BER budget allocation for AUIs

Adee Ran, Cisco

Introduction

- Various options of BER allocation for AUIs have been laid out in brown_3dj_elec_01a_230406 with simple additive budgeting.
- Latency has been analyzed in brown_3dj_optx_01b_230413
- The effect of correlated errors in the AUI has been addressed in he_3dj_optx_01a_230413 focusing on RS codeword interleaving.
- This contribution:
  - Presents results with 2/4 RS codeword interleaving (independent analysis)
  - Compares various AUI BER allocations and levels of error correlation.

What is included

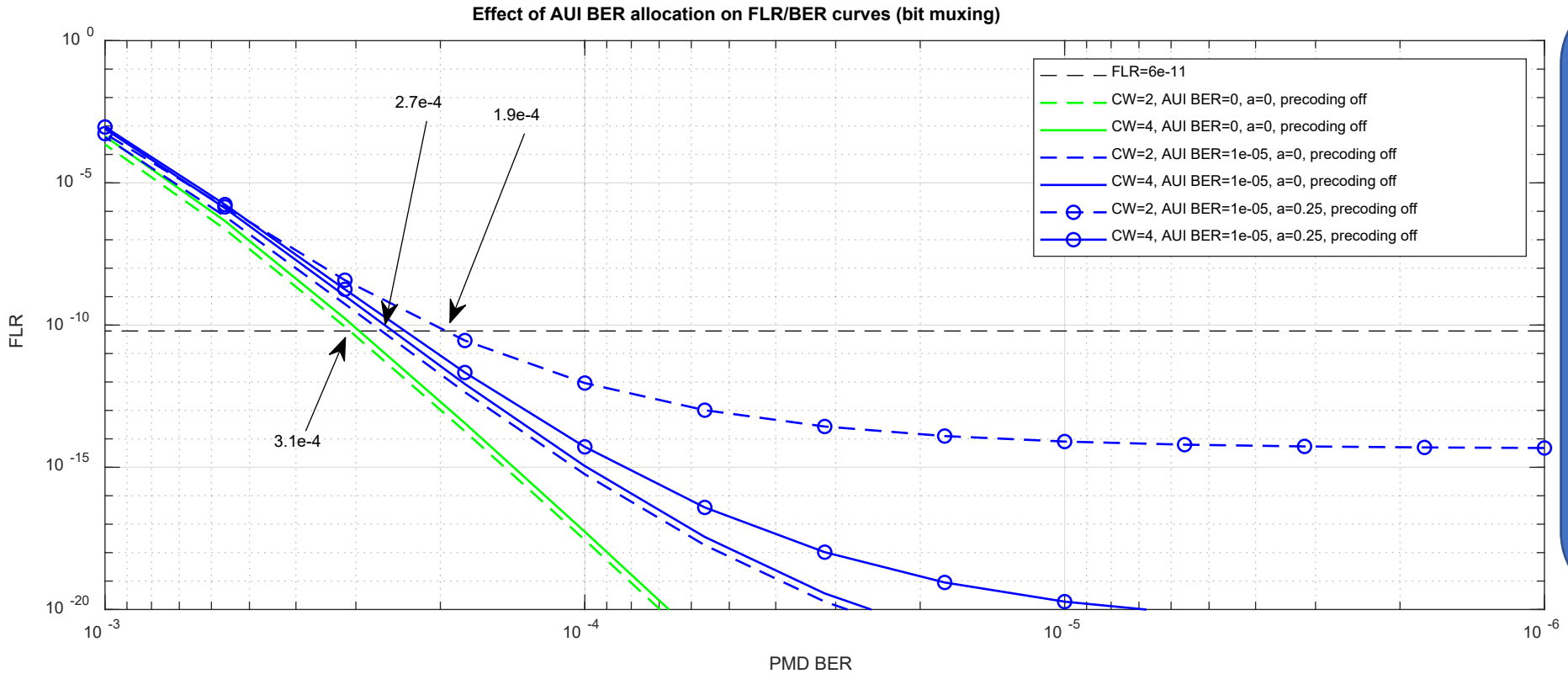
- Pure statistical analysis
- Non-segmented RS-FEC
- “PMD BER” includes a possible inner FEC decoder effect
  - This is the BER at the module output
- Number of RS codewords: 2 or 4
- 4 AUIs (2 on each side) with sweep of
  - AUI BER (before any error propagation): 0, 1e-5, 2.5e-5, 5e-5 on each (0, 2e-5, 5e-5, 1e-4 per PHY)
  - Error propagation factor a: 0, 0.25 (mild, e.g. MLSE), 0.75 (severe, e.g. strong DFE)
  - Precoding on or off (only with a=0.75)
- Bit muxing for 100G/lane; Symbol muxing for 200G/lane

