802.3dg line coding consideration

Tingting Zhang
Huawei Technologies

Introduction

- May interim meeting has motion passed PAM3 as modulation format. The straw polls show more supporters of using FEC for long-reach transmission and the same PAM with the same baud rate for both burst protection and low latency.

- Based on PAM3, three PCS presentations (Tingting_3dg_14_05_2024, Curran_3dg_01_06262024, Tingting_3dg_26_06_2024) show consensus on the dual-mode PCS at 80MBaud, PCS block coding, and RS-FEC (128,122) for only long distance. However, the line coding is different (8B6T or 4B3T).

- This presentation compares both line codes in terms of coding complexity, disparity bounding, and BER performance in the case of only AWGN.

Straw Poll #2

I support at least one PHY variant with forward error correction.

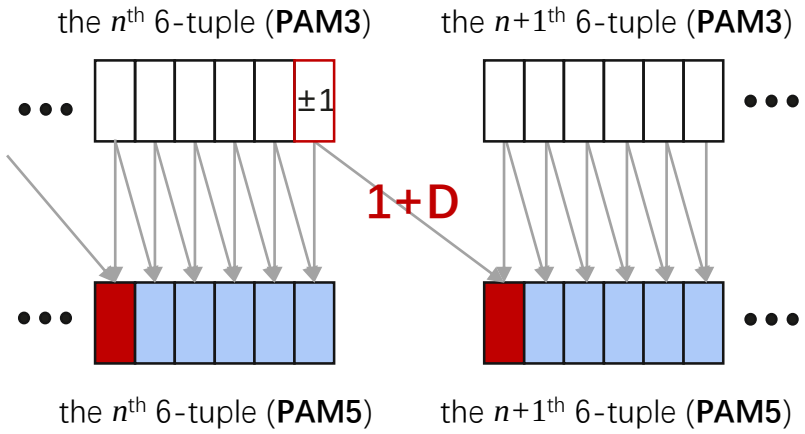
Y = 11 + 9 = 20
N = 1
A = 2 + 2 = 4

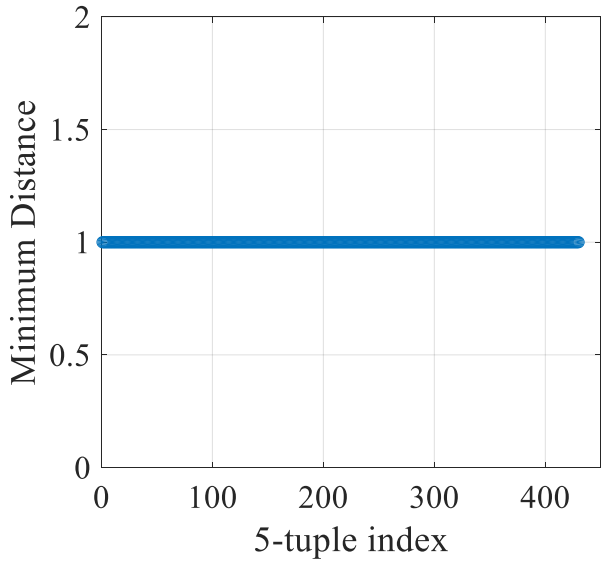
Straw Poll #6

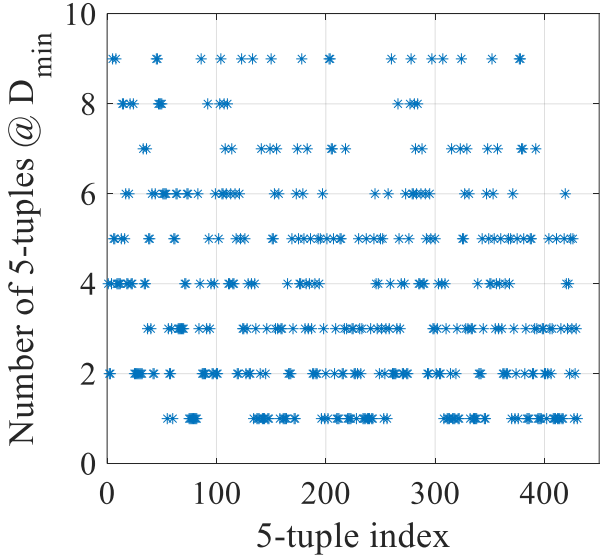
(This one applies only if #5 is Yes) Chicago Rules:
To better optimize low latency operation, I can support:
a) Same baud rate, same PAM for both full burst protection and low latency = 11 + 9 = 20
b) Same PAM, but fast baud rate for full burst protection and slower baud rate for low latency = 8 + 2 = 10
c) Same baud rate, but PAM4 for full burst protection and PAM3 for low latency = 0

