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Information technology — High efficiency coding and media delivery in heterogeneous environments —

Part 10:
MPEG Media Transport Forward Error Correction (FEC) codes

Technologies de l'information — Codage à haute efficacité et livraison des medias dans des environnements hétérogènes —

Partie 10: Codes de correction d'erreur anticipée pour le transport des medias MPEG

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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The committee responsible for this document is ISO/IEC JTC 1, *Information technology*, SC 29, *Coding of audio, picture, multimedia and hypermedia information*.

ISO/IEC 23008 consists of the following parts, under the general title *Information technology — High efficiency coding and media delivery in heterogeneous environments*:

— *Part 1: MPEG media transport (MMT)*

— *Part 2: High efficiency video coding (HEVC)*

— *Part 3: 3D Audio*

— *Part 10: MPEG Media Transport Forward Error Correction (FEC) codes*

— *Part 11: MPEG Media Transport Composition Information*

Introduction

This part of ISO/IEC 23008 specifies application level forward error correction (FEC) codes which can be used with application level-forward error correction (AL-FEC) framework of ISO/IEC 23008-1 MPEG Media Transport (MMT) to provide reliable delivery in IP network and non IP network environments that are prone to packet losses.

Information technology — High efficiency coding and media delivery in heterogeneous environments —

Part 10:
MPEG Media Transport Forward Error Correction (FEC) codes

1 Scope

This part of ISO/IEC 23008 specifies application level forward error correction (FEC) codes which can be used with AL-FEC framework of ISO/IEC 23008-1 MPEG Media Transport to provide reliable delivery in IP network and non IP network environments that are prone to packet losses.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 23008-1, *Information technology — High efficiency coding and media delivery in heterogeneous environments — Part 1: MPEG media transport (MMT)*

IETF RFC 5170, *Low Density Parity Check (LDPC) Staircase and Triangle Forward Error Correction (FEC) Schemes, June 2008*

IETF RFC 5510, *Reed-Solomon Forward Error Correction (FEC) Schemes, April 2009*

IETF RFC 6330, *RaptorQ Forward Error Correction Scheme for Object Delivery, August 2011*

SMPTE2022-1, *Forward Error Correction for Real-Time Video/Audio Transport Over IP Networks*

3 Terms, definitions, symbols, and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

3.1 Terms and definitions

3.1.1
code rate
ratio between the number of source symbols and the number of encoding symbols

3.1.2
encoding symbol
unit of data generated by the encoding process

3.1.3
encoding symbol block
set of encoding symbols from the encoding process of a source symbol block

3.1.4
3FEC code
algorithm for encoding data such that the encoded data flow is resilient to data loss

3.1.5
FEC payload ID
identifier that identifies the contents of a MMT packet with respect to the MMT FEC scheme

3.1.6
repair symbol
encoding symbol that is not a source symbol

3.1.7
repair symbol block
set of repair symbols which can be used to recover lost source symbols

3.1.8
source symbol
unit of data used during the encoding process

3.1.9
source symbol block
set of source symbols which is used to generate repair symbol block by FEC code

3.1.10
systematic code
any error correction code in which the source symbols are part of output encoded symbols

3.2 Symbols and abbreviated terms

For the purpose of this document, the symbols and abbreviated terms given below apply.

AL-FEC	application layer (level) forward error correction
FEC	forward error correction
LA	layer aware
LA-FEC	layer aware forward error correction
LDGM	low density generator matrix
LDPC	low density parity check
MMT	MPEG media transport
RS	Reed-Solomon
S-LDPC	structured low density parity check

3.3 Conventions

The following conventions apply in this document:

- The Big Endian number representation scheme is used.

4 Overview

This part of ISO/IEC 23008 specifies application level forward error correction (FEC) codes. All codes specified in this part are systematic codes.

This specification defines six FEC code algorithms which each FEC code algorithm shall generate a repair symbol block from a source symbol block as shown in Figure 1. The source symbol block consists of K source symbols of size T (in bytes) and the repair symbol block consists of P repair symbols of size T (in bytes).