Error correlation

- “AUI BER” is used in this presentation as **the rate of random errors** (essentially DER/2)
  - Correlation due to error propagation is a swept parameter
  - In COM analysis, the DER should be twice of AUI BER (2e-5, 5e-5, or 1e-4 per segment)
- “PMD BER” is after inner FEC decoding (if used) and is assumed to be uncorrelated.
  - The convolutional interleaver is assumed to spread each 120-bit block (which can contain several errors) across 12 different RS-FEC codewords.
  - The case of no convolutional interleaving (where up to 3 or 6 symbols of a single RS-FEC codeword can be affected) is not covered – planned as a future contribution.
  - Correlated errors/noise on the optics can affect the PMD BER but have no other effect in this analysis.

Results

Sanity check: AUI budget allocation with bit muxing (100 Gb/s)



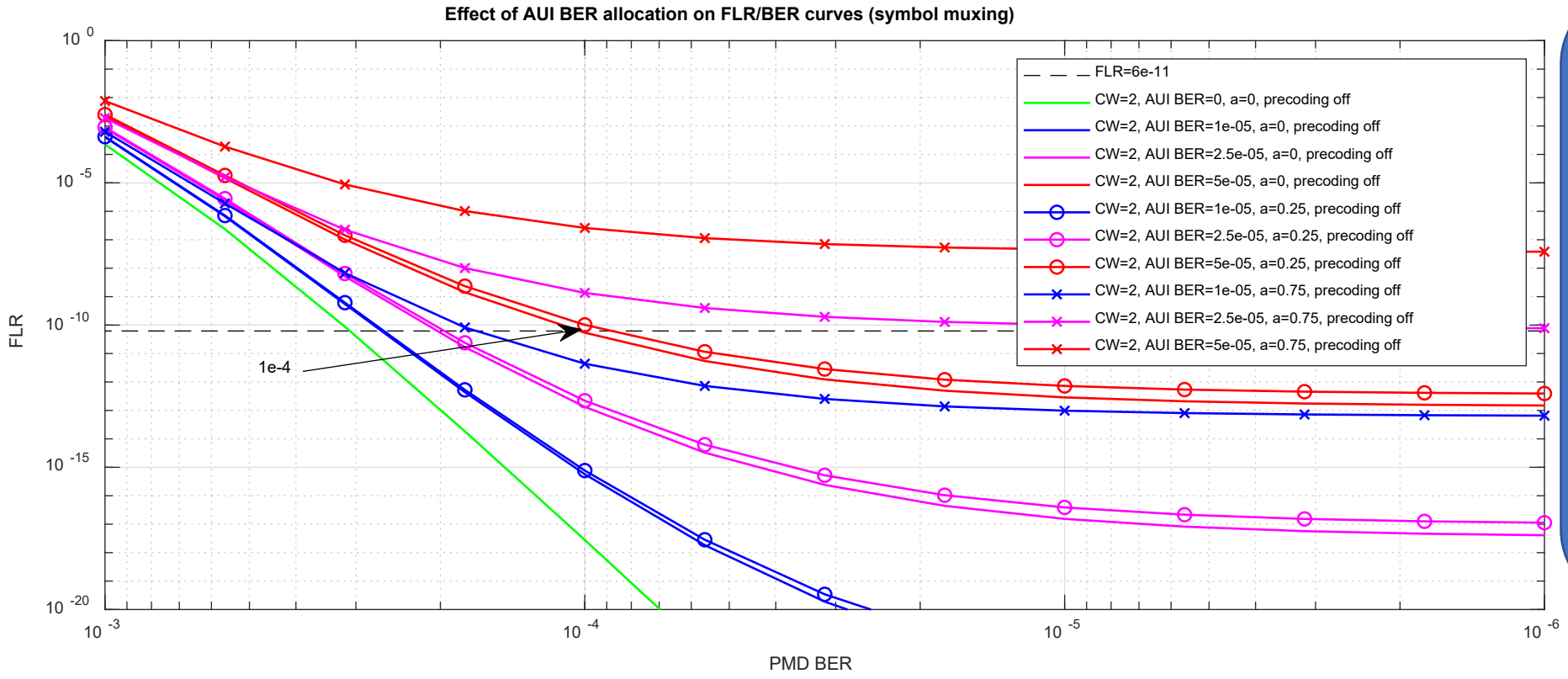
PMD BER for FLR=6.2e-11 is:

- ~3.1e-4 if AUI BER is taken as 0
- ~2.7e-4 if AUIs are allocated 1e-5 with no error correlation

With 2-CW interleaving, even mild error correlation (corresponding to a limited DFE in AUI-C2M) has a significant FLR floor effect.

With 4 codewords the effect is smaller.

AUI budget allocation with symbol muxing (200 Gb/s), 2 CW interleaving on AUIs

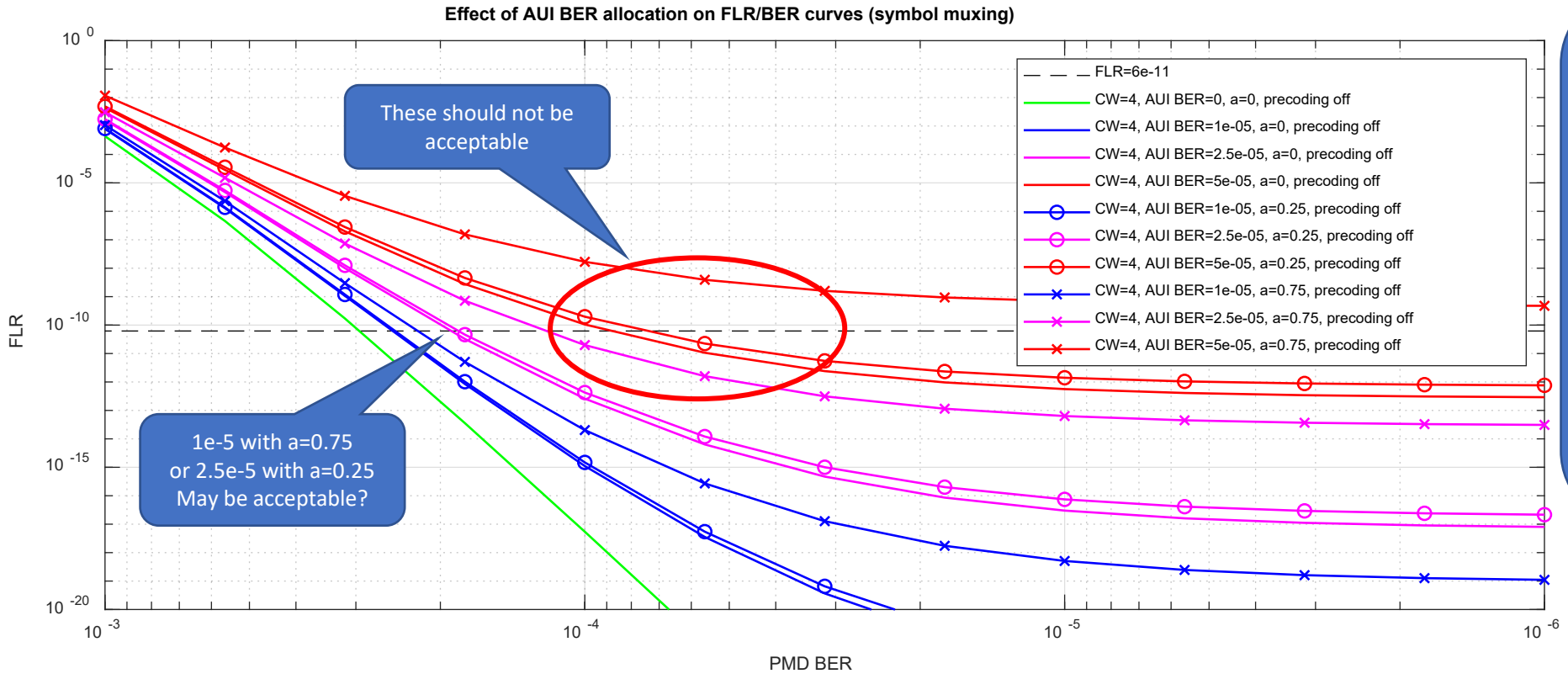


