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# PAM12 LDPC-CRC Framing


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# Agenda

- A Complete Specification for the Framing:
  - CRC
  - LDPC
  - Bit ordering
- A Complete Specification of the Mapping Algorithm.
- Mean Time to False Packet Acceptance Analysis.

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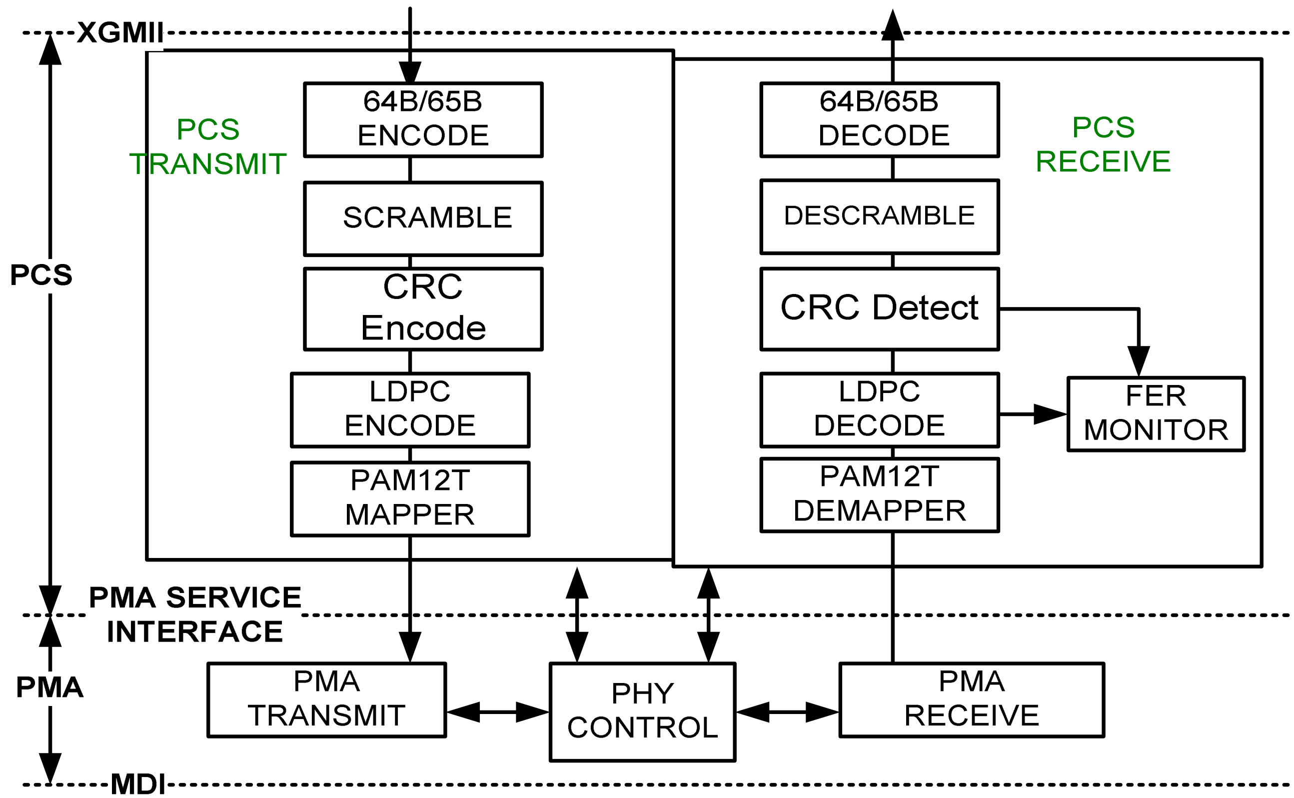
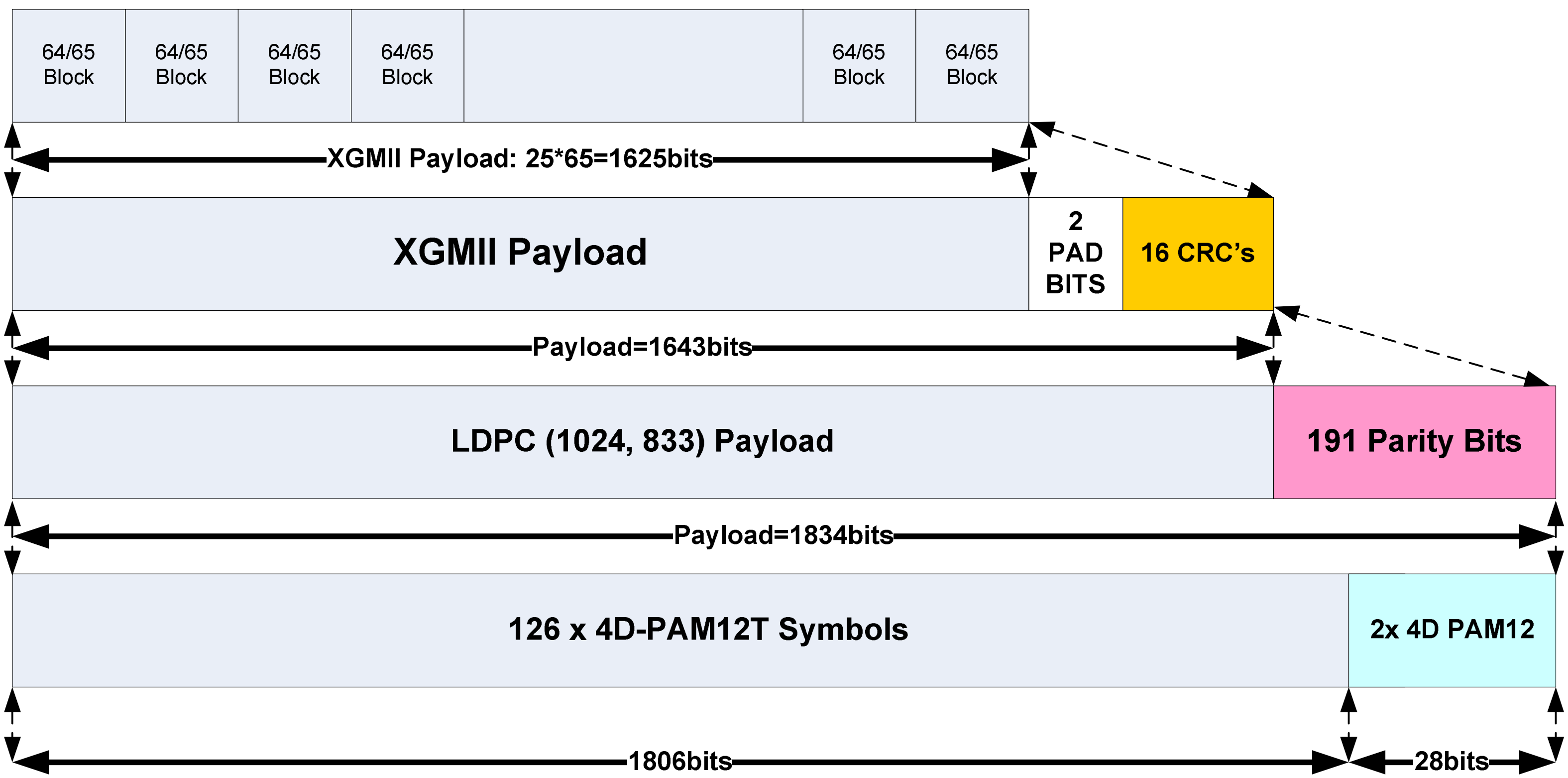
# Framing Highlights