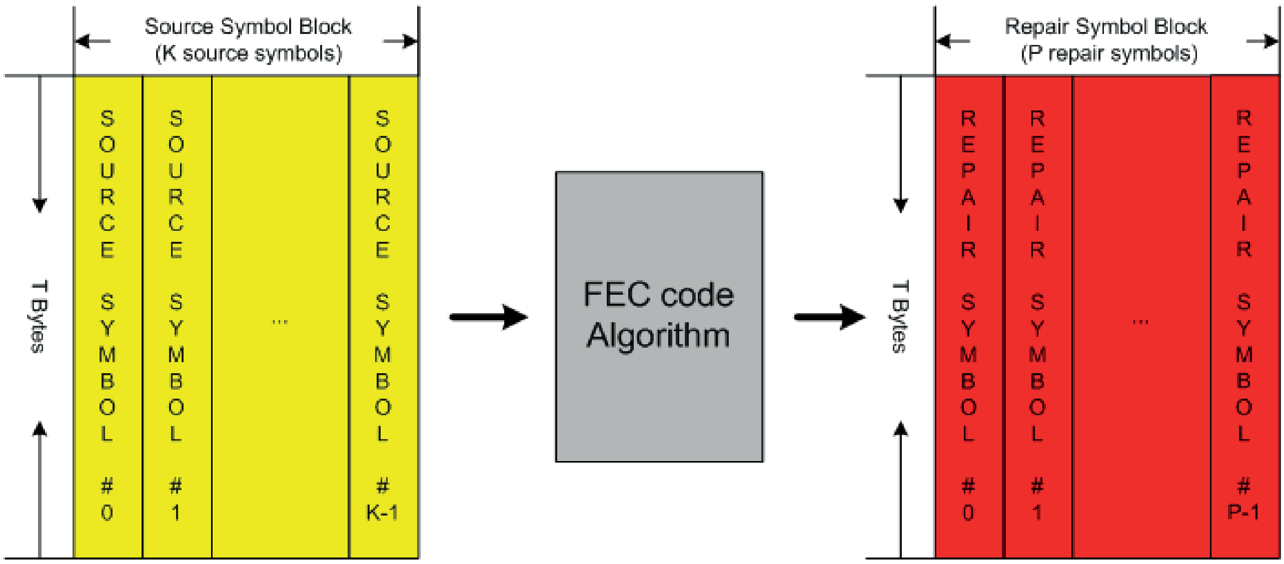

Figure 1 — Input and Output of FEC code

5 FEC Code Points

Table 1 specifies the code points for the FEC code algorithms specified in this part of ISO/IEC 23008. The FEC code algorithms themselves are specified in Clauses 6 to 10.

Table 1 — FEC Code Algorithms and Its Code Point

Code Point	FEC Code Algorithm
0	Reserved for ISO use
1	RS code (sub-Clause 6)
2	S_LDPC code (sub-Clause 7)
3	6330 code (sub-Clause 8.2)
4	RaptorQ LA code (sub-Clause 8.3)
5	FireFort-LDGM code (sub-Clause 9)
6	FEC code algorithm in SMPTE 2022-1 (sub-Clause 10)
7 ~ 255	Reserved for ISO use

NOTE When one of the FEC code algorithms specified in this specification is used for MMT AL-FEC framework, fec_code_id_for_repair_flow field as defined in ISO/IEC 23008-1:2014 Annex C.6 is set to its corresponding code point as specified in Table 1.

6 Specification for Reed-Solomon Codes

6.1 Introduction

In this clause, the following notations are used.

— *K*: number of source symbols in a source symbol block

— *P*: number of repair symbols in a repair symbol block

- **G** = [**I**; **A**]: a systematic generator matrix for [*K*+*P*, *K*]-RS code where **I** is the identity matrix of order *K* and **A** is a *K*× *P* matrix.

A (*N*, *K*) Reed–Solomon code is a linear block code of length *N* (over Galois Field *F*) with dimension *K* and minimum Hamming distance *N* – *K* + 1. The Reed–Solomon code is optimal in the sense that the minimum distance has the maximum value possible for a linear code of size (*N*, *K*); this is known as the Singleton bound. Such a code is also called a maximum distance separable (MDS) code.

The clause 8 of IETF RFC5510 gives full specification of the RS code for the erasure channel and especially, the clause 8.2.1 of IETF RFC5510 gives encoding principle for RS encoding algorithm. The generate matrix **G** perfectly characterizes the RS code. In this specification, it specifies only the case when $m = 8$ (over GF(2^8)) with the generator matrix given in the sub-clause 6.2. Therefore, an encoding symbol block shall be generated from a source symbol block by the given generator matrix in the sub-clause 6.2 and this FEC code shall output the repair symbol block of the encoding symbol block.

