "should not" indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.

The keywords "may" and "need not" indicate courses of action permissible within the limits of the document.

The keyword "reserved" indicates a provision that is not defined at this time, shall not be used, and may be defined in the future. The keyword "forbidden" indicates "reserved" and in addition indicates that the provision will never be defined in the future.

## 3 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this recommended practice. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this recommended practice are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below.

IETF RFC 3550, RTP: A Transport Protocol for Real-Time Applications

IETF RFC 2733, An RTP Payload Format for Generic Forward Error Correction

IETF RFC 4340, Datagram Congestion Control Protocol (DCCP)

## 4 Acronyms (Informative)

**ASI:** Asynchronous Serial Interface

**CSRC:** Contributing Sources List

**FEC:** Forward Error Correction

**IANA:** Internet Assigned Numbers Authority

**IP:** Internet Protocol

**RTCP:** Real Time Control Protocol

**RTP:** Real Time Protocol

**SDI:** Serial Digital Interface

**SDTI:** Serial Digital Transport Interface

**SNbase:** Base RTP Sequence Number

**SSRC:** Synchronization Source List

**TS:** Timestamp

**UDP:** User Datagram Protocol

**XOR:** Exclusive OR

# 5 Definitions

## 5.1 Traffic Shaping

The process of reducing peak variations in instantaneous bit rate so as to produce a more constant data flow.

## 5.2 XOR

The term XOR is an acronym for exclusive-OR, a Boolean operation.

## 5.3 Latency

Latency is the time for data to become available for a subsequent process.

## 5.4 Delay

Delay is time consumed by all sources such as processing delay, accumulation and de-accumulation delay, FEC processing delay, IP transfer delay, IP delay variation buffering and FEC latency delay.

# 6 Background (Informative)

In many applications, errors are generally not acceptable; therefore support for some sort of FEC scheme may be required. The use of FEC as defined in this Standard is recommended, but there are applications where occasional errors are preferable to the overhead of the FEC, so manufacturers may support a non-FEC mode.

On IP networks, packet losses typically come from three sources – gross reordering, bit-error induced packet drops and burst losses/drops. For any FEC scheme to operate properly, the error from these sources needs to be low enough so that the FEC scheme can correct these errors to meet the application requirements. Implementers should be aware of limitations of any FEC scheme and take steps to ensure that application of this Standard will meet their objectives, given uncorrected link performance.

Because, when using the protocols in this Standard, the entire packet will be discarded if there is even a single bit error, there is no requirement for an error correction scheme that can handle packets containing errors – every packet will either arrive correctly or not at all.

An RTP payload format for Generic Forward Error Correction Packets has been defined in the RFC 2733 to enable error correction of real time media. RFC2733 allows the use of traditional error correcting codes. A major advantage of this scheme is that it can be used with any standardized video/audio transport (ASI, SDI, SDTI,…) as long as it is encapsulated in an RTP packet. However, RFC2733 limits the scope of packets used to generate the Forward Error Correction payload, to 24 consecutive packets.

To recover burst loss, an extension to the existing RFC is proposed. The same traditional error correcting codes are applied to non-consecutive media packets that can be spaced over more than 24 packets. Each FEC packet is associated to packets periodically selected. Therefore, consecutive RTP packets can be recovered from consecutive FEC packets.

# 7 Encapsulation Scheme

This clause defines the limitations on construction of the media packets which will be protected by the FEC scheme.

## 7.1 RTP/UDP/IP Layer

The use of RTP shall be required, as it provides a standard header for the packets.

Equipment shall only use RTP as specified in RFC 3550 and consequently shall not require the use of any additional communication.

The following additional constraints on RFC3550 shall apply:

The usage, by senders and receivers, of the following bits shall be defined by the associated video/audio transport standards:

The Padding (P) bit

The Marker (M) bit

The Extension (X) bit, with the additional constraint that the extension bit and the length of the extension shall be constant for the duration of the session.