- Data payload of 25* 64 = 1600 bits.
- 16 bits of the Frame CRC to reduce the undetectable frame error rate.
- LDPC payload:
  - 1625 bits = 25 (blocks) x 65 (bits/blocks)
  - 2 bits of the control bits, usable for synchronization or back channel.
  - 16 bits of the CRC's.
- Frame has single LDPC (1024, 833) block
- Symbol rate: 10G/(1600 /128) = 800MHz
- Symbol rate of 800MHz = 32* 25MHz
  - Easy to generate with standard xtals/oscillators with simple *N/M* PLL multiplication
  - Results in low jitter PLL

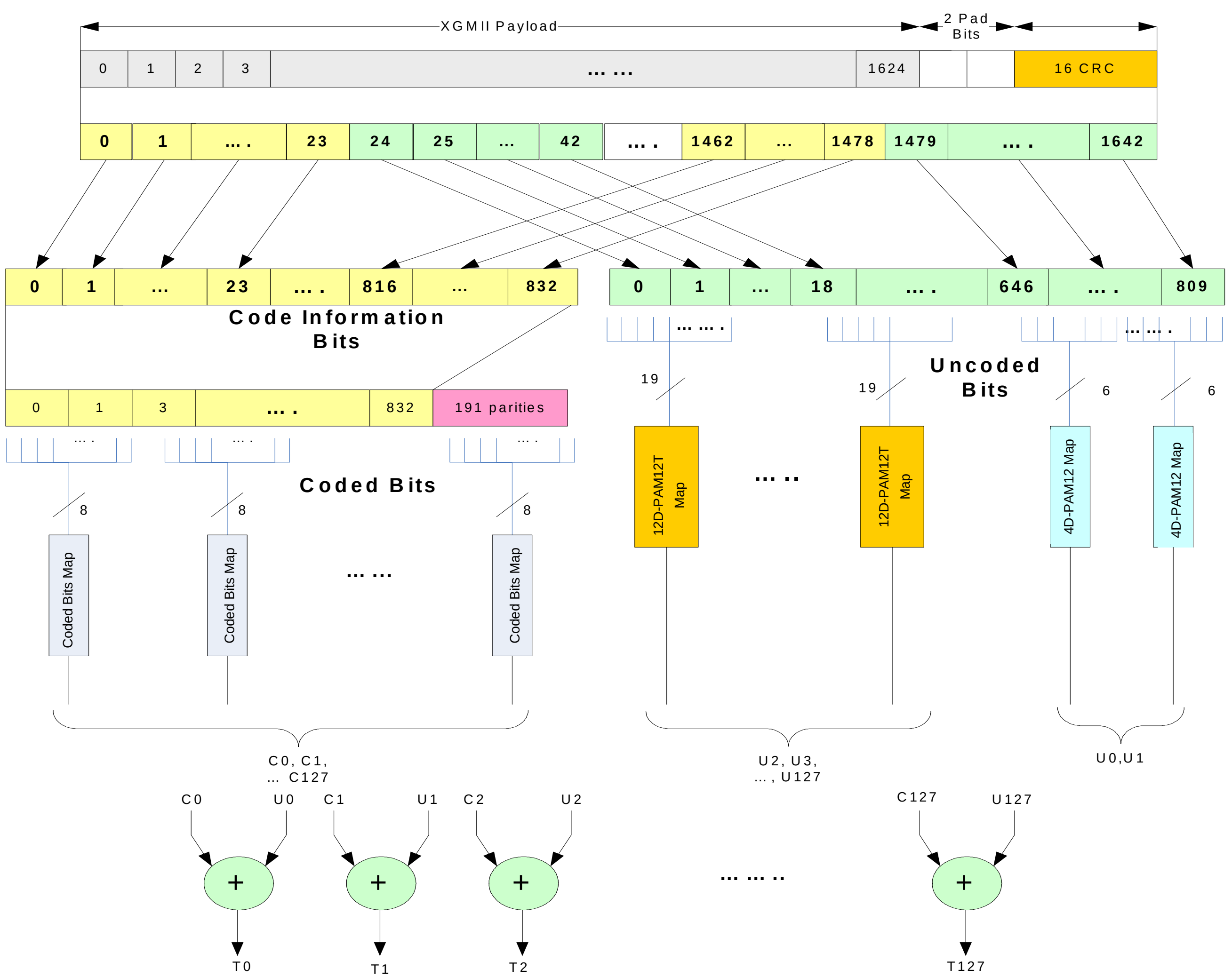
# PCS Functional Block



# Framing Overview



# A More Detailed View



# XGMII to LDPC

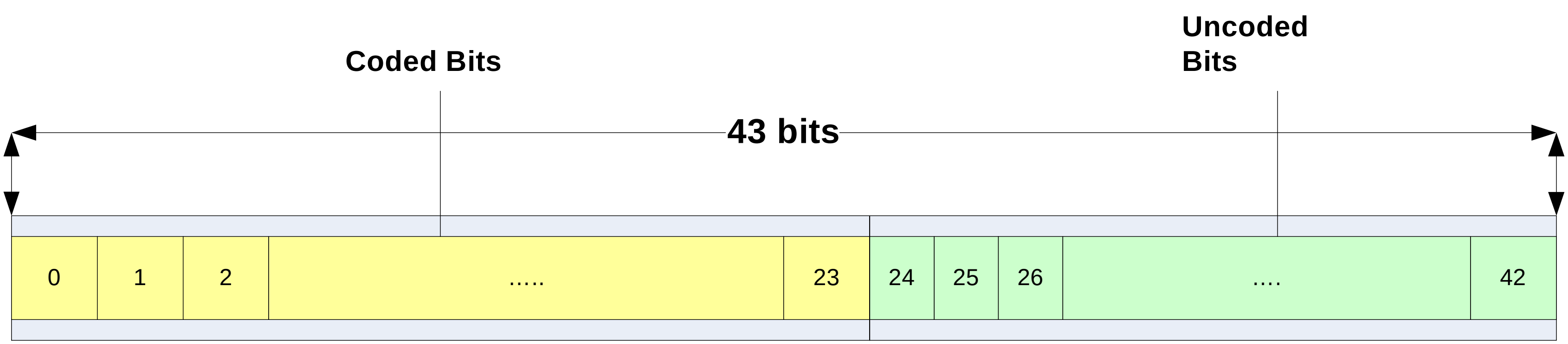
- The XGMII payload consists of 1625 bits.
- The LDPC payload has 16 additional bits of CRC’s and 2 pad bits.
- The LDPC payload is split between:
  - information bits for the LDPC(1024, 833).
  - uncoded payload bits.

# CRC16

- $G(X) = X^{16} + X^{15} + X^{11} + X^8 + X^6 + X^5 + X^4 + X^3 + X + 1$.
- Introduced in:
  - D. Chun, J. Wolf, "Special Hardware for Computing the Probability of Undetected Error for Certain Binary CRC Codes and Test Results", IEEE Trans. Commun. Vol. 42, pp2769-2772, Oct. 94.
  - The authors have given a *rigorous proof* of the upper bound $2^{-16}$ on the probability of undetectable frame error for this code.