PMD BER for FLR=6.2e-11 is:

- Same as bitwise muxing under "sanity check" conditions
- ~1e-4 if AUIs are allocated 5e-5 with no error correlation
- Mild error correlation (a=0.25) creates a small increase

High "FLR floor" seen if AUI BER=5e-5 and/or a=0.75

AUI budget allocation with symbol muxing (200 Gb/s), 4 CW interleaving on AUIs

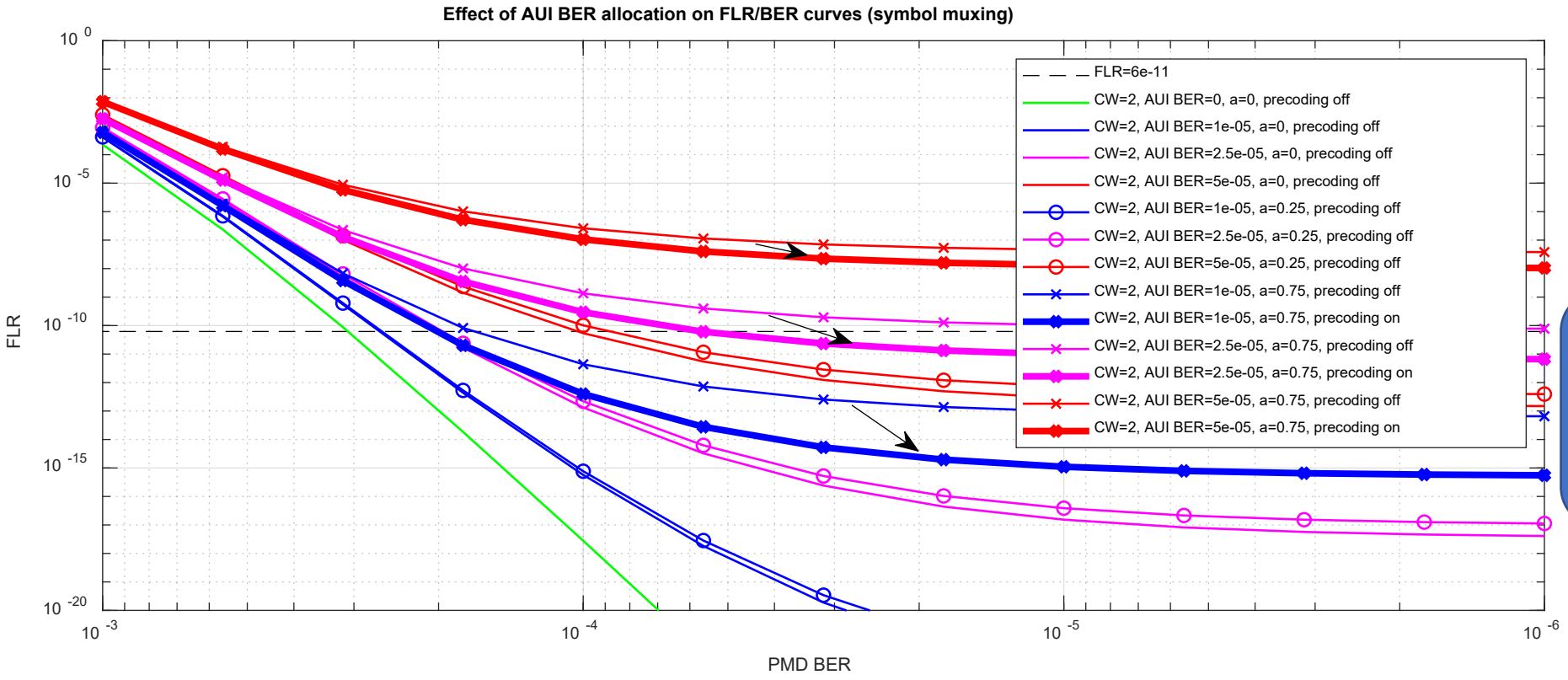


The PMD BER for FLR=6.2e-11 is:

- Same as bitwise muxing under “sanity check” conditions
- Similar to 2-CW with no error correlation
- Better (higher) than 2-CW with error correlation

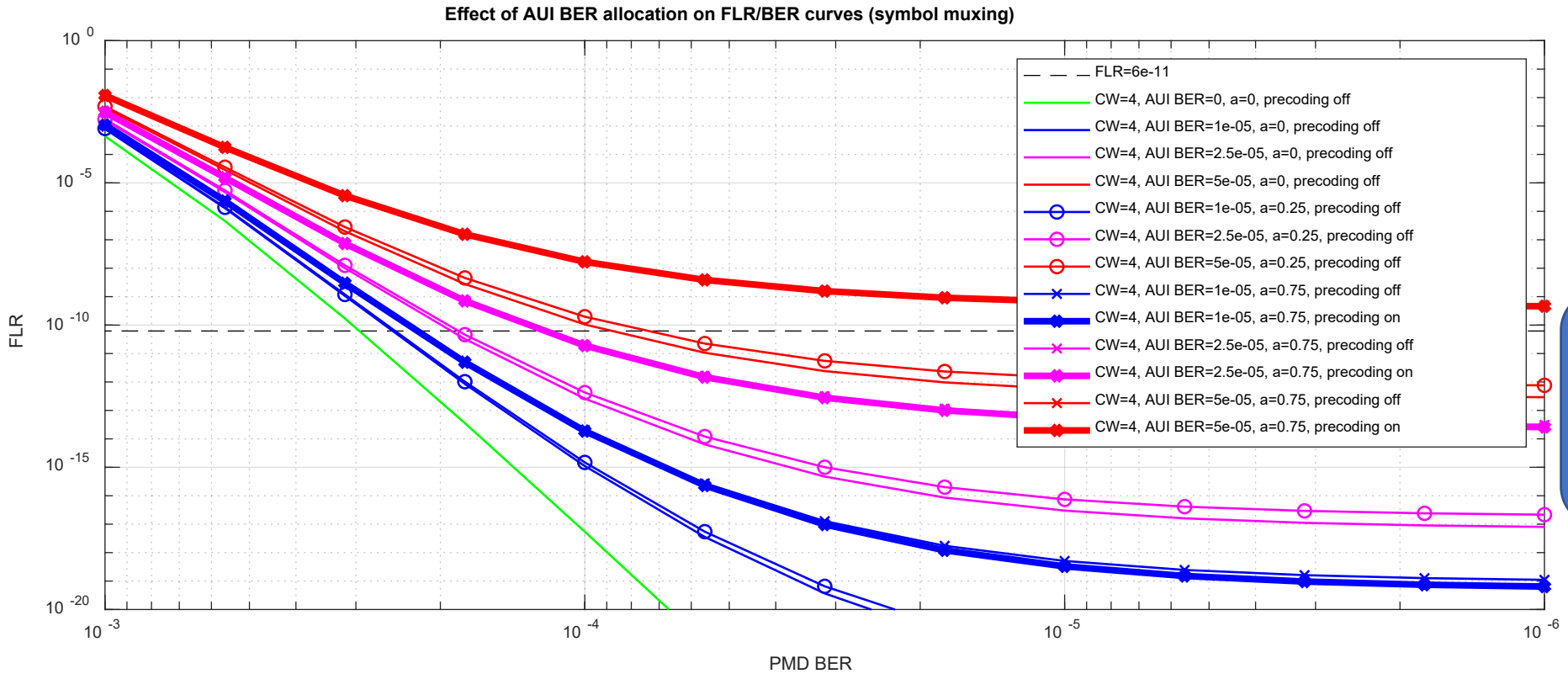
“FLR floor” still observed with AUI BER>5e-5, and with 2.5e-5 and a=0.75

Effect of precoding with 2-CW interleaving



With severe error correlation (a=0.75), precoding (thick line plots) somewhat reduces the FLR floor

Effect of precoding with 4-CW interleaving



Precoding (thick line plots) has negligible effect.

