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

Part2 -Effects of precoding and Inner FEC code

Upen Reddy, Kareti

David , Nozadze

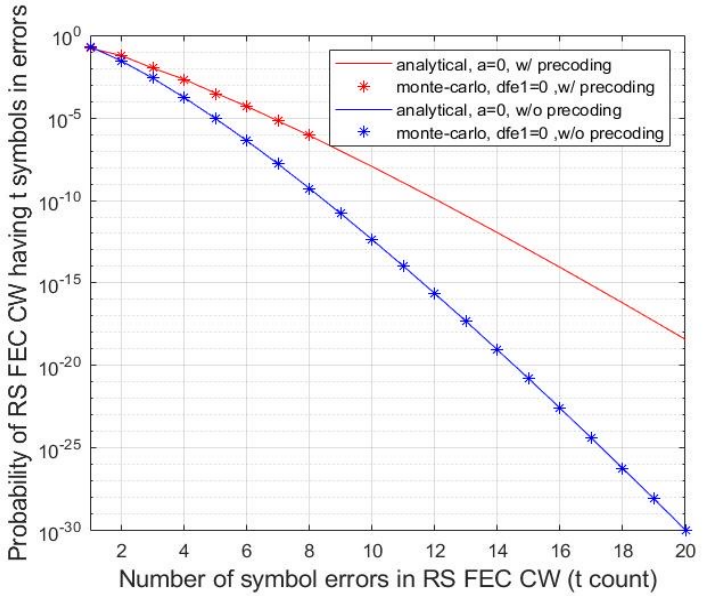
Cisco Systems Inc.

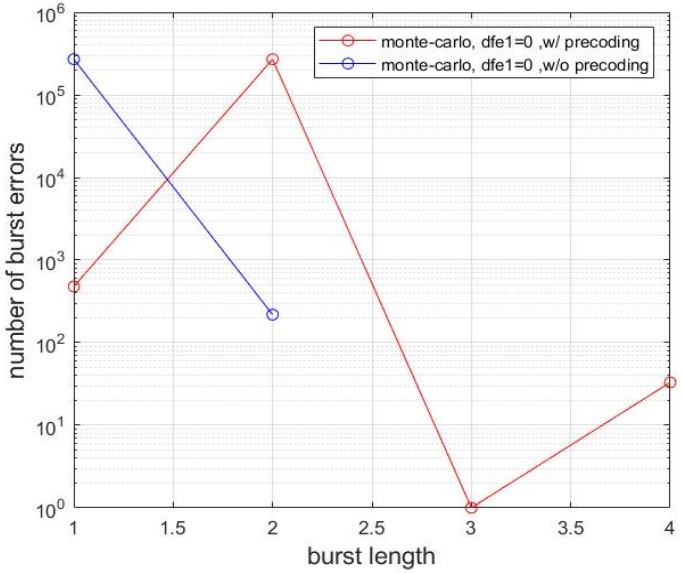
Overview

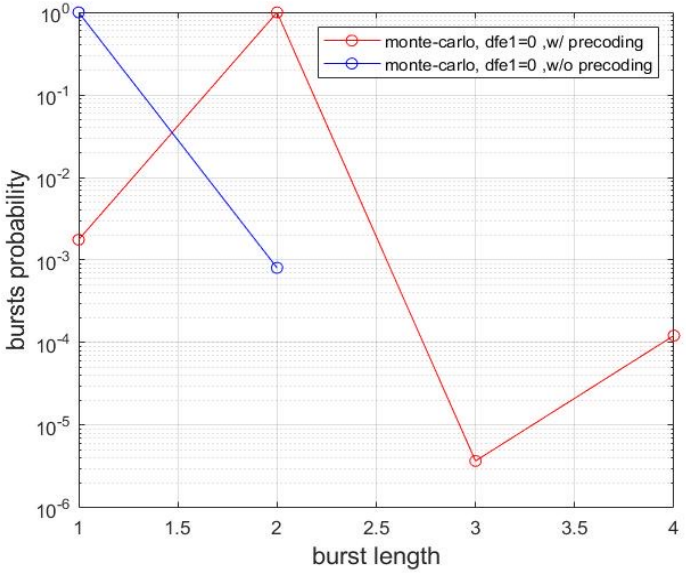
This is continuation of the work presented in kareti_3dj_01a_230116 to further investigate by using Monte Carlo analysis

- The effectiveness of (1+D) precoding, when skip level errors and high level of correlated errors exist
- The effectiveness of Inner FEC code like BCH (144,136) to accommodate higher level of DER_0 in optical sub-link

Precoding : Link with DER_0 of 1e-4, random errors only (DFE tap1 =0/a=0)