- CRC is calculated after scrambling and checked prior to descrambling to prevent error propagation.
- CRC error detected in frame N will cause erasure for all 25 65B blocks in the frame and the first 65B block in frame N+1.

# XGMII to LDPC Split

- The LDPC payload split:
  - The first 1462 bits of the LDPC payload is divided into 34 groups of 43 bits.
  - The next 17 bits (bit 1462 to bit 1478) are coded bits.
  - The rest of the bits (bit 1479 to bit 1642) are all uncoded bits.



# LDPC Encoder

- A systematic encoder that generates 191 parity bits for 833 information bits.
- A systematic generator matrix for this code will be provided.

# Mapping of Coded Bits

- Generates levels Xn = {-3, -1, 1, 3}, n = 0:511 according the following Gray map table.
- Each 4D coset representative, Tm = (X4m, X4m+1, X4m_2, X4m+3),  m = 0, 1, 2, … 127.

| LDPC_data_group <2n:2n+1><br>n=0:511 (coded bits) | Xn<br>(512 cosets) |
|---|---|
| 00 | -3 |
| 01 | -1 |
| 11 | 1 |
| 10 | 3 |

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# 4D-PAM12 Map

- Converts 3-tuples of uncoded bits to points, Xn in the 2D constellation: $\{-8, 0, 8\}^2$ according to the 2D-PAM 12 Table.
- Tn = (X2n, X2n+1) defines the 4D coset points.

| | |
|---|---|
| (-8,-8) | 000 |
| (-8,0) | 001 |
| (-8,8) | 011 |
| (0,8) | 010 |
| (8,8) | 110 |
| (8, 0) | 111 |
| (8, -8) | 101 |
| (0, -8) | 100 |