The following parameters shall be set by the sender as indicated:

The CSRC count (CC) field shall be set to zero. This means there are no entries in the CSRC (Contributing SouRCes list).

The value of the SSRC field shall not be relied upon at the receiver; the transmitter is free to assign this to any value.

There is no requirement for the initial sequence number to be randomly assigned, as suggested in RFC3550.

# 8 FEC Scheme

## 8.1 FEC Packet Arrangement

The FEC scheme constitutes an extended version of RFC2733. Each FEC packet is associated with media packets periodically selected. Therefore, consecutive media packets can be recovered from consecutive FEC packets. The process is detailed in Figure 1. In this Standard, L shall designate the number of columns of protected packets and D shall designate the number of rows.

The main advantage of this scheme over RFC2733 is the burst error correction capacity. The error correcting function chosen is XOR which has the ability to recover any one lost packet. If a one dimensional scheme based on XOR is used (i.e. applied to D consecutive packets), a burst error of two or more lost packets is not recoverable. However, if the two dimensional scheme is used, the recoverability is greatly improved, since it can recover up to L consecutive packets.

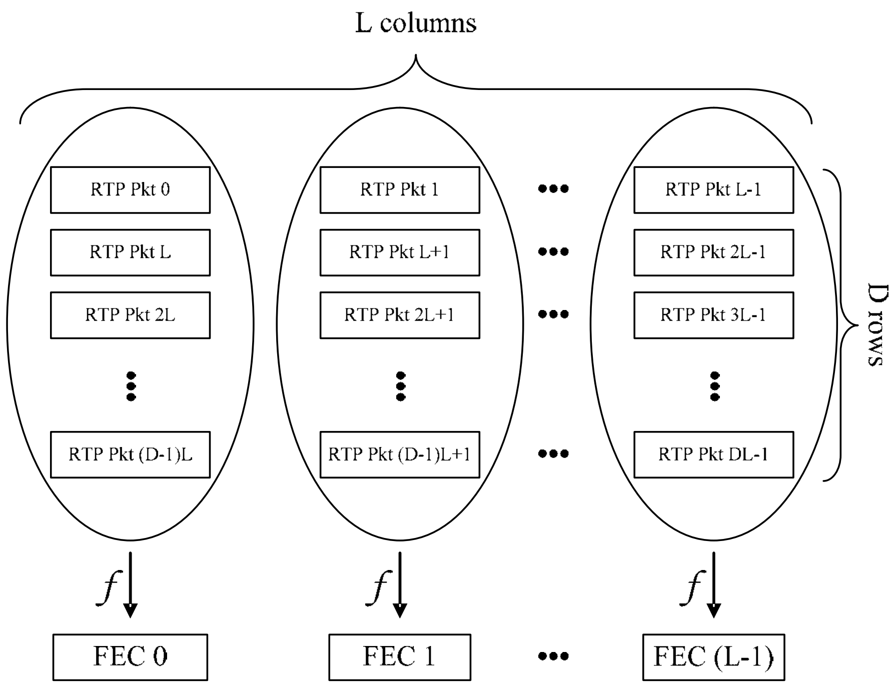


**Figure 1 – Encoding scheme**

In Figure 1, the encoding scheme is schematized for *L*D* media packets. The period chosen between media packets covered by a given FEC packet is *L*. Thus the payload of the $k^{th}$ FEC packet is computed based on the D packets numbered $nL+k$ ($0 \leq n \leq D - 1$).

The alignment of the columns is for illustration. Implementations may use this alignment for simplicity, but there are some advantages to be gained by offsetting the columns - see Annex B. This means that receiving devices shall not make any assumptions about the relationship between FEC packets beyond those that are explicitly specified.

This standard defines two levels of FEC protection – Level A and Level B. Level A devices shall support one FEC stream. Level B devices shall support two simultaneous FEC streams. These FEC streams shall be carried on separate UDP ports to allow them to have separate sequence number handling, and to maintain backward compatibility with implementations that only support a single FEC stream.

