Reliability Analysis of In-Band signaling Message Fields for Type 2 PHYs

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Goal of this Presentation

This presentation describes the detailed overview of In-band signaling (aka: Padding) messaging field and reliability of such in-band signaling field.

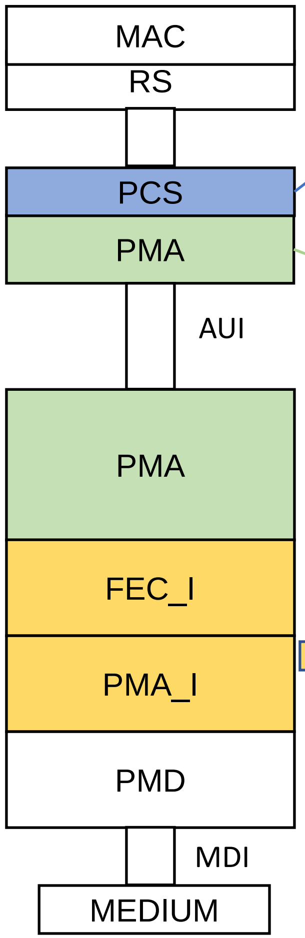
Outline # 1:

Framing of in-band signaling field : Size, Content, Bit-rate, Protection schemes, Message types carried in signaling field and their usage for link maintenance

Outline # 2:

Analysis of MTTFPA vs probability of successful transmission for in-band signaling field for worst case BER scenarios