8B6T with partial response

- As presented in Curran_3dg_01_05132024, the last symbol of any 6T PAM3 code-group is NOT zero. With the disparity bounding method in Curran_3dg_01_06262024, low-frequency components of the transmitted PAM3 signal can be suppressed.
- 1+D partial response leads to memoryless relationship between each 6T PAM3 code-group and the last 5 symbols of the associated 6-tuple (PAM5), whilst the 1st PAM5 symbol depends on the last PAM3 symbol in the previous 6T code-group.
  - 6T PAM3 or 8 bits can be recovered from the last 5 PAM5 symbols of the 6-tuple. However, the minimum Euclidean distance between the last 5 symbols is 1. Therefore, no performance gain.





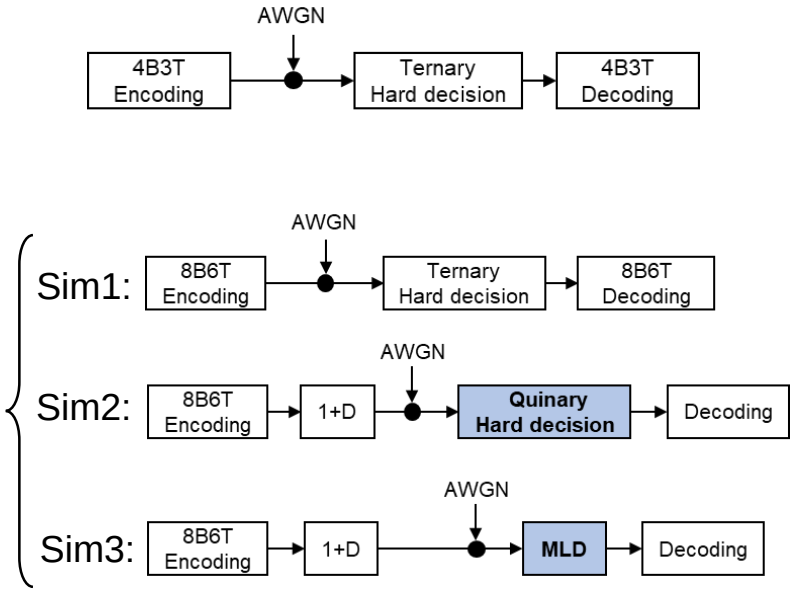


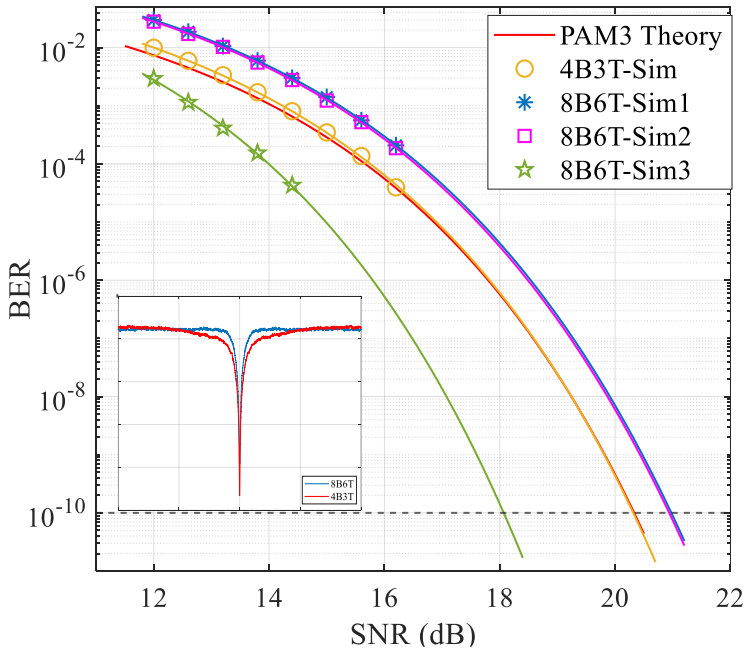
8B6T with partial response (cont.)