# 12D-PAM12T

- Follows mcclellan_2_0904.pdf.
- Each 12D-PAM12T symbol consists of 3  4D-symbols.
- Each 4D symbol is viewed as 2  2D-symbols.
- The 2D-constellation $\{-8, 0, 8\}^2$ is divided into two sets, the point in the origin, denoted by R, and the rest of the points denoted by B.
- The 4D constellation is divided into 3 subsets:
  - X = BxB.(64 points)
  - Y = RxB + BxR.(16 points)
  - Z = RxR. (one point).
- The unique prefix of the 19-bit input specifies which subsets should be used for each of the 3 4D-symbols.

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# Prefix Map Table

| Prefix | Subset | No of Suffix Bits | Total Bits |
|---|---|---|---|
| 0* | (X, X, X) | 18 | 19 |
| 100* | (X, X, Y) | 16 | 19 |
| 101* | (X, Y, X) | 16 | 19 |
| 110* | (Y, X, X) | 16 | 19 |
| 11100* | (Y, Y, X) | 14 | 19 |
| 11101* | (Y, X, Y) | 14 | 19 |
| 11110* | (X, Y, Y) | 14 | 19 |
| 1111100* | (X, X, Z) | 12 | 19 |
| 1111101* | (X, Z, X) | 12 | 19 |
| 1111110* | (Z, X, X) | 12 | 19 |
| 1111111* | (Y, Y, Y) | 12 | 19 |

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# 12D-PAM12T

- The suffix bits define which points of the 4D subsets should be used.
- Any point 4D point $U = (u_0, u_1, u_2, u_4)$ in
  - X, carries 6 bits according to the 4D-PAM12 mapping rules.
  - Y, carries 4 bits $(b_0, b_1, b_2, b_3)$:
    - If $b_0 == 0$:
      - $u_0 = u_1 = 0$;
      - Use $(b_1, b_2, b_3)$ to find $(u_2, u_4)$ according to the 2D-PAM12 Table.
    - If $b_0 == 1$:
      - $u_2 = u_4 = 0$;
      - Use $(b_1, b_2, b_3)$ to find $(u_0, u_1)$ according to the 2D-PAM12 Table.
  - Z, carries no bits.

# Mean Time to False Packet Acceptance

- Since the minimum distance of the (1024, 833) code is lower bounded by 12, the length of a single undetectable error event can never be less than 12 .
- Therefore, at BER = 1e-12, the undetectable FER < 8.33e-11.
- Assuming that all errors made by the SPA algorithm for the (1024, 833) code, are undetectable (*very pessimistic assumption*).
- The probability of undetectable erroneous frame is 2^(-32) * 2^(-16) * FER.
- Therefore in average one out of 3.4e24 frames have undetectable errors.
- Therefore Mean Time to False Packet Acceptance is about 1.7e10 years: 1.7 x life of universe.

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# Discussions

- Our estimates tend to be pessimistic because:
  - For a good code with a high minimum distance (like (1024, 833)) most errors tend to be pseudo-codewords, not codewords.
  - The dmin of the (1024, 833) is likely to be larger than 12.
- The upper bound $2^{-R}$ does *not* necessarily hold for any code:
  - A good counter example is the probability of undetectable error for the widely used CCITT CRC16 code which exceeds $2^{-16}$ for some code lengths:
    - J. K. Wolf, R.D. Blakeney, “An Exact Evaluation of the Probability of Undetectable Errors for Certain Shortened Binary CRC codes”, MIILCOM’ 88, pp. 15.2.1-15.2.6.
- For the CRC 16 presented in this paper, this bound *has been* proved rigorously.
- For the Ethernet CRC-32 this bound *has been* proved rigorously.

# Conclusions

- We have shown a simple framing based on (1024, 833) LDPC code.
- The (1024, 833) LDPC-CRC guarantees "life of the universe" MTTFPA for undetected errors.
- The CRC covers uncoded bits in cases of impulse events.
- The (1024, 833) LDPC-CRC satisfies the 800MHz PAM12 target set by the Task Force.