Recap of Status of FEC_I Architecture & topic of discussion: Padding

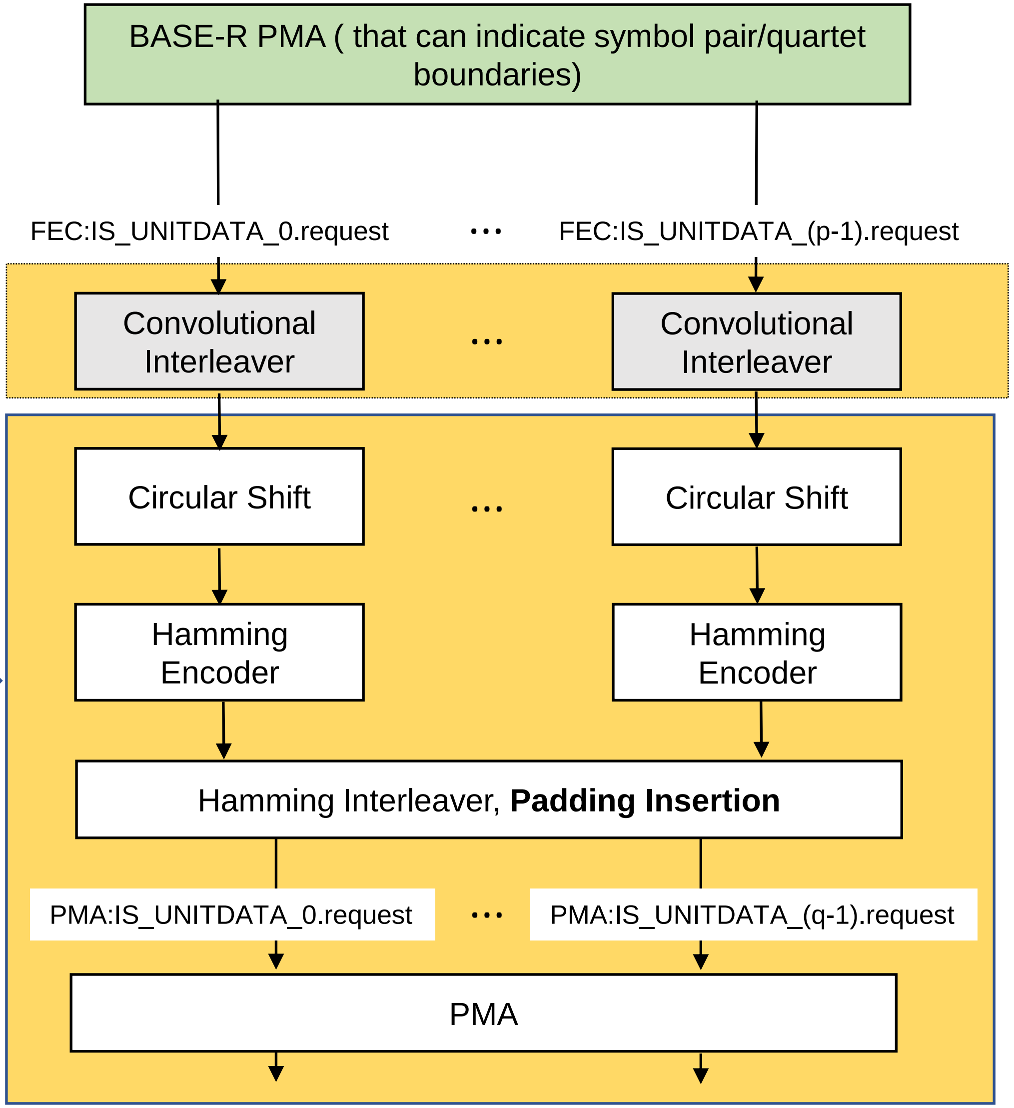


Type 2 scheme

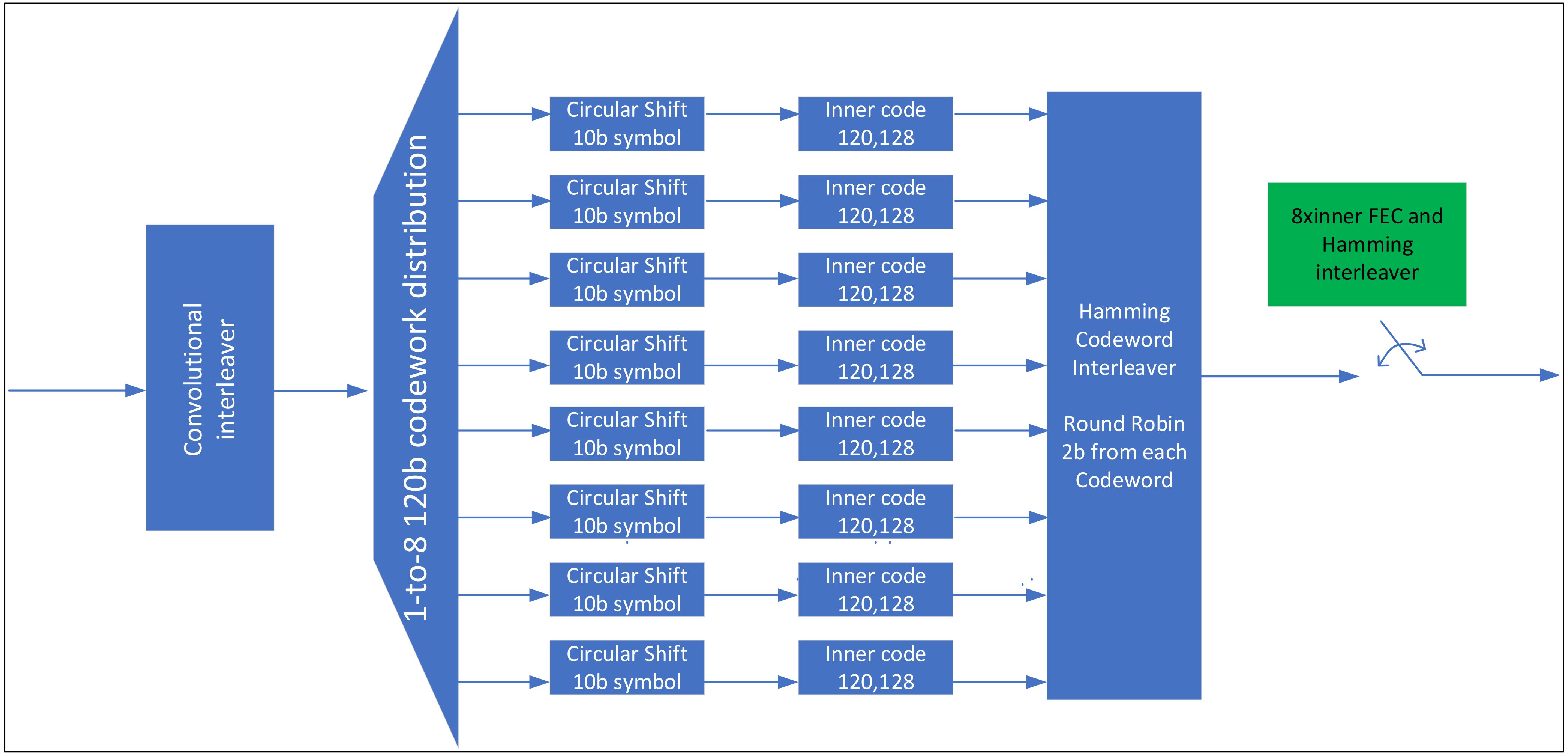
200G, 400G, 800G, 1.6T PCS is already adopted as per CL-119, CL-172 PCS