6.2 Generator matrix

The generator matrix **G** has the form **G** = [**I**; **A**] where **I** is an identity matrix of size *K* and **A** is a *K* × *P* matrix, (K + P) ≤ 255. Let α be the root of the polynomial $1 + x^2 + x^3 + x^4 + x^8$ which is the primitive polynomial of degree 8 given in sub-clause 8.1 of IETF RFC5510. The non-zero elements of the finite filed GF(2^8) are generated by a primitive element α and the elements of GF(2^8) are represented by bytes (group of 8 bits), using the polynomial base representation, with ($\alpha^7, \alpha^6, \alpha^5, \alpha^4, \alpha^3, \alpha^2, \alpha, 1$) as a basis. The root α is thus represented as: α = 00000010. For RS code specified in this specification, the matrix **A** is a Cauchy matrix which shall have entries

$$A_{i,j} = 1/(x_i + y_j) \text{ for } 0 \le i < K \text{ and } 0 \le j < P$$

where x_i and y_j are elements in GF(2^8) and are defined as:

$$x_i = \alpha^{254-i} \text{ and } y_j = \alpha^j.$$

Therefore, the matrix **A** is given by

$$A = \begin{bmatrix} \frac{1}{x_0+y_0} & \frac{1}{x_0+y_1} & \cdots & \frac{1}{x_0+y_{P-2}} & \frac{1}{x_0+y_{P-1}} \\ \frac{1}{x_1+y_0} & \frac{1}{x_1+y_1} & \cdots & \frac{1}{x_1+y_{P-2}} & \frac{1}{x_1+y_{P-1}} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \frac{1}{x_{K-2}+y_0} & \frac{1}{x_{K-2}+y_1} & \cdots & \frac{1}{x_{K-2}+y_{P-2}} & \frac{1}{x_{K-2}+y_{P-1}} \\ \frac{1}{x_{K-1}+y_0} & \frac{1}{x_{K-1}+y_1} & \cdots & \frac{1}{x_{K-1}+y_{P-2}} & \frac{1}{x_{K-1}+y_{P-1}} \end{bmatrix}$$

NOTE Any submatrix of the Cauchy matrix is invertible.

7 Specification for Structured Low-Density Parity-Check (S-LDPC) Codes

7.1 Introduction

A Low-Density-Parity-Check (LDPC) code is a linear block code defined by its parity-check matrix. In this specification, we use a special case of LDPC codes, called structured LDPC (S-LDPC) codes, which have an efficient encoding algorithm and adopted as an FEC code in standardizations such as IEEE 802.16e and 801.11n.

In this document, we use the following notations.

- *K*: number of source symbols in a source symbol block

- K': number of source symbols in an extended source symbol block
- P: number of repair symbols in a repair symbol block
- P': number of repair symbols in an extended repair symbol block
- $S(i)$: the i-th source symbol in a source symbol block ($0 \le i < K$). It can be represented as a binary column vector of length $8T$ or a column vector of length T over GF(2^8)
- $R(i)$: the i-th repair symbols in a repair symbol block ($0 \le i < P$). It can be represented as a binary column vector of length $8T$ or a column vector of length T over GF(2^8)
- $\boldsymbol{H}$: a sparse parity-check matrix of an S-LDPC code.

7.2 Structured LDPC Codes

In this clause, S-LDPC codes are described by parity-check matrices which consist of circulant permutation matrices or the zero matrix.

Let $\boldsymbol{Q}$ be the $L \times L$ permutation matrix given by

$$\boldsymbol{Q} = \begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 1 \\ 1 & 0 & 0 & \cdots & 0 \end{bmatrix}$$

Note that $\boldsymbol{Q}^i$ is just the circulant permutation matrix which shifts the identity matrix $\boldsymbol{I}$ to the right by i times for any integer i, $0 \le i < L$. For simple notation, $\boldsymbol{Q}^\infty$ denotes the zero matrix.

