**101.3.2.4 FEC encoding process**

The {EPoC\_PMD\_Name} encodes the transmitted data using a systematic Low-Density Parity-Check (LDPC) (FC, FP) code. A LDPC encoder encodes Fp information bits into a codeword



by adding FR parity bits obtained so that



where is an FR×FC binary matrix containing mostly ‘0’ and relatively few ‘1’, called low-density parity-check matrix, [1] and [2]. The detailed description of such parity check matrices is given in 101.3.2.4.1.

{References to be included: **[1]** R. G. Gallager, “Low density parity check codes,” *IRE Trans. Inform. Theory*, vol. IT-8, pp. 21–28, Jan. 1962.; [**2]** T. Richardson and R. Urbanke, “Modern Coding Theory," Cambridge University Press, 2008. }

The CLT {EPoC\_PMD\_Name} PCS operating on active CCDN shall encode the transmitted data using one of the LDPC (FC, FP) codes per Table 101-1, as selected using register TBD. The CNU {EPoC\_PMD\_Name} PCS operating on active CCDN shall encode the transmitted data using one of the LDPC (FC, FP) codes per Table 101-2, as selected using register TBD.

Annex 101A gives an example of LDPC (FC, FP) FEC encoding. {we will need to select one of the codes from the family of codes we use in either downstream or upstream and then generate examples}

TABLE101-1: LDCP codes used by the CLT {EPoC\_PMD\_Name} PCS for active CCDN

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Codeword FC [bits] | Payload FP [bits] | Parity FR [bits] | Payload | | Parity | | |
| 65-bit blocks BQ | Padding bits BP | 64-bit blocks CQ | Parity bits in last block CPL | Padding bits CP |
| 16200 | 14400 | 1800 | 221 | 2 | 28 | 40 | 24 |

{content of this table was taken from the approved baseline: [prodan\_3bn\_01a\_0713.pdf](http://www.ieee802.org/3/bn/public/jul13/prodan_3bn_01a_0713.pdf), separated into upstream and downstream directions}

TABLE 101-2: LDCP codes used by the CNU {EPoC\_PMD\_Name} PCS for active CCDN

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Codeword FC [bits] | Payload FP [bits] | Parity FR [bits] | Payload | | Parity | | |
| 65-bit blocks BQ | Padding bits BP | 64-bit blocks CQ | Parity bits in last block CPL | Padding bits CP |
| 16200 | 14400 | 1800 | 221 | 2 | 28 | 40 | 24 |
| 5940 | 5040 | 900 | 77 | 2 | 14 | 36 | 28 |
| 1120 | 840 | 280 | 12 | 27 | 4 | 56 | 8 |

{content of this table was taken from the approved baseline: [prodan\_3bn\_01a\_0713.pdf](http://www.ieee802.org/3/bn/public/jul13/prodan_3bn_01a_0713.pdf), separated into upstream and downstream directions; more FEC codes are likely to be }

**101.3.2.4.1 LDPC defintion**

The low-density parity check matrix H for LDPC (FC, FP) encoder can be divided into blocks of L2 sub-matrices. Its compact circulant form is represented by an m-by-n block matrix:



where the submatrix *Hi,j* is an L-by-L all-zero submatrix or a cyclic right-shifted identity submatrix. The last  sub-matrix columns represent the parity portion of the matrix. Moreover,,  and the code rate is (n–m)/n = (FC-FP)/FC . In this specification, the sub-matrix size L is called the lifting factor.

In this specification, the sub-matrix *Hi,j* is represented by a value in {-1, 0,…, L-1}, where a ‘-1' value represents an all-zero submatrix, and the remaining values represent an L by L identity submatrix cyclically right-shifted by the specified value. Such representation of the parity-check matrix is called a base matrix.

Table 1a through Table 1c present a 5-by-45 base matrix of the low-density parity-check matrix H for LDPC (16200, 14400) code listed in TABLE 101-1 for downstream and TABLE 101-2 for upstream, respectively. The lifting factor of the matrix is L=360.