For senders emitting one FEC stream, media packets shall be sent to destination port N (where N is an even integer per RFC 3550), and the single stream of FEC packets shall be sent to destination port N+2. For senders emitting two FEC streams, the first FEC stream shall be sent to destination port N+2 and the second FEC stream shall be sent to destination port N+4. The FEC function on a sending device shall be capable of being enabled or disabled.

Level A receivers shall process zero or one FEC streams. Level A receivers shall be able to continue to function nominally in the presence of two FEC streams. Level B receivers shall be able to process zero, one or two FEC streams.

The second FEC stream shall be applied to a run of consecutive packets the length of the L parameter of the first stream. If the columns are aligned this will produce an FEC structure as shown in Figure 2, where the packets labeled RTP are the media packets, the packets labeled FEC are the first FEC stream packets, and the packets labeled FEC’ are the second FEC stream packets.

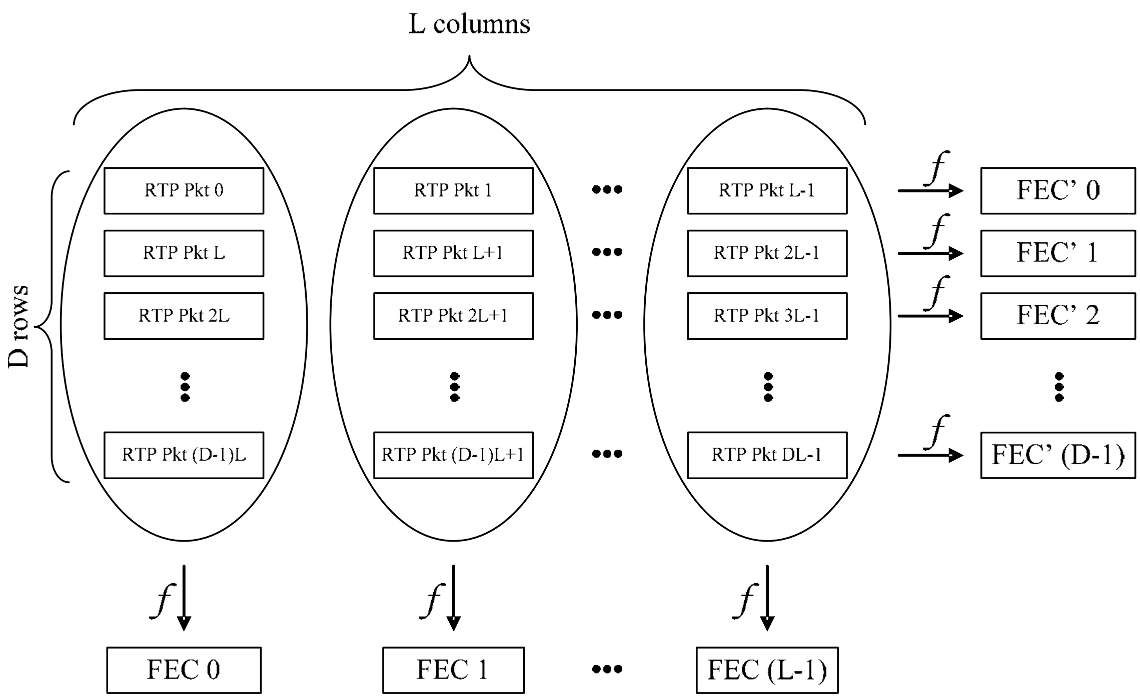


**Figure 2 – Dual FEC mode structure**

The second FEC stream can cope with any single packet loss, and the first FEC stream can cope with burst losses up to ‘L’ in length.

### 8.2 FEC Buffer Overhead and Latency Implications

To promote interoperability and simplify implementation, limits shall be specified for values of the L and D parameters. These limits are media type specific and are defined in the appropriate media document. Devices shall support all combinations of values of L and D that comply with all limits. Devices may extend beyond these values if desired. A device shall only support two FEC streams in the case where $L \geq 4$.