Let $\boldsymbol{H}$ be the P' by $K' + P'$ matrix defined by

$$\boldsymbol{H} = \begin{bmatrix} Q^{a_{0,0}} & Q^{a_{0,1}} & \cdots & Q^{a_{0,k+p-2}} & Q^{a_{0,k+p-1}} \\ Q^{a_{1,0}} & Q^{a_{1,1}} & \cdots & Q^{a_{1,k+p-2}} & Q^{a_{1,k+p-1}} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ Q^{a_{p-1,0}} & Q^{a_{p-1,1}} & \cdots & Q^{a_{p-1,k+p-2}} & Q^{a_{p-1,k+p-1}} \end{bmatrix}$$

where p and k are given by $p = P' / L$ and $k = K' / L$, respectively and $a_{i,j} \in \{0, 1, \ldots, L-1, \infty\}$. If the locations of 1's in the first row of the i-th row block

$$\boldsymbol{H}_i = \left[Q^{a_{i,0}} \cdots Q^{a_{i,k+p-1}} \right]$$

are fixed, then the locations of other 1's in $\boldsymbol{H}_i$ are uniquely determined.

7.3 Creating Parity-Check Matrix

For efficient encoding, it restricts the parity part of $\boldsymbol{H}$ to an almost lower triangular matrix with additional constraints as follows:

$$\boldsymbol{H} = \left[\boldsymbol{H}_I \quad \boldsymbol{H}_P \right]$$

$$= \left[\begin{array}{c cccccc} & \boldsymbol{Q} & \boldsymbol{I} & \boldsymbol{0} & \cdots & \boldsymbol{0} & \boldsymbol{0} \\ & \boldsymbol{0} & \boldsymbol{I} & \boldsymbol{I} & \cdots & \boldsymbol{0} & \boldsymbol{0} \\ & \vdots & \boldsymbol{0} & \boldsymbol{I} & \cdots & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{H}_I & \boldsymbol{I} & \vdots & \vdots & \cdots & \vdots & \vdots \\ & \vdots & \vdots & \vdots & \cdots & \boldsymbol{I} & \boldsymbol{0} \\ & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{I} & \boldsymbol{I} \\ & \boldsymbol{Q} & \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{0} & \boldsymbol{I} \end{array} \right]$$

In the first column block of $\boldsymbol{H_P}$, $\boldsymbol{I}$ is placed only at the ceil(p/2)-th row block , $\boldsymbol{H}_{\mathrm{ceil}(p/2)-1}$, where ceil(x) is the smallest integer not less than x.

Let $\boldsymbol{BM}$ be a mother matrix having 400 column blocks and 20 row blocks with L = 16, i.e. the matrix $\boldsymbol{BM}$ has 6400 columns and 320 rows. Each column block and row block of $\boldsymbol{BM}$ has exactly 7 and 140 circulant permutation matrices of size 16, respectively. The remaining part of $\boldsymbol{BM}$ is filled with zero matrices of size 16. The i-th row block of $\boldsymbol{BM}$ can be represented as a sequence of pairs $(t_{i,j}, e_{i,j})$ where $t_{i,j}$ is the index of column block corresponding to the j-th circulant permutation matrix and $e_{i,j}$ is its exponent. The $\boldsymbol{BM}$ matrix supports various values of K and P with techniques called scaling down and row splitting. The resulting matrix is used as $\boldsymbol{H_I}$ for encoding process.

In order to support short source symbol blocks efficiently, the matrix $\boldsymbol{BM}$ is scaled down by a scaling factor S_1. The resulting matrix is composed of circulant permutation matrices and zero matrices of size $16/S_1$, i.e. it has $6400/S_1$ columns and $320/S_1$ rows. The scaling factor can be obtained as $S_1 = 2^a$ where a is the largest integer satisfying $K \leq (400 \cdot 16) / 2^a$. Note that the resulting matrix can be represented as the sequence of pairs $(t_{i,j}, e_{i,j} \bmod (16/S_1))$ since the size of circulant permutation matrices and zero matrices are reduced from 16 to $16/S_1$.

As mentioned above, the matrix $\boldsymbol{BM}$ has $320/S_1$ rows after downscaling. It means that the number of repair symbols P is $320/S_1$ at maximum. To support larger values of P, we extend the matrix $\boldsymbol{BM}$ by splitting its rows. In this process, each row block is splitted into S_2 row blocks. For given repair symbol block length P and the scaling factor S_1, the row splitting factor S_2 can be obtained as $S_2 = \mathrm{ceil}(P/(320/S_1))$.

