200G/lane PAM4: Error Profile Error Propagation and Error Correction Considerations

Part3 -Multi part links cases - FEC strategies and their solution space

Upen Reddy, Kareti

David , Nozadze

Cisco Systems Inc.

Overview

- Consider different cases of Multipart links and evaluate solution space with Monte Carlo simulations for different FEC strategies
- Multipart links cases span from two AUI sub-links on each side of the optical sub-link.
  - AUI sub-links comprise of
    1. High loss AUI sub-links up to ~36 dB with DER_0 up to 1e-4
    2. Medium Loss AUI sub-links up to ~ 22db with DER_0 up to 1e-5
    3. Combination of High loss and medium sub-links
  - Optical sub-link comprise of optional inner FEC code
    - Inner BCH FEC code with correction capability of 1 bit up to 5 bits
  - RS FEC options
    1. End to end RS FEC (544,510,10) - referred as RS544 FEC
    2. 2 segment RS FEC
    3. 3 segment RS FEC
  - Receiver options include
    1. DFE or MLSE in AUI sub-links and No DFE in optical sub-slink
    2. DFE in in all sub-links
    3. MLSE in all sub-links

Simulation Environment

- Monte Carlo with DFE use DFE feed back loop to determine PAM4 levels in determining error propagation
- Monte Carlo with MLSD uses α to find appropriate levels and confidence values of those levels based on trace back length of 5 symbols.
- With these two options the possibility of Skip level errors exist.
  - The results will reflect if they play any role, particularly when (1+D) precoding is included.
- Using 4 RS FEC code word interleave required CER of 1.5e-11 or FLR of 6.2e-11 is considered as passing criteria. See slide 6 in opsasnick_3df_logic_220630a

Simulation Environment

- 4 RS FEC codeword interleaving
  - Symbol mux is used in PMA (not a blind symbol mux)
  - No bit mux case in included as it is considered to have significant impact to link performance. See ran_3df_01a_2211
- (1+D) Precoding on electrical segments only
  - No Precoding applied to Optical segment
- Inner code : BCH (144,136) with convolutional interleave for optical segment for coding convenience for Monte Carlo analysis. See he_3dj_01a_230206
  - a sample test is run (not shared here) to confirm BCH (128,120) is similar in Inner FEC code performance

Multipart link : Case 1 High Loss DFE/MLSE

High Loss
~36 dB
1e-4

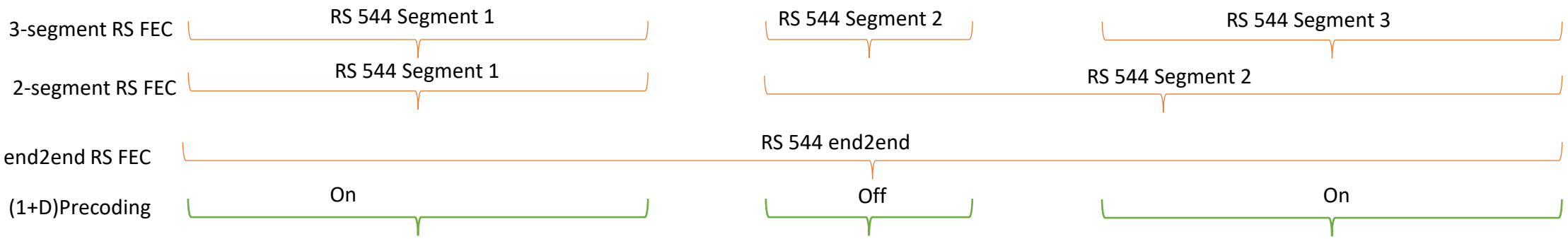
High Loss
~36 dB
1e-4

Optional FEC Inner code concatenation BCH W/conv. Inter leave
t Count = 1 to 5
2.4e-4
3.3e-3
4.6e-3
DFE = 0.01,0.2,0.5