Table 1a: LDCP (16200, 14400) code matrix, columns 1-15

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row** | **Column** | | | | | | | | | | | | | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
| **1** | 93 | 271 | -1 | 83 | 26 | 208 | 245 | 200 | -1 | 175 | 331 | 17 | 86 | -1 | 337 |
| **2** | 274 | 115 | 329 | 338 | 124 | -1 | 293 | -1 | 69 | 64 | 342 | -1 | 88 | 139 | -1 |
| **3** | 134 | 355 | 175 | 24 | 253 | 242 | -1 | 187 | 94 | 26 | 87 | 302 | -1 | 191 | 323 |
| **4** | -1 | -1 | 184 | 70 | 247 | 14 | 22 | 7 | 285 | 54 | -1 | 352 | 26 | 108 | 10 |
| **5** | 253 | 273 | 90 | -1 | -1 | 151 | 311 | 320 | 339 | -1 | 295 | 148 | 48 | 91 | 62 |

Table 1b: LDCP (16200, 14400) code matrix, columns 16-30

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row** | **Column** | | | | | | | | | | | | | | |
| **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** |
| **1** | -1 | 238 | 81 | -1 | 307 | -1 | 165 | -1 | 47 | 76 | 73 | 150 | 349 | 139 | 331 |
| **2** | 137 | 212 | -1 | 157 | 195 | 357 | 81 | 194 | 1 | 159 | 56 | 72 | 126 | 277 | 156 |
| **3** | 22 | -1 | 245 | 294 | 240 | 84 | 76 | 342 | 345 | 174 | 269 | 329 | -1 | 214 | -1 |
| **4** | 298 | 123 | 139 | 117 | -1 | 336 | 49 | 202 | 359 | 342 | -1 | 224 | 106 | -1 | 273 |
| **5** | 100 | 232 | 146 | 200 | 135 | 12 | -1 | 179 | -1 | -1 | 232 | -1 | 21 | 331 | 313 |

Table 1c: LDCP (16200, 14400) code matrix, columns 31-45

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row** | **Column** | | | | | | | | | | | | | | |
| **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** | **39** | **40** | **41** | **42** | **43** | **44** | **45** |
| **1** | 118 | 345 | 27 | 294 | -1 | 145 | 279 | 97 | 106 | 160 | 143 | -1 | -1 | -1 | -1 |
| **2** | 32 | 111 | 175 | -1 | 306 | 224 | -1 | 206 | -1 | 29 | 106 | 334 | -1 | -1 | -1 |
| **3** | -1 | -1 | -1 | 218 | 104 | 40 | 197 | 73 | 229 | 63 | -1 | 270 | 72 | -1 | -1 |
| **4** | 177 | 245 | 98 | 355 | 178 | 176 | 147 | -1 | 280 | -1 | -1 | -1 | 221 | 208 | -1 |
| **5** | 349 | 34 | 97 | 187 | 38 | -1 | 235 | 52 | 170 | 58 | -1 | -1 | -1 | 257 | 0 |

Table 2a and Table 2b present a 5 × 33 base matrix of the low-density parity-check matrix H of LDPC (5940, 5040) code listed in TABLE 101-2 for upstream. The lifting factor of the matrix is L=180.

Table 2a: LDCP (5940, 5040) code matrix, columns 1-11

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row** | **Column** | | | | | | | | | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
| **1** | 142 | 158 | 113 | 124 | 92 | 44 | 93 | 70 | 172 | 3 | 25 |
| **2** | 54 | 172 | 145 | 28 | 55 | 19 | 159 | 22 | 96 | 12 | 85 |
| **3** | 63 | 11 | 112 | 114 | 61 | 123 | 72 | 55 | 114 | 20 | 53 |
| **4** | 28 | 160 | 102 | 44 | 8 | 84 | 126 | 9 | 169 | 174 | 147 |
| **5** | 52 | 159 | 75 | 74 | 46 | 71 | 42 | 11 | 108 | 153 | -1 |

Table 2b: LDCP (5940, 5040) code matrix, columns 12-22

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row** | **Column** | | | | | | | | | | |
| **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** |
| **1** | 44 | 141 | 160 | 50 | 45 | 118 | 84 | -1 | 64 | 66 | 97 |
| **2** | -1 | 128 | 5 | 158 | 120 | 51 | 171 | 65 | 141 | -1 | 42 |
| **3** | 114 | 42 | 33 | 4 | 66 | 163 | 50 | 46 | 17 | 175 | -1 |
| **4** | 24 | 145 | -1 | 26 | -1 | -1 | -1 | 67 | 82 | 4 | 177 |
| **5** | 72 | -1 | 163 | -1 | 9 | 2 | 168 | 158 | -1 | 1 | 49 |

Table 2c: LDCP (5940, 5040) code matrix, columns 23-33

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row** | **Column** | | | | | | | | | | |
| **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** |
| **1** | 1 | 115 | 8 | 108 | -1 | -1 | 22 | -1 | -1 | -1 | -1 |
| **2** | 83 | 7 | -1 | 39 | 121 | 84 | 101 | 171 | -1 | -1 | -1 |
| **3** | -1 | -1 | 92 | -1 | 41 | 138 | -1 | 34 | 74 | -1 | -1 |
| **4** | 151 | 131 | 139 | 117 | 36 | 18 | -1 | -1 | 23 | 8 | -1 |
| **5** | 89 | 63 | 179 | 10 | 75 | 161 | -1 | -1 | -1 | 177 | 19 |

Table 3a and Table 3b present a 5 × 20 base matrix of the low-density parity-check matrix H of LDPC (1120, 840) code listed in TABLE 101-2 for upstream. The lifting factor of the matrix is L=56.