NOTES

1 For MPEG-2 Transport streams these limits are defined in SMPTE 2022-2.

2 Given the FEC header format defined in this document (§ 7.4), L and D values are limited to 255.

### 8.3 FEC Packet RTP Header Format

RFC2733 places constraints on the values of the fields in the RTP header. It specifies that the P, X, M, and CC fields are computed from the media packets, but because of the restrictions in § 6.1 the values of these fields are as defined in this Standard.

As there is no simple mechanism available for resolving a dynamic payload type, and the only RTP traffic being sent and received by units corresponding to this Standard would logically be the FEC data and the media data, the FEC data shall be sent using the first available dynamic payload type number, which is 96 decimal.

The following additional restrictions shall be applied:

The sender shall set the SSRC field to zero to be compliant with this document. Other values of SSRC are reserved. The value of the SSRC field shall be used by the receiver.

There is no requirement for the initial sequence number to be randomly assigned, as suggested in RFC3550.

The time stamp field on FEC packets shall be ignored by the receiver.

### 8.4 FEC Header Format

The FEC header described in the RFC 2733 is originally 12 bytes. To allow for the extension to the error correction scheme, the FEC header shall be defined as detailed in the text below.

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       SNBase low bits         |        Length Recovery        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|E| PT recovery |                    Mask                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          TS recovery                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|N|D|type |index|    Offset     |      NA       |SNBase ext bits|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

**Figure 3 – Definition of the FEC header**

The following fields shall be used as defined in RFC2733:

SNBase low bits: Minimum sequence number of the packets associated to the FEC packet, and where 16 bit sequence numbers are sufficient, this parameter shall contain the entire sequence number. For transport protocols with longer sequence numbers this field shall contain the least significant 16 bits of the sequence number.

Length Recovery: This field should be used to determine the length of any media packets associated with the FEC packet.

PT recovery: This field should be used to determine the Payload Type of any media packets associated with the FEC packet.

TS Recovery: This field should be used to recover the timestamp of any media packets associated with the FEC packet.

The additional fields below shall be modified from RFC2733, or are new. The definition of these is:

E: This shall be set to ‘1’ to indicate that the header is extended.

Mask: The mask field shall be set to zero for implementations supporting this Standard, and the NA field shall be used instead.

N: This bit is reserved for future header extensions and shall be set to zero.

D: This bit shall be set to 0 for FEC packets from the first FEC stream, and set to 1 for FEC packets from the second FEC stream.

NOTE – This bit is provided as an additional means of determining which FEC packets are associated with which FEC stream.

Type: This field indicates which error-correcting code is chosen and shall be set to zero. Receivers shall ignore packets with an unrecognized type value.

Index: This field is used for more complex error protection codes and shall be set to zero.

NOTE – For the XOR method, only one FEC packet protects each group of media packets and hence the index field will always contain 0.

Offset: This 1-byte field is the period used to select the media packets associated with this FEC packet, and shall be the L parameter as defined in § 7.1 for packets computed over columns (the first FEC stream). For packets computed over rows (the second FEC stream) this parameter shall always be one. This field shall be kept constant by the sender during a transmission for each FEC stream.

NA: This 1-byte field indicates the number of media packets associated with this FEC packet, and shall be the D parameter as defined in § 7.1 for packets belonging to the first FEC stream, and shall correspond to the L parameter as defined in § 7.1 for packets belonging to the second FEC stream. This field shall be kept constant by the sender during a transmission for each FEC stream.

SNBase ext bits: This field is for use with protocols which require extended sequence numbers longer than 16 bits. Where 16 bit sequence numbers are sufficient, this parameter shall be set to zero. For protocols with longer sequence numbers this field shall contain the next eight most significant bits of the sequence number beyond those contained in the SNBase.