High Loss
~36 dB
1e-4

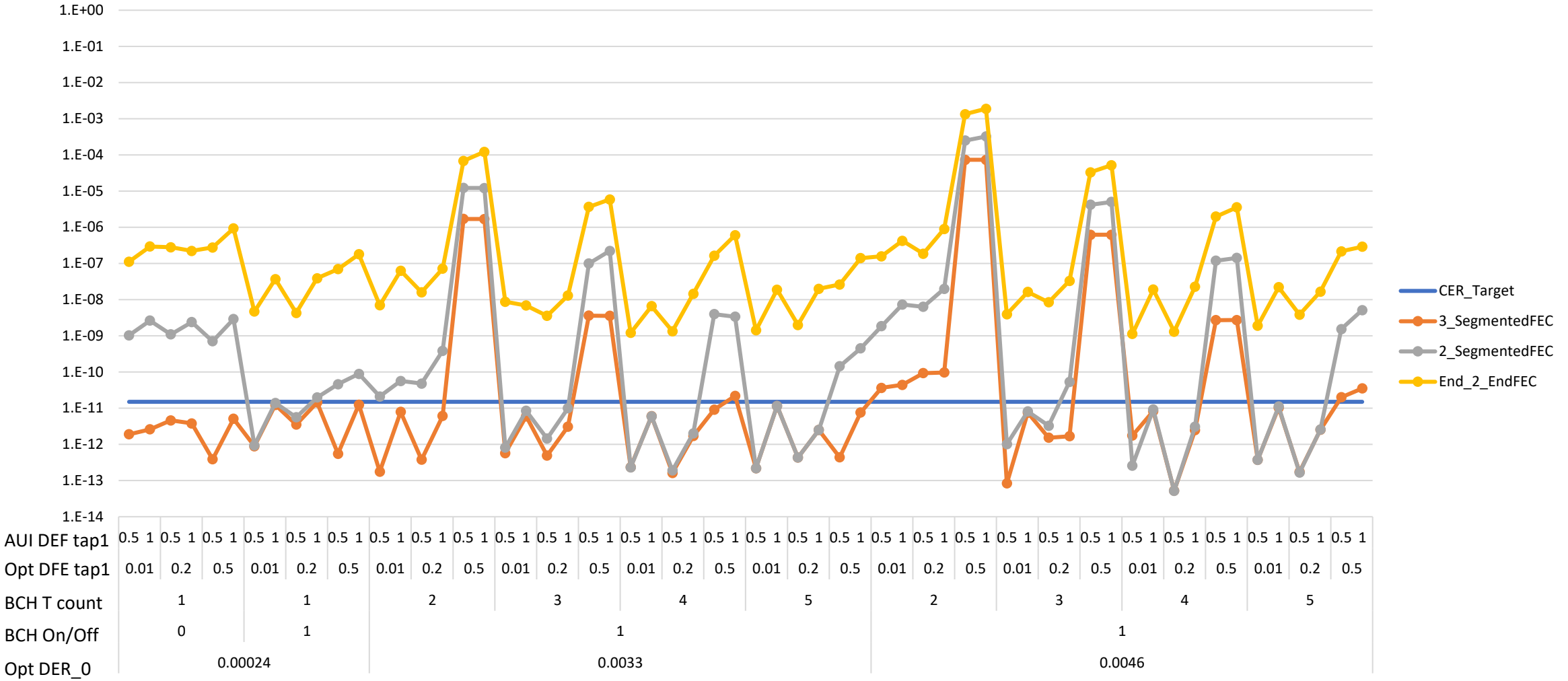
High Loss
~36 dB
1e-4

4 RS544 codeword Interleaving
Symbol MUX at PMA



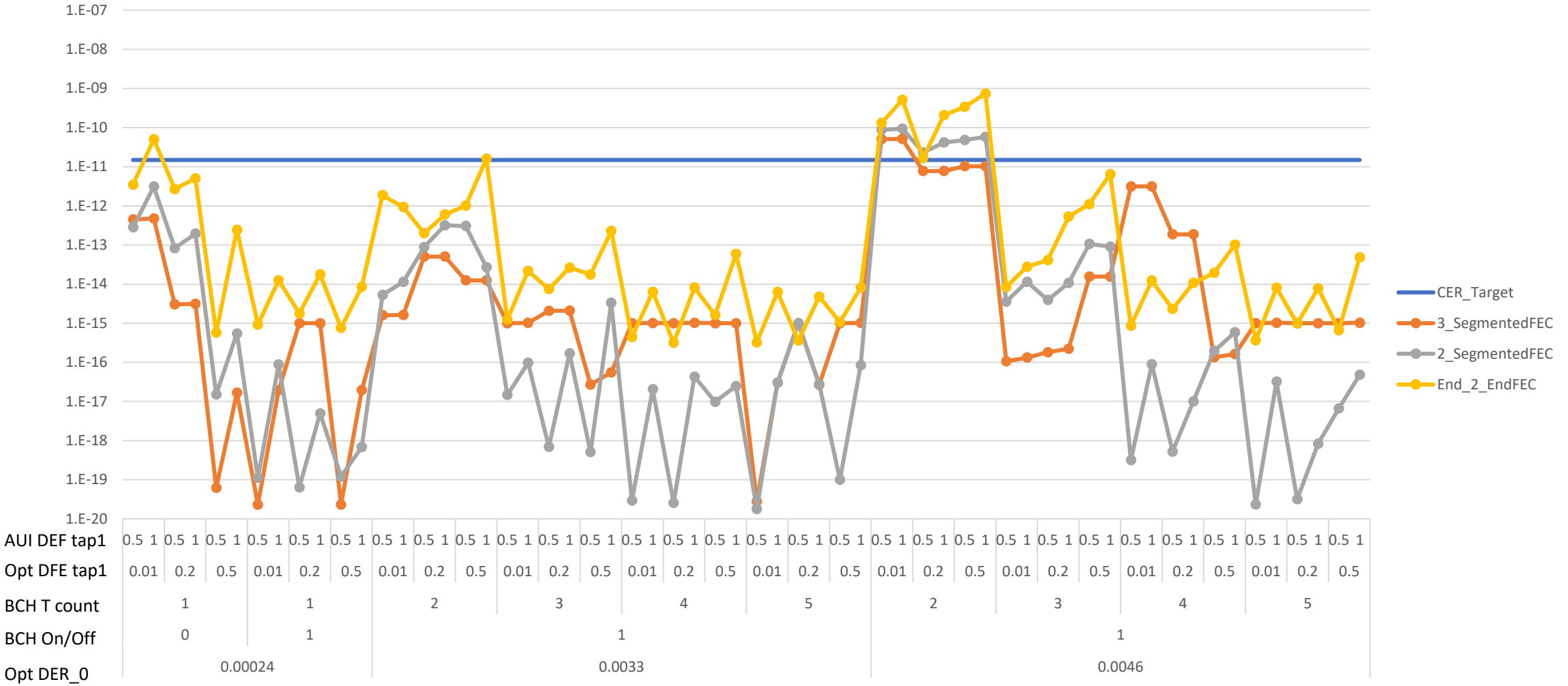
Multipart link : Case 1: High Loss AUIs

- DFE at all sub-link receivers



Multipart link : Case 1a: High Loss AUIs