Table 3a: LDCP (1120, 840) code matrix, columns 1-10

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row** | **Column** | | | | | | | | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **1** | 5 | 14 | 12 | 1 | 2 | 37 | 45 | 26 | 24 | 0 |
| **2** | 0 | 35 | 1 | 26 | 0 | 10 | 16 | 16 | 34 | 4 |
| **3** | 12 | 28 | 22 | 46 | 3 | 16 | 51 | 2 | 25 | 29 |
| **4** | 0 | 51 | 16 | 31 | 13 | 39 | 27 | 33 | 8 | 27 |
| **5** | 36 | 6 | 3 | 51 | 4 | 19 | 4 | 45 | 48 | 9 |

Table 3b: LDCP (1120, 840) code matrix, columns 11-20

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row** | **Column** | | | | | | | | | |
| **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| **1** | 3 | -1 | 34 | 7 | 46 | 10 | -1 | -1 | -1 | -1 |
| **2** | 2 | 23 | 0 | 51 | -1 | 49 | 20 | -1 | -1 | -1 |
| **3** | 19 | 18 | 52 | -1 | 37 | -1 | 34 | 39 | -1 | -1 |
| **4** | 53 | 13 | -1 | 52 | 33 | -1 | -1 | 38 | 7 | -1 |
| **5** | -1 | 11 | 22 | 23 | 43 | -1 | -1 | -1 | 14 | 1 |

**101.3.2.4.2 LDPC encoding process within CLT (downstream)**

The process of padding FEC codewords and appending FEC parity octets in the {EPoC\_PMD\_Name} CLT transmitter is illustrated in Figure 101-1. The 64B/66B encoder produces a stream of 66-bit blocks, which are then delivered to the FEC encoder. The FEC encoder accumulates BQ (see Table 101-1 for CLT PCS and Table 101-2 for CNU PCS) of these 66-bit blocks to form the payload of a FEC codeword, removing the redundant first bit (i.e., sync header bit <0>) in each 66-bit block received from the 64B/66B encoder. The first bit <0> of the sync header in the 66-bit block in the transmit direction is guaranteed to be the complement of the second bit <1> of the sync header – see 49.2.4.3 for more details.

Next, the FEC encoder calculates CRC32 over the aggregated BQ 65-bit blocks, placing the resulting 32 bits of CRC32 code prepended with one bit truncated sync header (with the binary value of “1”) immediately after the BQ 65-bit blocks, forming the payload of the FEC codeword. Finally, the FEC encoder prepends BP (see Table 101-1 for CLT PCS and Table 101-2 for CNU PCS) padding bits (with the binary value of “0”) to the payload of the FEC codeword as shown in Figure 101-1. This data is then LDPC-encoded, resulting in the FR bits of parity data. The first 32 bits of parity data are inserted into the 65-bit block carrying CRC32 code, complementing it. The remaining FR-32 bits of parity data is then divided into CQ 64-bit blocks, each of which is then prepended with one bit sync header <1> with the value of binary “1”. The last 64-bit block of the parity data contains CPL bits of parity data, and the remaining CP bits are filled with padding (binary “0”).

**101.3.2.4.3 LDPC codeword transmission order within CLT (downstream)**

Once the process of calculating FEC parity is complete, the payload portion of the FEC codeword and the parity portion of the FEC codeword are then transferred towards the PMA across the PMA service interface, one 65-bit block at a time. Note that the BP padding bits used to generate the FEC codeword are not transmitted across the PMA service interface. The CP padding bits in the last parity codeword (block number CQ) are transmitted to PMA, where they are the discarded prior to encoding into OFDM medium.