200G Symbol Muxing PMA scheme is already adopted: *ran_3dj_01a_2303.pdf*

Inner Code FEC sublayer is already adopted



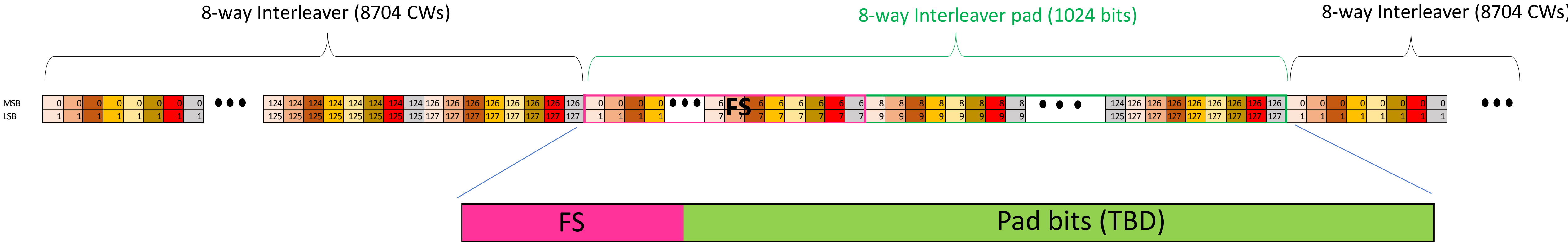
Recap of FEC_I Sublayer Architecture with Padding Insertion:



* There is a consensus now to use 8xCW based padding scheme with Hamming inter-leaver.

In-band Signaling (Padding) format:

- single type of stream:

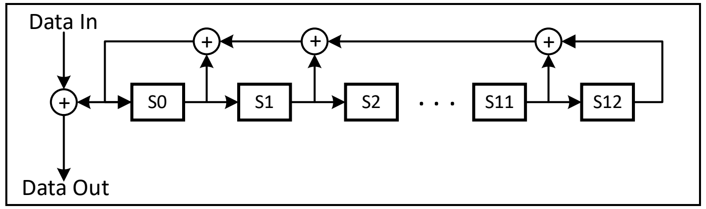


8704*128 + 1024 = 1115136 bits

In-Band Signaling (Padding) Field:

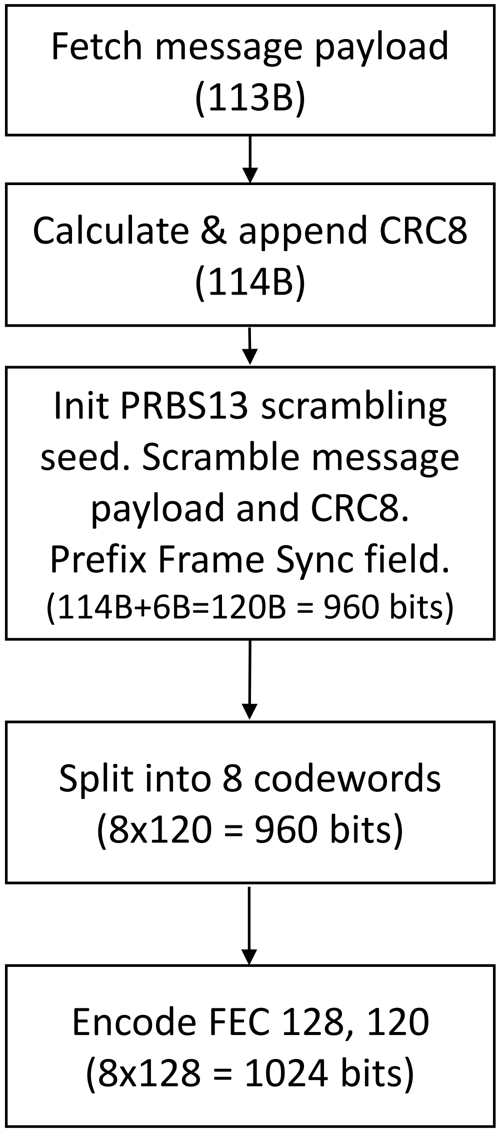
- **1024 bits = 8 CW using 128, 120 code**
  - Payload bits = 960 (=120 B), parity = 64 bits