- MLSE at all sub-link receivers



Multipart link : Case 2 Mixed Loss DFE/MLSE

High Loss
~36 dB
1e-4

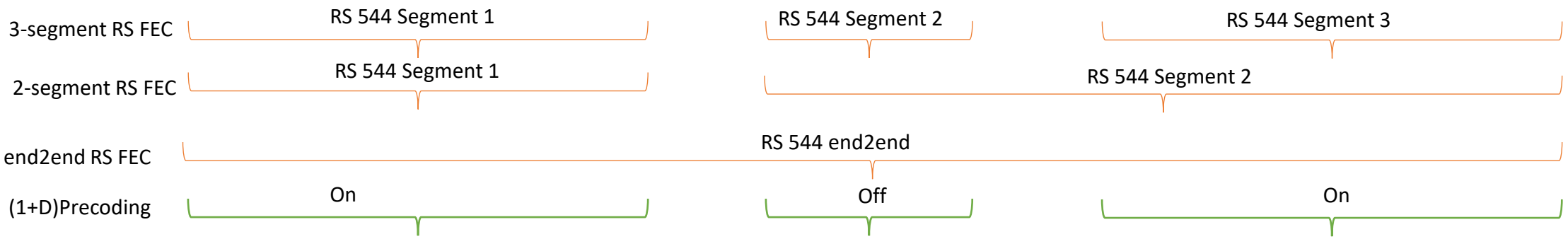
Medium Loss
~22 dB
1e-5

Optional FEC Inner code concatenation
BCH W/conv. Inter leave
t Count = 1 to 5
2.4e-4
3.3e-3
4.6e-3
DFE = 0.01,0.2,0.5