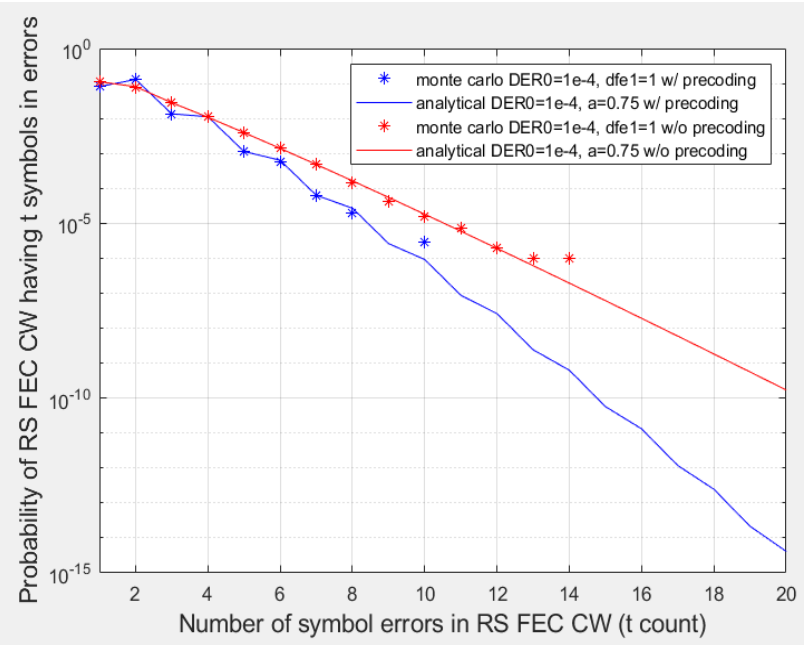


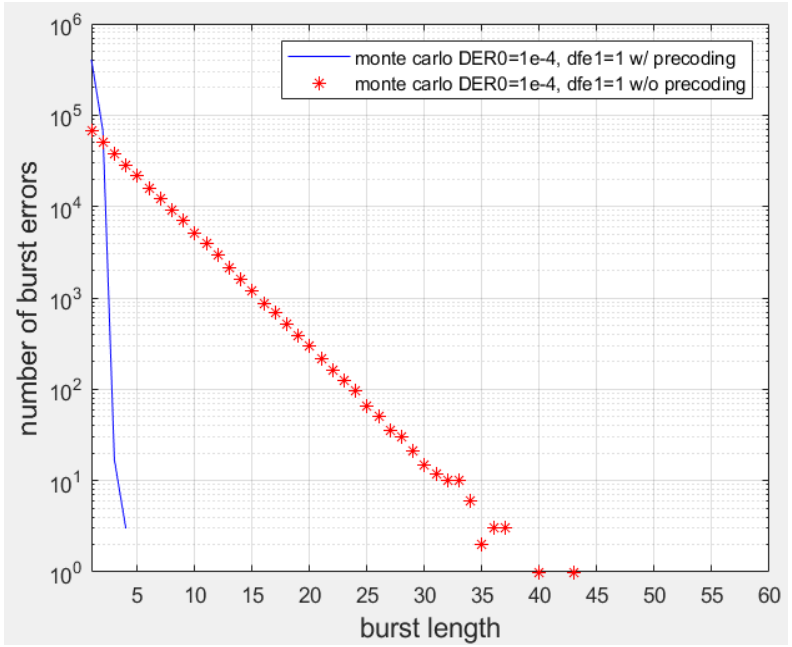


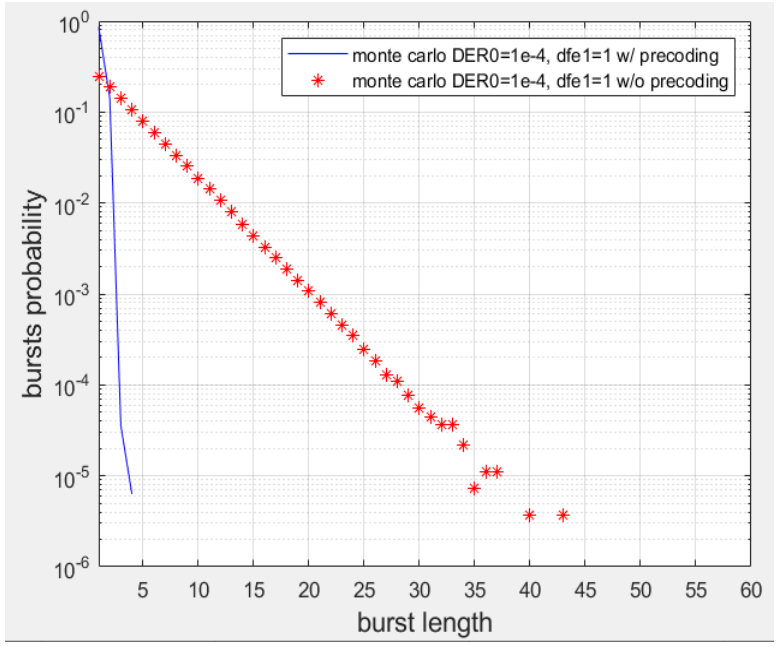
DER0=1e-4	DER	CER (analytical)	Prob of Skipped 2 level symbol errors (analytical)	Skipped 2 level symbol errors (monte-carlo)	Prob of Skipped 2 level symbol errors (monte-carlo)	average burst length (monte-carlo)
w/ precoder	2.0E-04	9.7E-15	0.25	135525	0.2502	2
w/o precoder	1.0E-04	2.7E-23	N.A.	N.A.	N.A	1