Summary

- 2-way RS-FEC interleaving is very sensitive to correlated errors in the AUI
  - a=0.75 on the AUIs flattens the FLR curve even with BER 1e-5
  - Performance with AUI BER of 1e-5 is similar to 2.5e-5 with 4-way interleaving
  - ➔ **Additional PMA codeword interleaving for 200G/400G is recommended**
- With 4-way interleaving, precoding has little effect and is not required
- AUI BER allocation can have a large impact on PMD BER:
  - 1e-5 per AUI (or 2e-5 per PHY) even with a=0.75 enables meeting the 6.2e-11 FLR target with PMD BER of ~2.2e-4 (**almost no reduction**) and does not create an FLR floor
  - 2.5e-5 per AUI (or 5e-5 per PHY) with a=0.75 enables meeting the 6.2e-11 FLR target but with a **reduction of the PMD BER by a factor of 2.5**
    - That is, from 3e-4 to 1.2e-4 (after inner FEC decoding)
    - This case as an FLR floor at ~1e-14, which may be unacceptable
  - BER above 5e-5 per PHY **creates a high FLR floor, making low FLR unachievable**
    - If AUIs have these BER levels, they can be used within a xGMII Extender

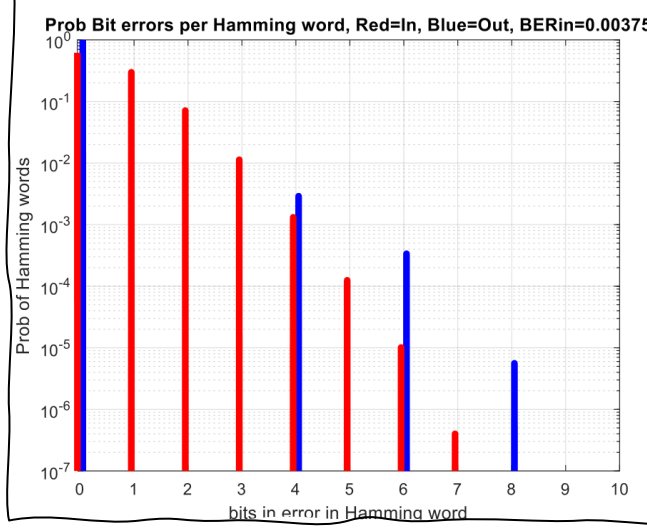
Backup

What is the BER of the optical link?

Error characteristics of Inner FEC code

- Dmin=4
- Hard decoder can always correct a block with a single-bit error (one “bad sample”)
- Blocks with 2 “bit errors” can be changed to either of two neighbors (either 0 or 4 output bit errors)
- Soft decoder can correct more errors on average, but occasionally create more errors
  - Blocks with 8 bit errors occur with non negligible probability
- If the convolutional interleaver is not used, this can cause up to 6 symbol errors in one codeword (2-CW case)
- The effect of these multi-error events without interleaving is planned to be explored in a future analysis.

Why are Large Interleavers needed, even on the AWGN channel?



- Example for channel BER_in=3.75e-3
- The AWGN channel produces bit errors that are ‘random’
- The probability of number of errors input to the Hamming block are binomially distributed
- The soft decoder corrects many / all Hamming words with a low number of errors
- But it leaves ‘mis-corrections’ and/or ‘uncorrected’ words with large number of bit errors
- Output words in error have at least 4 bits in error, demonstrating dmin=4 of the extended Hamming code
- NO Words with 5,7,9.. bit errors show the overall even parity of the extended Hamming code
- The distribution of errors in the Soft decoded output is very far from ‘random’

Source: bliss_3df_01a_220517, slide 9