Medium Loss
~22 dB
1e-5

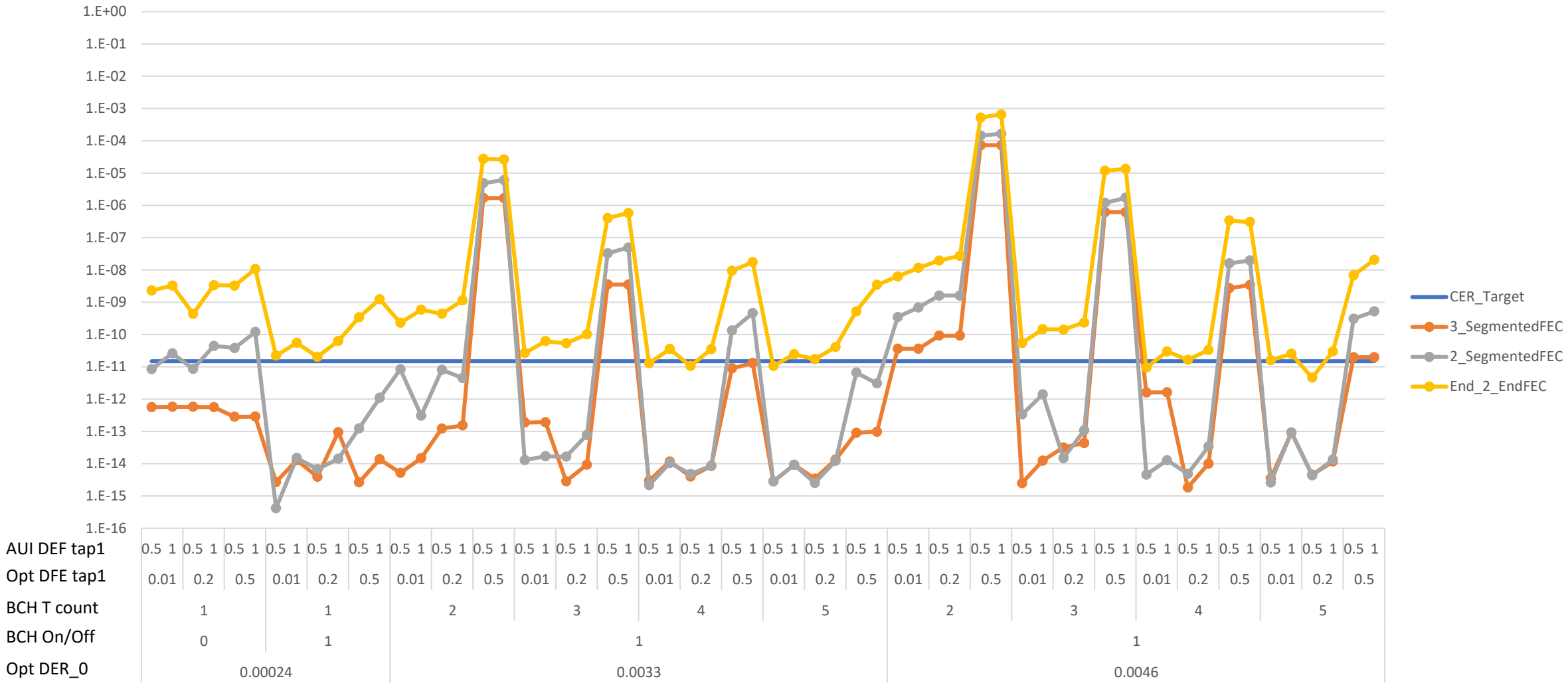
High Loss
~36 dB
1e-4

4 RS544 codeword Interleaving
Symbol MUX at PMA



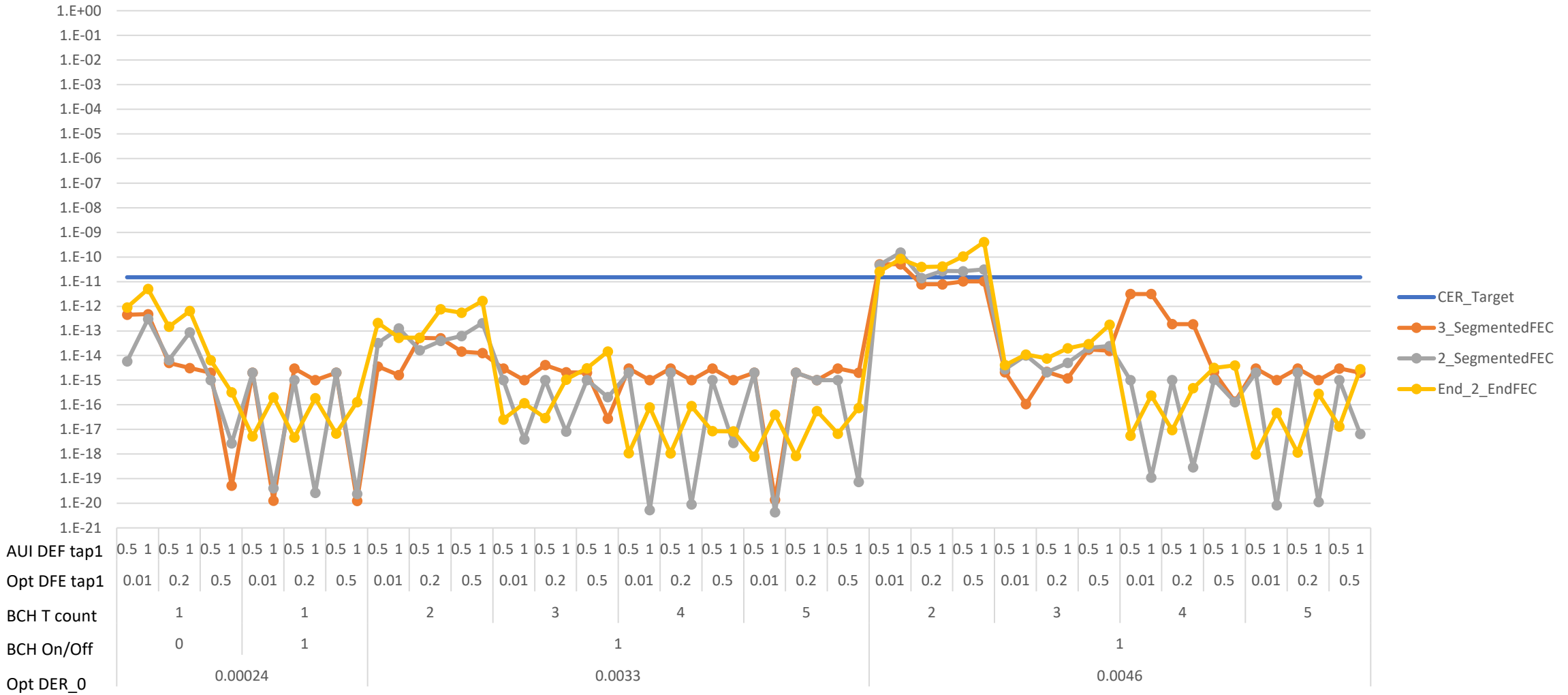
Multipart link : Case 2: Mixed Loss AUIs

- DFE at all sub-link receivers



Multipart link : Case 2a: Mixed Loss AUIs