- **120 data bytes composed as follows:**
  - 6 byte frame sync field (same as 200G/400G PCS AM, offers DC balance & hardware reuse): **0x9A 0x4A 0x26 0x65 0xB5 0xD9**
  - Remaining 912 bits are **additively** scrambled with PRBS13, using generator polynomial $X^{13} + X^{12} + X^2 + X + 1$, seed reset to 0xCCC for start of each 912 bit instance. Below is the reference picture for PRBS13 based additive scrambler

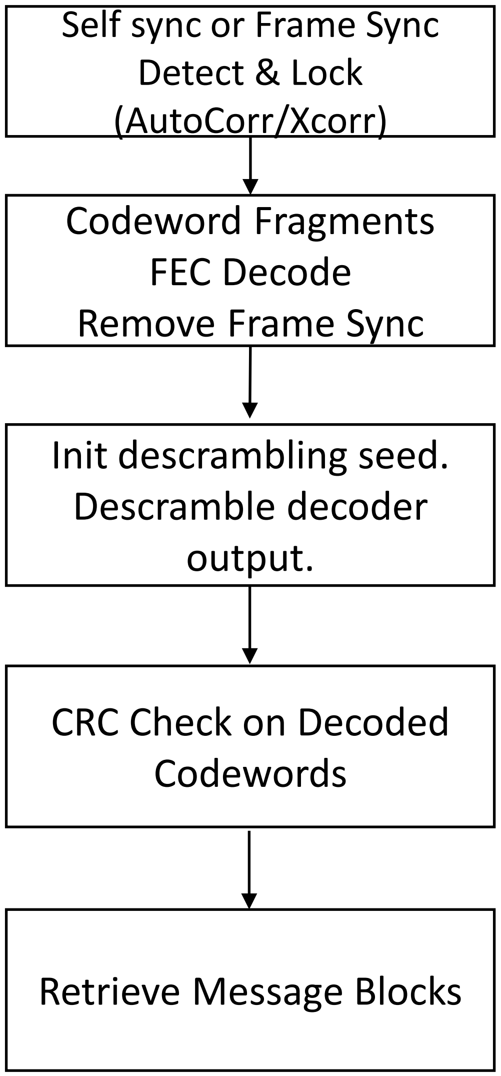


  - **113 byte** Message field – Start of scrambling with PRBS
    - 8 bit message index (8 bit counter 0 to 255)
    - 8 bit message type (see slides 4 & 5)
    - 111 bytes message content
  - 1 byte CRC8 (calculated on previous 113 bytes) – polynomial is $X^8+X^5+X^4+1$
- **The 113-bytes** message field (details to be worked out) needs to be used to convey link and signal-related information, such as receiver state, channel pulse response, FEC stats, etc

Signaling Field Construction – Reference Implementation



Signaling Field Consumption – Reference Implementation (Informative)



Illustrative usage of Message Types:

- **0x00 : Module RX State. Coding :-**
  - Bytes 0-7: States of up to 16 PMD lanes (set to 0x0 if not available).
    - 0x0: No signal detected
    - 0x1: Signal detected; lane not locked
    - 0x2: Lane locked
    - 0x3-0xf : Reserved
  - Bytes 8-110: Zero-stuffed.
- **0x01 : RX Histogram (64 bins, -32:31). Content : -**
  - Bytes 0-3:
    - 4 bits: PMD lane index
    - 28 bits: Nominal PAM4 levels, 7 bits per level (1 fractional bits)
  - Bytes 4-99: Hits for each 64 bin levels 12 bits each as; $\max(0, \mathrm{round}(4095 + 128 * \log_2(\mathrm{bin\_hits}/\max(\mathrm{bin\_hits}))))$
  - Bytes 100-110: Zero-stuffed
- **0x02 : Estimated RX Pulse Response. Content : -**
  - Byte 0 : 4 bits represent PMD lane index. Zero stuffing on 4 bits.
  - Bytes 1-35 : Tap coeffs from 10^{th} precursor to 24^{th} postcursor in sint8 format, main tap normalized to +127.
  - Bytes 26-110: Zero-stuffed
- **0x03 : Retransmit (reverse direction) message request. Content:-**
  - Byte 0: 8-bit message index
  - Bytes 1-110: zero-stuffed.