The media packets protected by any given FEC packet shall be defined as those with sequence numbers given by the formula:

$$SNBase + j \times Offset$$
$$0 \le j < NA$$

## 8.5 FEC Traffic Shaping Issues

Senders should ensure that FEC packets are interleaved with data packets in a way that avoids large changes in sending rate over time. The following constraints shall be applied in order to shape the output IP stream of the FEC system:

The row FEC packets shall be sent a minimum of 0 and a maximum of $L$ packets after the last media packet protected.

Column FEC packets shall be sent a minimum of $L$ packets after the last media packet protected, to ensure that the burst loss tolerance of the system is not compromised.

Column FEC packets shall be sent a maximum of $L \times D$ packets after the last media packet protected, to constrain the level of buffering required at the receiver.

Example schemes which comply with these constraints and which intrinsically resolve traffic shaping issues are presented in Annexes B and C. These are examples only – any interleaving scheme which meets the requirements above shall be permitted by this standard.  There are a wide variety of valid methods for organizing the data packets to create the column FEC stream, which meet the normative requirements of this standard.

It should be noted that in every case, each individual FEC packet indicates the base sequence number (SN-base), the offset (L) and a number of data packets (NA). Receivers shall observe these transmitted values in each FEC packet to correctly associate the FEC packet with the original data-stream packets.

### 8.6 Reorder Tolerance (Informative)

Packets traveling over IP networks are not guaranteed to arrive in the order sent. Sequence numbering is provided by RTP, which allows the receiving end equipment to correct for this effect. Any re-ordering that is present is likely to be of a small order, less than 10 packets out of sequence.

If a packet is grossly out of order then it can be discarded, and will be corrected by the FEC scheme as if it were a lost packet. If a system holds multiple FEC matrices then it can tolerate re-ordering within this group of matrices.

Receiving end equipment should re-order packets within a minimum of 10 packets before applying FEC.

## 9 System Configuration

The following parameters list shall be the required minimum configurable system parameters:

Senders and receivers shall support all port numbers from the registered port range, and the Dynamic and/or private ports range as identified in the IANA Ports Registry.

The FEC stream shall use the same IP destination address (either unicast or multicast) as the associated data stream.

The FEC stream shall use the same UDP source port as the associated data stream.

## Annex A (Informative)
## Bibliography

IETF Standard 6, User Datagram Protocol

SMPTE 2022-2-2007, Unidirectional Transport of Constant Bit Rate MPEG-2 Transport Streams on IP Networks

IANA Ports Registry http://www.iana.org/assignments/port-numbers

## Annex B (Informative)
## Non-Block Aligned FEC Arrangement

Readers are cautioned that this is an example only – any interleaving scheme which meets the requirements in this standard shall be permitted. There are a wide variety of valid methods for organizing the data packets to create the column FEC stream, which meet the normative requirements of this standard.

Figure B.1 shows an example alternative arrangement for the case of (L=4, D=5). In this example, the FEC packet F0 protects data packets [0,4,8,12,16] while FEC packet F5 protects data packets [5,9,13,17,21].