- MLSE at all sub-link receivers



Multipart link : Case 3 Medium Loss DFE/MLSE

Medium Loss
~22 dB
1e-5

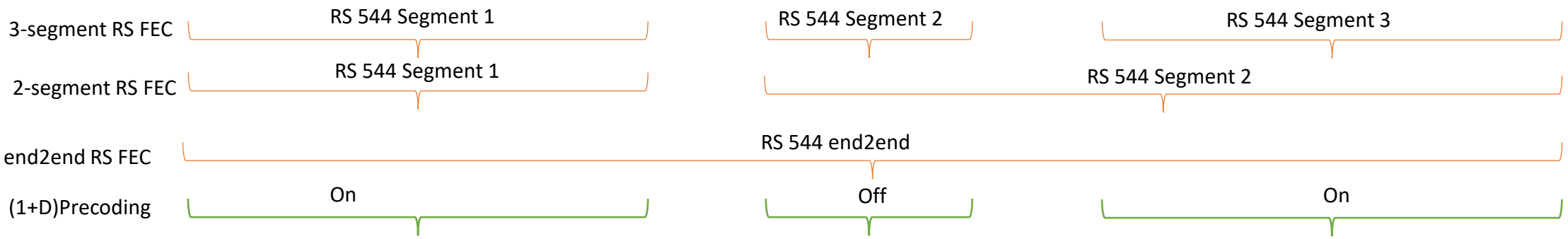
Medium Loss
~22 dB
1e-5

Optional FEC Inner code concatenation BCH W/conv. Inter leave
t Count = 1 to 5
2.4e-4
3.3e-3
4.6e-3
DFE = 0.01,0.2,0.5