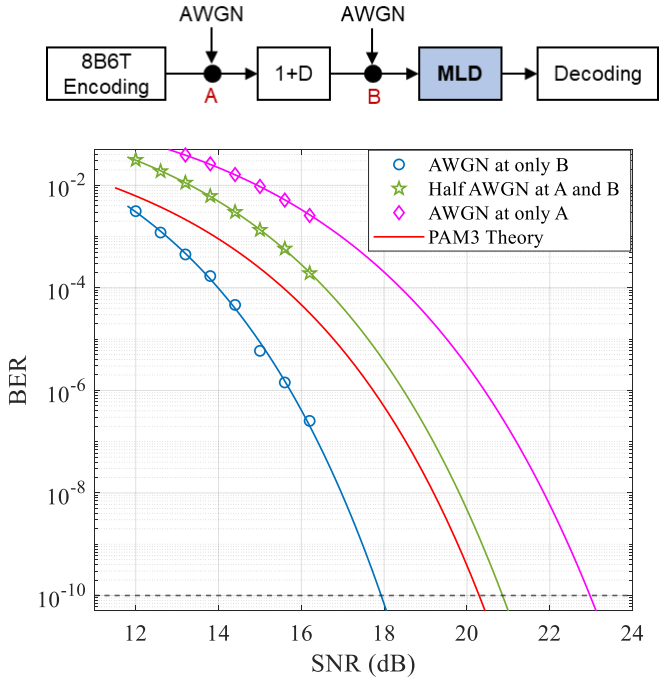
- All six PAM5 symbols of each received 6-tuple should be used in the ML detection, in order to increase the minimum distance to $\sqrt{2}$. Moreover, 6-tuple delimiting needs to be performed before the detection.
- For each received 6-tuple ($y_{n,1-6}$) with noise, 6-tuple with PAM5 is decided from the minimum Euclidean distance. The distance is calculated as $D_{n,m}=\sqrt{\sum_{k=1}^{k=6}\left(y_{n,k}-R_{m,k}\right)^2}$, where $R_{m,1-6}$ refers to each possible reference 6-tuple (PAM5).
- High-resolution multiplication is required in the distance calculation. The last PAM3 symbol of the transmitted 6-tuple can be 1 or -1. Therefore, the number of the reference PAM5 6-tuples is twice as much as the transmitted 6T code-group. More efforts need to be made to balance the detection complexity and latency.

Performance comparison in the case of only AWGN

- AWGN noise power is calculated with regard to the transmitted PAM3 signal power for each given SNR. With only AWGN, simulation results should be close to theory, as exemplified by 4B3T.
- 4B3T outperforms 8B6T with Ternary/Quinary hard-decision. 4B3T also enables better low-frequency suppression.
- For 8B6T with MLD, BER performance depends on how AWGN is added. Only when AWGN is added AFTER 1+D, the coding gain can be achieved.