Illustrative usage of Message Types:

- **0x04 : Specific (reverse direction) message transmit request. Content:-**
  - Byte 0: 8-bit message type (0x0-0x2; values 0x3-0xf shall be ignored).
  - Bytes 1-110: zero-stuffed.
- **0x05 : FEC CW Stats**
  - Bytes 0-5: Total codewords received
  - Bytes 6-11: Codewords received with 0 errors
  - Bytes 12-17: Codewords with 1 error
  - Bytes 18-23: Uncorrectable codewords
  - Bytes 24-110: Zero-stuffed
- **0x06 – 0xF: Reserved for future definition**
- **0x10-0xFE : Reserved for CMIS messages, terminating in switch (tunneling format to be specified)**
- **0xFF : Idle**
  - Bytes 0-110: zero-stuffed.

Reliability of In-band signaling (Padding) Field

Terminology used for reliability Analysis:

- **Successful transmission:** Event where receiver decodes all the data of transmitted message correctly, and recognizes correct reception
  - This is the most desired outcome for transmitted messages
- **Success Rate:** Probability of successful transmission of message sequence
- **Detected error:** Event where receiver recognizes its inability to correctly receive and decode the received message
  - May occur in an error-prone channel, but can be overcome with retransmissions
- **Undetected error:** Event where receiver incorrectly believes the packet is decoded correctly, despite errors in reception and decoding
  - MUST never occur in practice, and we try to drive its probability of occurrence to 0.
  - Egs. Undetected errors during decoding of a FEC protected transmission
- **MTTFPA :** Mean elapsed time from when transmission of messages begins until the first occurrence of an undetected error

Methodology for MTTFPA calculation

- A good reference in IEEE 802.3df when using KP4 FEC

Generated an easy-to-see formula based off this Eugene's contribution.
Note: This contribution is intended for "Stateless 64/66B encoding", but MTTFPA is part of the essential component to support this contribution.

https://www.ieee802.org/3/df/public/22_12/opsasnick_3df_01a_2212.pdf

MTTFPA Analysis and Updates for Stateless 64B/66B Coding

Eugene Opsasnick – Broadcom

802.3df December 2022

MTTFPA = [• At 800GE, an RS-FEC codeword arrives every 6.4ns] / [• Probability of undetected error packet from an undetected FEC error:
  • (FLR for FEC CWs with >15 FEC symbol errors) * Prob(FEC escape) * Prob(CRC32 escape)
  • 5.35E-9 * 1E-16 * 2.33E-10 = 1.24E-34]

Calculated MTTFPA needs to be > • Age of the universe ≈ 1.38E+10 years

- MTTFPA calculated based on **error** in transmission not detected in the PHY

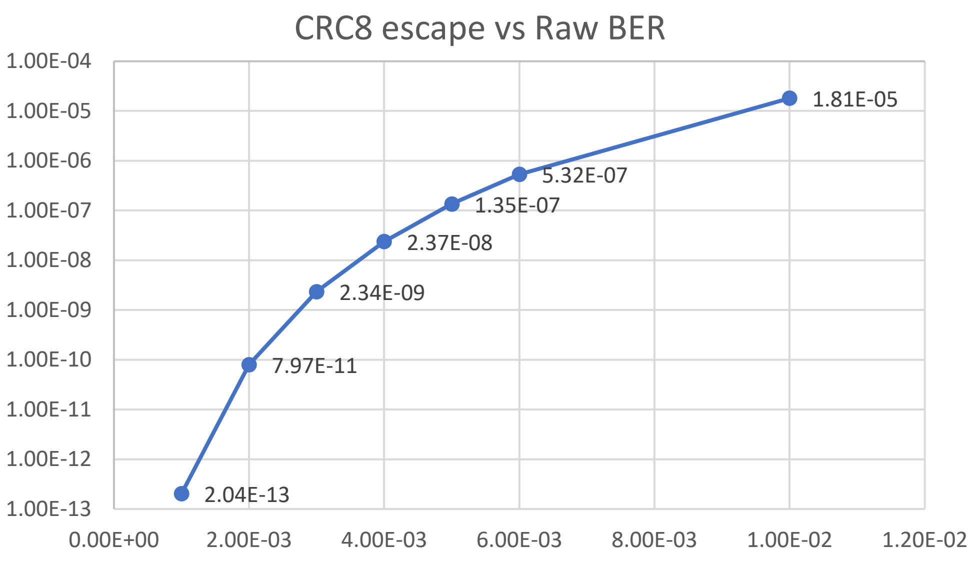
Calculating ***error*** in transmission that is not detected – for padding