Medium Loss
~22 dB
1e-5

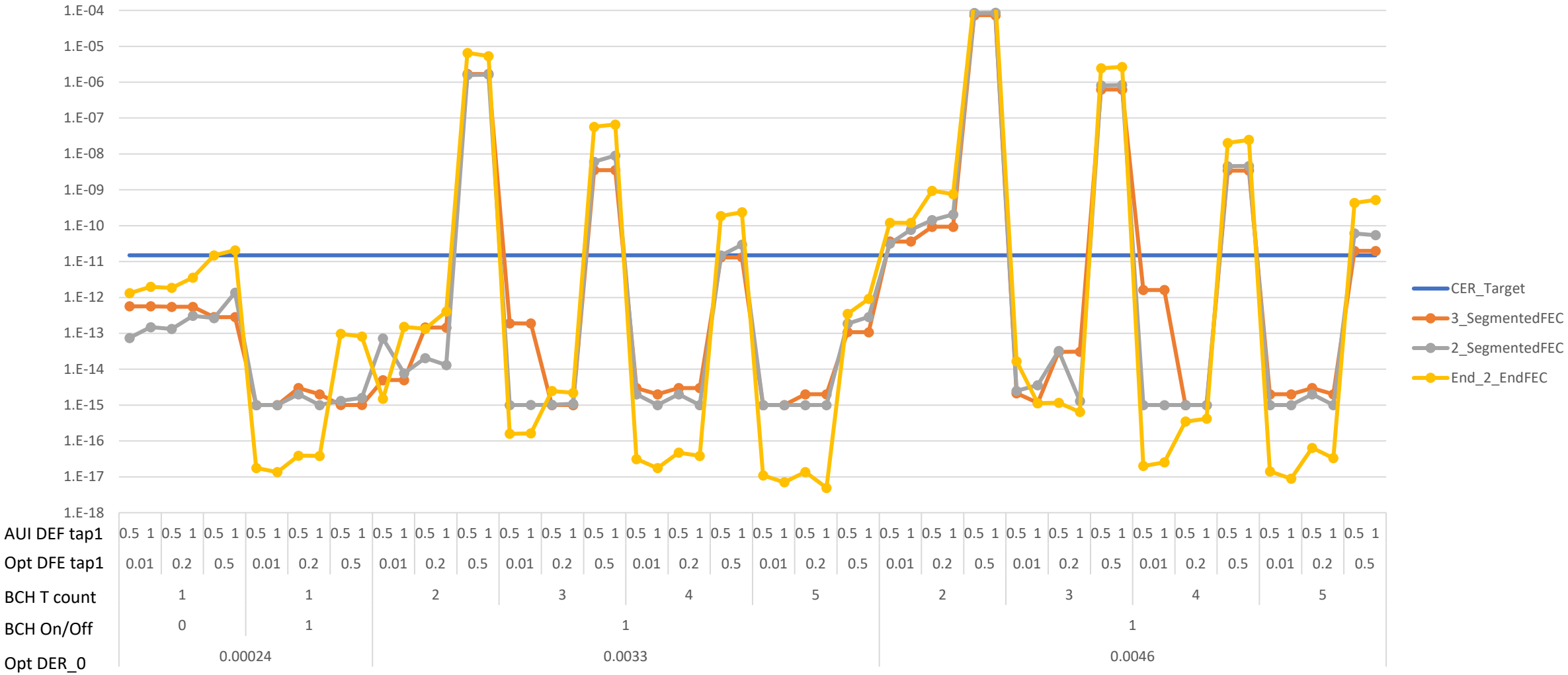
Medium Loss
~22 dB
1e-5

4 RS544 codeword Interleaving