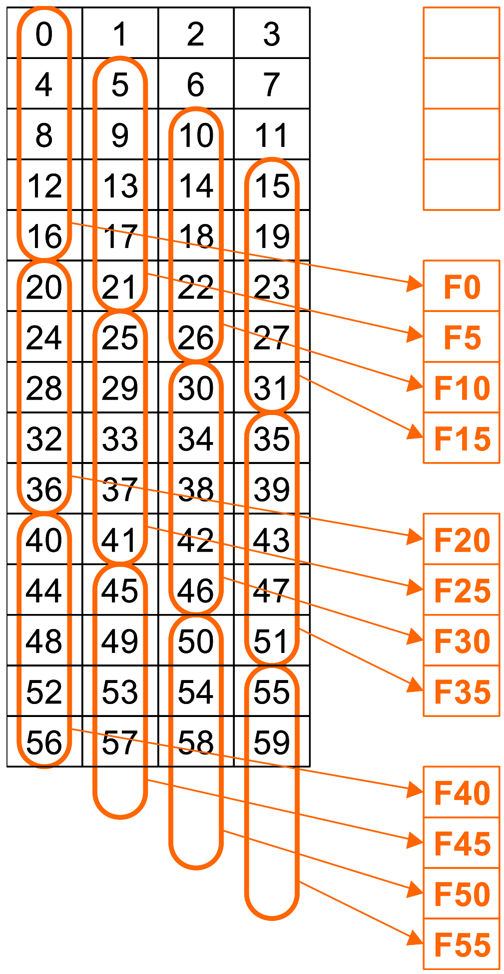


**Figure B.1 – Alternative FEC arrangement**

Each FEC packet is transmitted L packet times after the last data packet it pertains to, creating a highly time-linear packet flow on the FEC stream.

It should be noted that in every case, each individual column-FEC packet indicates the base sequence number (SN-base), the offset (L) and a number of data packets (NA). Receivers should observe these transmitted values in each FEC packet to correctly associate the FEC packet with the original data-stream packets.

## Annex C (Informative)
## Block Alignment FEC Arrangement

Readers are cautioned that this is an example only – any interleaving scheme which meets the requirements in this standard shall be permitted. There are a wide variety of valid methods for organizing the data packets to create the column FEC stream, which meet the normative requirements of this standard.

It should be noted that in every case, each individual column-FEC packet indicates the base sequence number (SN-base), the offset (L) and a number of data packets (NA). Receivers should observe these transmitted values in each FEC packet to correctly associate the FEC packet with the original data-stream packets.

The goal of this example arrangement is to allow the most linear use of the bandwidth by ensuring that FEC packets are regularly inserted among data packets of the next matrix. This arrangement means that the latency due to FEC is twice (L x D).

Column FEC packets are sent by using an interleaver. The depth of the interleaver is chosen to be D so as to make sure that the L column FEC packets will be regularly inserted among the L*D data packets of the next matrix. It is chosen to send the first column FEC at the “same time” as the first data packet of the next matrix so a receiver can easily detect it.

Figure C.1 illustrates such an arrangement with L=4 and D=5. FEC’n packet refers to the row FEC packet computed over row #n and FECn packet refers to the column FEC packet computed over column #n. Packets are sequenced in the reading direction (from left to right then from top to bottom).

Packets in the same cell are sent at the “same time” (by different ports and using different RTP sequences). Receivers should not depend on the packet ordering from the same cell of a matrix.

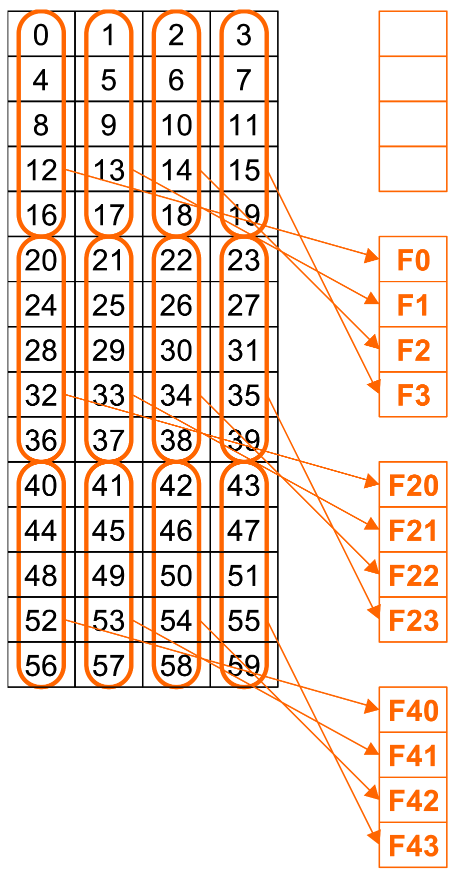


**Figure C.1 – Linearizing example for L = 4 and D = 5**

As a second example, Figure C.2 shows this arrangement for the case where L = 4 and D = 2.