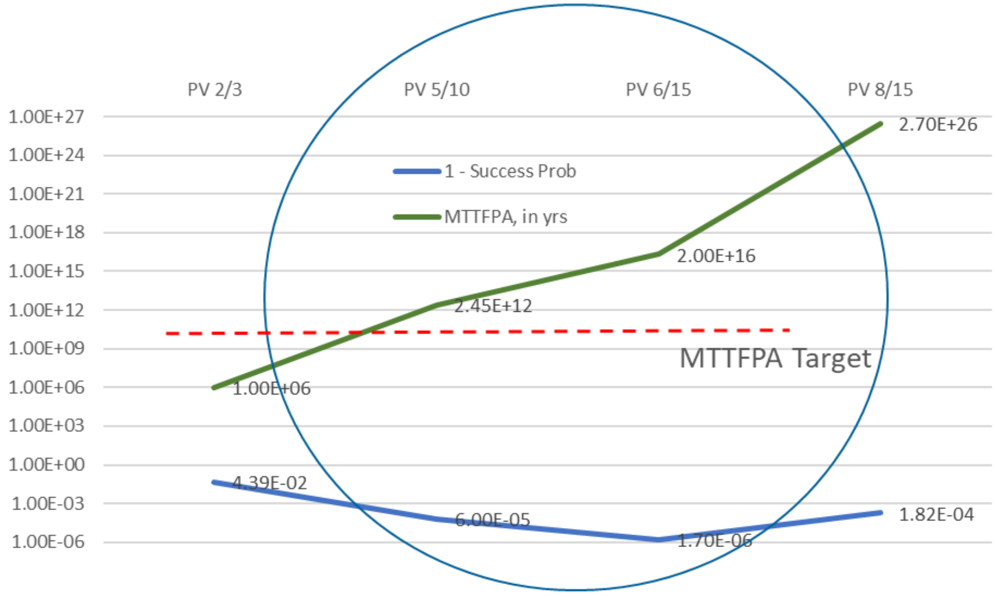
- Adopt the existing criteria for in-band signaling field, with the following error protection:
  - Hamming(128,120) coding, CRC-8, and repetition coding of signaling field

- This analysis illustrates step-by-step:
  - Given an input BER, calculate corresponding CER (codeword error rate)
  - Using CER, calculate success rate when ***repetition*** of transmission is used
  - From success rate, calculate the failure rate (i.e., error) in transmission
    - Highlight the importance of proper PV (plurality voting) criterion as used in repetition
  - From failure rate, calculate ***"false positive***" rate in repetition of transmission
    - For example, in 2/3 PV scheme, 2 padding codewords wrong in the same way is regarded as success, but is in fact a "false positive"
  - From false positive rate (per padding codeword): (1) extend the calculation to 8 padding codewords in every 8704 codewords, (2) include "CRC-8 escape", (3) consider 800G and 1.6T, and calculate the final MTTFPA. Lastly, compare with age of universe = 13.8 billion years (1.38E10 years)

MTTFPA Statistical Analysis:

- Assume worst-case link BER = ~4.8E-3
- Hamming(128,120)
  - Consider hard decision: able to correct 1 bit error in 128-bit codeword
- 128-bit codeword as 1 in-band signaling codeword (with 8 in-band signaling codewords sent every 8704 AUI payload codewords, or roughly 4.8 us)
- ***HD is the focus. With repetition & PV, MTTFPA target can be met***





Summary

- Complete details of In-band messaging format is presented in this proposal, which provides the overview of scrambling scheme used to construct the messaging.

- Reliability analysis of In-band messaging scheme is also presented using MTTFPA calculation methodology
  - MTTFPA of in-band signaling bits that meets AoU (age of universe) by using Hamming(128,120) encoding & CRC-8 protection with 10 repetitions in 5/10 PV criterion
  - Repetition can be autonomously set by transmitter, and updated with or without negotiation with receiver, based on prevailing BER.
  - PV scheme can be determined by receiver, based on BER

- Baseline setting of 10 repetitions and 5 out 10 PV is recommended

Thank you!