Symbol MUX at PMA



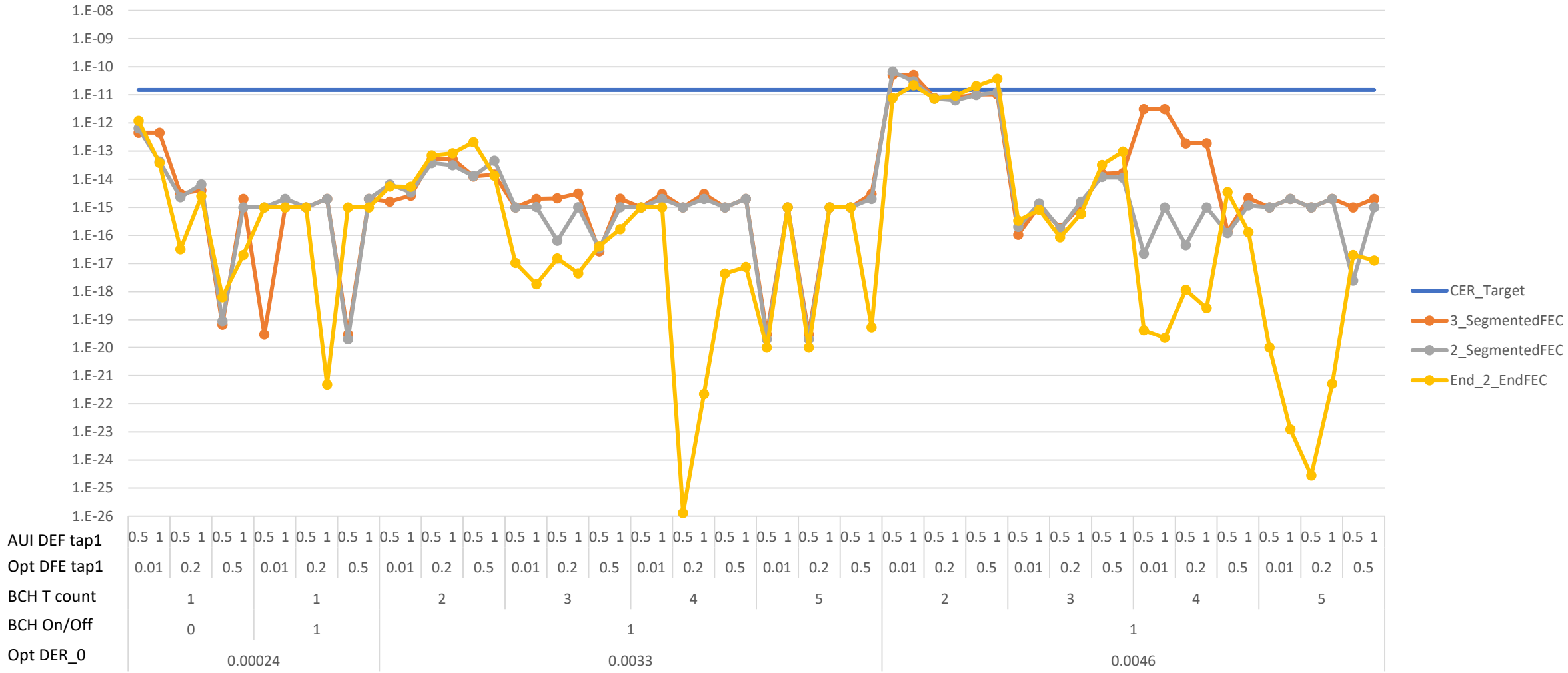
Multipart link : Case 3 Medium Loss AUIs