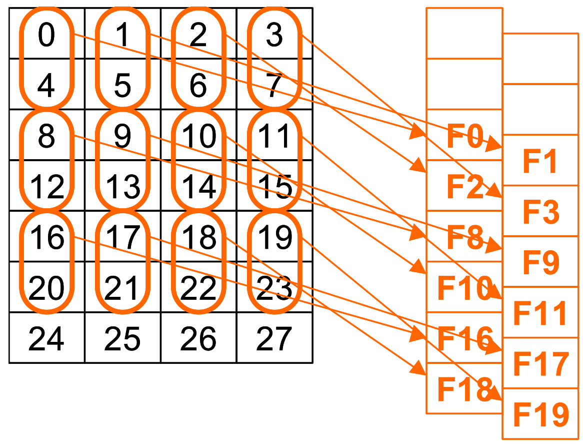


**Figure C.2 – Linearizing example for L = 4 and D = 2**

## Annex D (Informative)
## Delay

Delay within an IP adaptation unit is bounded by a combination of the jitter tolerance buffer, the FEC system latency, FEC processing delay (implementation depended) and the clock recovery mechanism (not covered by this Standard). The latency required for handling of jitter is independent of the FEC system and not included in the examples below. There are additional delays caused by the IP network transmission and encode/decode process if applicable.

A number of professional applications have demanding round-trip delay requirements. A round-trip delay of 400 ms is widely accepted as the worst that would be acceptable for live interview applications employing video and audio. Camera control by remote telemetry has been shown to require as low as 200 ms. Buffering requirements as part of the error-correction/protection mechanism make these difficult targets to attain for a system following this Standard.

The table that follows gives the latency that will be incurred by the FEC process for different bit rates and FEC configurations using various combinations of the 1D FEC code sending only column packets and non block aligned FEC arrangement, Annex B. In this case is the FEC latency LxD.

The FEC latency for the block aligned FEC arrangement, Annex C, is implementation dependent on the traffic shaping applied. A typical value may be derived by using the formula 2xLxD–D for both For 2D FEC code sending both column and row packets. In the case of the 2D code, it may be possible to recover multiple lost media packets by iterative FEC processing. Especially in the case of non block aligned FEC, packets belonging to previous blocks may be recoverable provided sufficient latency is configured. Note that the number of 2D recovery iterations possible may be limited by the size of the FEC latency buffer and this may limit the recovery capability of the code.

**Table D.1 – FEC latency Delay for 1 D codes for example MPEG-2 Transport Streams with non-block aligned FEC (Annex B). FEC Iterations limited to one block. The FEC processing delay is not included.**

| | FEC latency | | | |
|---|---|---|---|---|
| | 3 Mbps | 3 Mbps | 30 Mbps | 100 Mbps |
| TS Packets per IP Frame | 1 | 4 | 7 | 7 |
| XOR (L=5, D=10) | 25.1 ms | 100.3 ms | 17.5 ms | 5.3 ms |
| XOR (L=10, D=10) | 50.1 ms | 200.5 ms | 35.1 ms | 10.5 ms |
| XOR (L=20, D=5) | 50.1 ms | 200.5 ms | 35.1 ms | 10.5 ms |
| XOR (L=8, D=8) | 32.1 ms | 128.3 ms | 22.5 ms | 6.7 ms |
| XOR (L=10, D=5) | 25.1 ms | 100.3 ms | 17.5 ms | 5.3 ms |
| XOR (L=8, D=5) | 20.1 ms | 80.2 ms | 14.0 ms | 4.2 ms |
| XOR (L=5, D=5) | 12.5 ms | 50.1 ms | 8.8 ms | 2.6 ms |
| XOR (L=4, D=6) | 12.0 ms | 48.1 ms | 8.4 ms | 2.5 ms |
| XOR (L=6, D=4) | 12.0 ms | 48.1 ms | 8.4 ms | 2.5 ms |