The matrix $\boldsymbol{H_I}$ is obtained from the matrix $\boldsymbol{BM}$ as follows. Let $\boldsymbol{BM}_i = \{(t_{i,0}, e_{i,0}), (t_{i,1}, e_{i,1}),\ldots, (t_{i,139}, e_{i,139})\}$ be the ordered sequence of pairs $(t_{i,j}, e_{i,j})$ representing the i-th row block of $\boldsymbol{BM}$. Let S_1 and S_2 be the scaling factor and the row splitting factor, respectively. They are determined uniquely by K and P. Then the $(S_2 \times i + j)$-th row block of $\boldsymbol{H_I}$ can be represented as follows:

$$\boldsymbol{T}_{(S2\times i)+j} = \{(t_{i,k}, e_{i,k} \bmod (16/S_1)) \mid k \bmod (S_2) = (S_2 - 1 - j),\ 0 \leq k < 140\}$$

Note that the matrix $\boldsymbol{H_I}$ has 400 column blocks and $S_2\times20$ row blocks with $L = 16/S_1$, i.e., it has $(6400/S_1)$ columns and $(S_2\times320/S_1)$ rows.

Finally, the parity-check matrix $\boldsymbol{H}$ is obtained by augmenting the matrix $\boldsymbol{H_P}$ with appropriate size to the matrix $\boldsymbol{H_I}$. H has $400 + S_2\times20$ column blocks and $S_2\times20$ row blocks with $L = 16/S_1$, i.e. H consists of $(6400 + S_2 \cdot 320)/S_1$ columns and $(S_2 \cdot 320/S_1)$ rows.

7.4 Encoding Algorithm

The encoding of an S-LDPC code is performed based on the following $p'\times L'$ by $(k'+p')\times L'$ parity-check matrix:

$$\boldsymbol{H} = \begin{bmatrix} \boldsymbol{H_I} & \boldsymbol{H_P} \end{bmatrix} = \left[\begin{array}{ccccccc} & \boldsymbol{Q} & \boldsymbol{I} & \boldsymbol{0} & \cdots & \boldsymbol{0} & \boldsymbol{0} \\ & \boldsymbol{0} & \boldsymbol{I} & \boldsymbol{I} & \cdots & \boldsymbol{0} & \boldsymbol{0} \\ & \vdots & \boldsymbol{0} & \boldsymbol{I} & \cdots & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{H_I} & \boldsymbol{I} & \vdots & \vdots & \cdots & \vdots & \vdots \\ & \vdots & \vdots & \vdots & \cdots & \boldsymbol{I} & \boldsymbol{0} \\ & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{I} & \boldsymbol{I} \\ & \boldsymbol{Q} & \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{0} & \boldsymbol{I} \end{array}\right]$$

where $L' = 16/S_1$, $p' = S_2\times20$ and $k' = 400$. It has $P' = S_2\times320/S_1$ rows.

The $\boldsymbol{H}$ is divided into the form

$$\boldsymbol{H} = \begin{bmatrix} \boldsymbol{A} & \boldsymbol{B} & \boldsymbol{T} \\ \boldsymbol{C} & \boldsymbol{D} & \boldsymbol{E} \end{bmatrix}$$

where $\boldsymbol{A}$ is $(p'-1)\times L$ by $k'\times L$, $\boldsymbol{B}$ is $(p'-1)\times L$ by L, $\boldsymbol{T}$ is $(p'-1)\times L$ by $(p'-1)\times L$, $\boldsymbol{C}$ is L by $k'\times L$, $\boldsymbol{D} = \boldsymbol{Q}$ is L by L and $\boldsymbol{E}$ is L by $(p'-1)\times L$. Let $\boldsymbol{c} = (\boldsymbol{s}, \boldsymbol{r_1}, \boldsymbol{r_2})$ be a codeword specified by $\boldsymbol{H}$, that is $\boldsymbol{Hc}^T = \boldsymbol{0}^{\mathrm{T}}$ where $\boldsymbol{s}$ is the systematic part, $\boldsymbol{p_1}$ and $\boldsymbol{p_2}$ are the parity parts which have length L and $(p'-1)\times L$, respectively. That is $\boldsymbol{s}$