- DFE at all sub-link receivers



Multipart link : Case 3a Medium Loss AUIs

- MLSE at all sub-link receivers

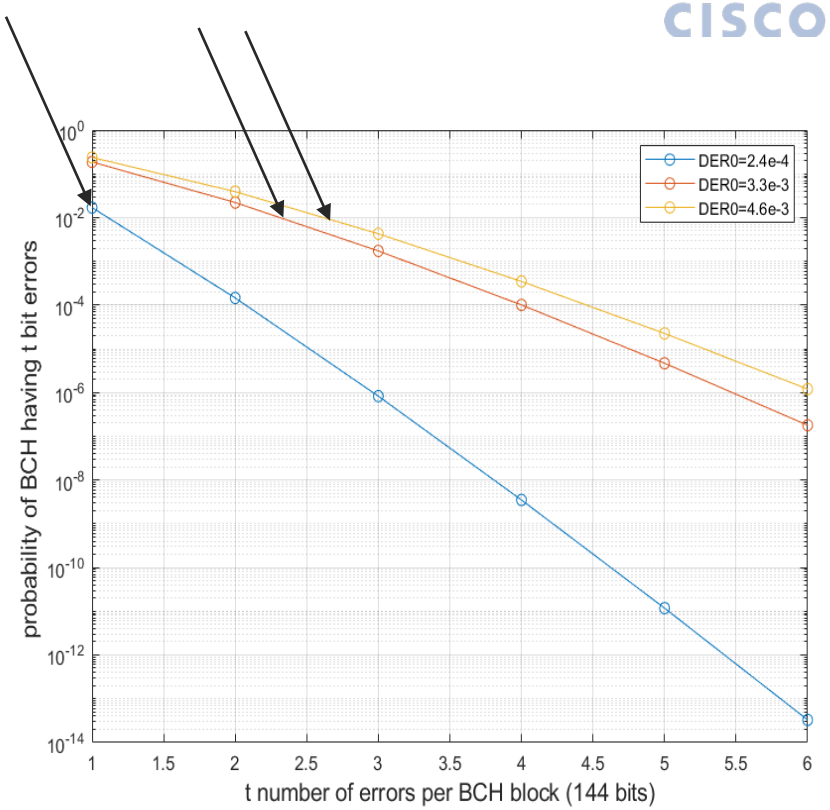


Observations from results

- Given Optical Sub-link proposals so far are with concatenated FEC
  - Outer end2end RS- 544 FEC
  - Inner FEC either (144,136) or (128,120) BCH blocks with overheads pertaining to 1 bit error correction in inner FEC blocks and SFEC is proposed to get additional bit corrections and convolutional interleave is to redistribute the errors left after correction.
  - With BCH 1 bit correction – target DER_0 of 6.1e-4
  - With SFEC get additional bit corrections per bch block (~2.4 bits) - target 3.3e-3
  - With SFEC get additional bit corrections per bch block (~2.4 bits) and with convolutional interleave in Optical PMA to get up to DER_0 of 4.6e-3

Looking into the results data for error profiles at various stages of the analysis the following observations are made

1. After inner FEC- BCH correction, even though they meet DER targets as stated above, the remaining burst errors distributed into Outer RS544 FEC is influencing the link performance.
2. To achieve DER_0 3.3e-3 we need to up to 4-bit correction per BCH block and > 4.4 bits of correction per BCH block for DER_0 of 4.6e-3 to get equal to DER_0 of 2.4e-4
3. Even with moderate correlated errors like error propagation present, end2end Outer RS544 is not sufficient to meet required CER/FLR
4. In the presence of 4 codeword interleave , BCH convolutional interleave is not providing any discernable benefit. (But in this analysis, it is still used).
5. The coding gain due to convolutional interleave in optical PMA, may not be realizable because of the way the remaining errors after inner FEC correction are redistributed into outer RS 544 FEC symbols.



t	0	1	2	3	4
DER0	post_FEC DER	post_FEC DER	post_FEC DER	post_FEC DER	post_FEC DER
3.30E-03	3.30E-03	6.94E-04	7.82E-05	5.95E-06	3.40E-07
4.60E-03	4.60E-03	0.0013	2.00E-04	2.10E-05	1.67E-06

Observations from results

MLSE at all sub-link receivers

- ALL FEC strategies work including concatenated FEC
  - but for DER_0 of 3.3e-3 needs at least 2-bit corrections in inner code BCH Blocks
  - And for DER_0 of 4.6e-3 needs at least needs 3-bit corrections in inner code BCH blocks

DFE at all sub-link receivers

- 3-Segemented RS FEC is needed for high loss AUIs (case 1)
- 2-segmented RS FEC is marginal for mixed loss AUIs(case 2) and sufficient for Medium loss AUIs (Case 3)
- Concatenated FEC (with end2end RSFEC) may work for medium loss AUIs (Case 3)
- For optical sub-link DER_0 of 3.3e-3 needs 4-bit error correction in BCH blocks and for DER-0 of 4.6e-3 needs >4.4-bit error correction

Conclusions

- Propose to adopt 3-segmented RS FEC with DFE at all sub-link receivers and Inner code BCH code only if Optical sub-link targets higher DER_0 (cases 1,2,3)
- Option to use end2end RS FEC for Medium loss AUIs (Case3)
- Option to use 2-segemented RS FEC for Mixed loss AUIs (cases 2, 3)
- when moderately high correlated errors present in optical link:
  a. For optical link DER_0 of 3.3e-3 needs 4-bit correction in BCH inner code
  b. For optical link DER_0 of 4.6e-3 needs >4.4-bit correction in BCH inner code

- Leave MLSE at all sub-link receivers as optional to implement to meet the some stressed sub-link channels both for Electrical AUIs and for Optical sub-link, as MLSE seems to be reducing number of bits needed to be corrected for higher DER_0 optical targets