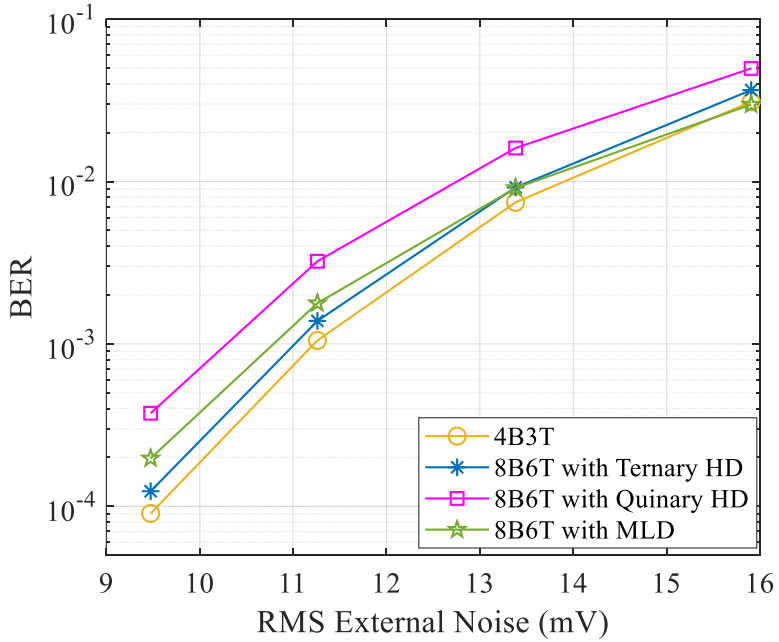


Details of time-domain simulation

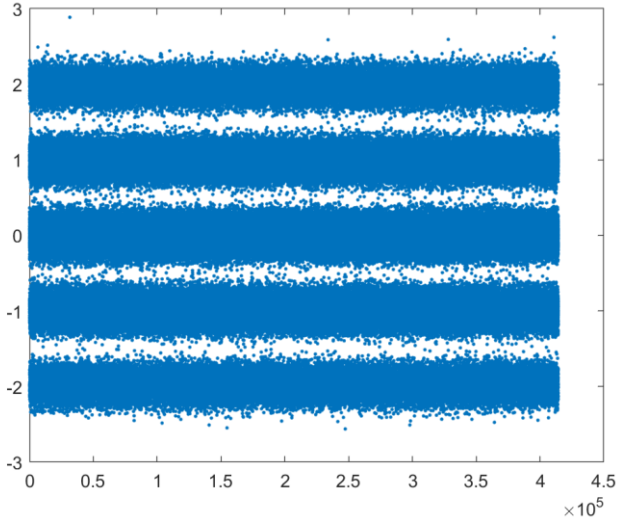
- Time-domain simulation details:
  - 2.4V transmit level
  - Ideal line driver, 12-bit DAC and ADC
  - AWGN added after 500m (802.3dg IL limit) transmission before Rx equalization
  - Simulation bandwidth is set to the same as symbol rate, eliminating the use of LPFs
  - AWGN rms voltage is calculated over 80MBaud
  - 30-tap FFE and 5-tap DFE
- Considering that SNR does not intuitively show BER, we evaluate BER by comparing the recovered and generated bit streams.
- To ensure confidential BER within acceptable simulation time, higher AWGN noise is used in the simulation.

Time-domain simulation results

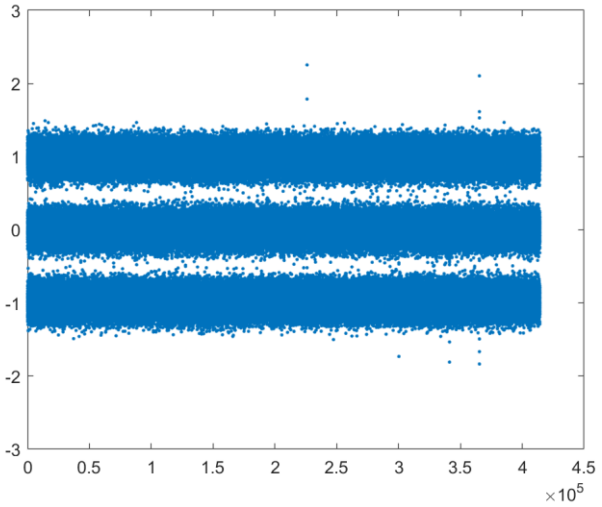
- In terms of equalization for 8B6T, Quinary slicer (PAM5) makes the equalizer (EQ) more difficult to get convergence than using Ternary slicer (PAM3). Therefore, 100k synchronized symbols are utilized for training first and then switched to blind decision mode.
  - For fair comparison, the equalizers regardless of slicer types all operate in training mode before switching to the blind data mode. This also reduces the impact of equalizer parameters on BER.
- Time-domain simulation shows that for 500m transmission, 4B3T outperforms 8B6T regardless of the detection method.



Quinary EQ output @ 9.5mV niose



Ternary EQ output @ 9.5mV niose



Summary

- In the case of only AWGN, 4B3T outperforms 8B6T with Ternary/Quinary hard-decision. 4B3T also enables better low-frequency suppression.
- Only when AWGN is added AFTER 1+D, the coding gain can be achieved. For 8B6T, more efforts need to be made to balance the detection complexity and latency.
- Time-domain simulation shows that 500m transmission using 4B3T achieves better performance than 8B6T, regardless of the detection method. Rx equalizer using Ternary slicer is more stable and easier to get convergence than using Quinary slicer.
- With all taken into account, 4B3T is a better option for 802.3dg.

Thank you!