**101.3.2.4.4 LDPC encoding process within CNU (upstream)**

{the upstream FEC encoding for CNU will be described when we have a consistent proposal on how to mix three different FEC codes into a single transmission slot}

**101.3.2.4.5 LDPC codeword transmission order within CNU (upstream)**

{the content of this subclause ought to be quite similar with the content of 101.3.2.4.3}



FIGURE 101-1: PCS Transmit bit ordering within CLT (downstream)

**101.3.2.4.4 State diagrams**

{State Diagrams for FEC will be added once we agree on the operational details, how padding is used and what we are actually aggregating at what time and in what fashion}

**101.3.2.5 Data Detector**

{The presence of the Data Detector remains for discussion at this time, given that EPoC does not use lasers and there was no clear need demonstrated until now for anything like a Data Detector function}

**101.3.3.3 FEC decoding process**

The {EPoC\_PMD\_Name} decodes the received data using Low-Density Parity-Check (LDPC) (FC, FP) code. The CLT {EPoC\_PMD\_Name} PCS operating on active CCDN shall decode the received data using one of the LDPC (FC, FP) codes per Table 101-2, as selected using register TBD. The CNU {EPoC\_PMD\_Name} PCS operating on active CCDN shall decode the received data using one of the LDPC (FC, FP) codes per Table 101-1, as selected using register TBD.

Annex 101B gives an example of LDPC (FC, FP) FEC decoding. {we will need to select one of the codes from the family of codes we use in either downstream or upstream and then generate examples}

**101.3.3.3.1 LDPC encoding process within CLT (upstream)**

{the upstream FEC decoding for CLT will be described when we have a consistent proposal on how to mix three different FEC codes into a single transmission slot}

**101.3.3.3.2 LDPC encoding process within CNU (downstream)**

The process of decoding FEC codewords in the {EPoC\_PMD\_Name} CNU receiver is illustrated in Figure 101-2.

{FEC codeword alignment needs to be tackled somewhere between the PMA and the bottom of the PCS – we had some proposals on how to find FEC codeword lock in the downstream, but I am not sure we baselined anything with sufficient level of detail to actually put it into the draft}

Once the alignment to FEC codeword is found, the {EPoC\_PMD\_Name} CNU receiver aggregates the total of BQ + 1+ CQ 65-bit blocks received from the PMA, forming the FEC payload (blocks number 1 to BQ, and bits <0> through <32> from the following 65-bit block) and the FEC parity (bits <33> through <64> from the 65-bit block following payload portion of the FEC codeword and followed by blocks number 1 to CQ) portions of the codeword. Note that the CP padding bits in the last parity codeword (block number CQ) are locally generated within the PMA and transmitted to the PCS.

Next, each 65-bit block in the FEC parity portion of the codeword (blocks 1 through CQ) is stripped from the sync header by removing bit <1>. Furthermore, the last 64-bit block of the FEC parity (block number CQ) is truncated, removing bits <CPL> … <63>, forming a single FEC parity portion of the codeword with size FR (in bits).

Then the FEC payload portion of the codeword is pre-pended with BP padding bits (with the binary value of “0”) and subsequently fed into the FEC decoder for processing together with the stripped FEC parity portion of the codeword.

The FEC decoder produces the FEC payload portion of the codeword with the size of FP (in bits), where bits <0> … <BP-1> contain padding (with the binary value of “0”). Next, the CRC32 is calculates over the remaining blocks 1 through BQ and then compared with the value of CRC32 retrieved from the received FEC codeword. If both CRC32 codes match, the decoded frame does not contain any detectable errors and it is treated as error-free. Otherwise, the decoded frame contains detected errors. The behavior of the FEC decoder in the presence of CRC32 code failure depends on status of the user-configurable option to indicate an uncorrectable FEC codeword.

Finally, the FEC decoder prepends each of the BQ 65-bit blocks with bit <0> of the sync header containing the binary inverse of the value carried in bit <1> of the sync header, producing 66-bit blocks. This also guarantees that properly decoded blocks meet the requirements of 49.2.4.3.

The FEC decoder in the CNU shall provide a user-configurable option to indicate an uncorrectable FEC codeword (due to an excess of symbols containing errors) to higher layers. If this user-configurable option is enabled and the calculated value of CRC32 does not match the value of CRC32 retrieved from the received FEC codeword, the FEC decoder replaces bit <0> and <1> in the sync headers in all BQ blocks with the binary value of “00”. If this user-configurable option is disabled, the FEC decoder does not make any further changes to the sync headers in in all BQ blocks.

Each resulting 66-bit block is then fed into the 64B/66B decoder, removing the sync header information (bit <0> and bit <1>), which is used to generate control signaling for the XGMII. Finally, the resulting 64-bit block is then separated into two 32-bit portions, which are transmitted across the XGMII on two consecutive transfers, with the proper control signaling retrieved from the sync header information retrieved in the 64B/66B decoder.



FIGURE 101-2: PCS Receive bit ordering within CNU (downstream)

**101.3.3.3.3 State diagrams**

{State Diagrams for FEC will be added once we agree on the operational details, how padding is used and what we are actually aggregating at what time and in what fashion}