	PAM symb #
Monte Carlo	2.72E+09

Precoding : Link with DER_0 of 1e-4, with correlated errors including skip level errors(DFE tap1 =1/a=0.75)





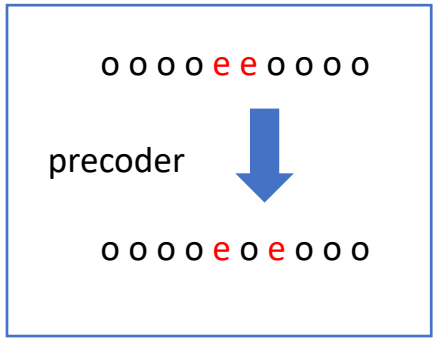


DER0=1e-4	DER	CER (analytical)	Prob of Skipped 2 level symbol errors (analytical)	Skipped 2 level symbol errors (monte-carlo)	Prob of Skipped 2 level symbol errors (monte-carlo)	average burst length (monte-carlo)
w/ precoder	2.0E-04	1.47E-11	NA	113838	**0.21**	2
w/o precoder	4.0E-04	2.77E-08	N.A.	N.A.	N.A	4

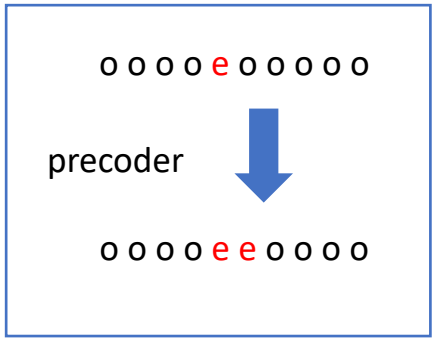
	PAM symb #
Monte Carlo	2.72E+09

Precoding : Error patterns with and without skip level errors

adjacent level errors only (no skipped level errors)

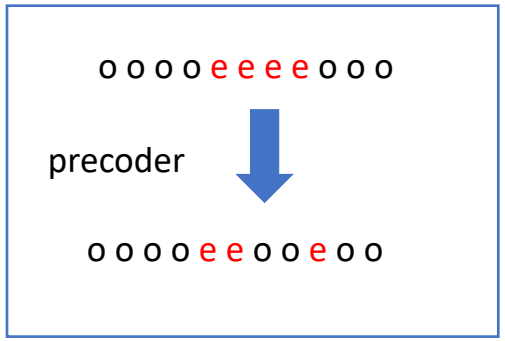


- Two consecutive symbol errors becomes 2 single symbol errors

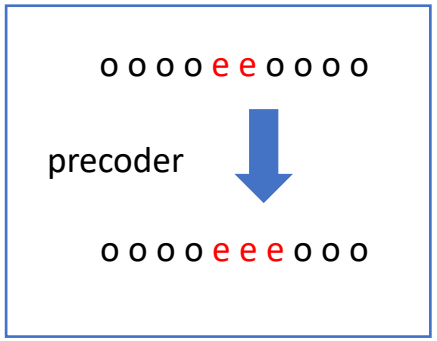


- Single symbol errors becomes single two symbol error

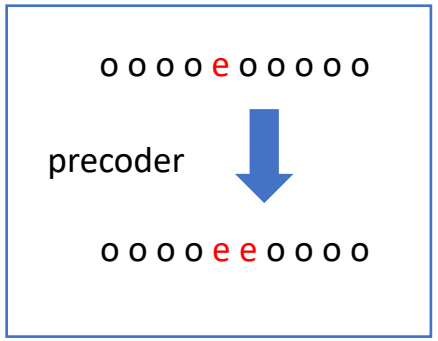
single skipped error in the beginning of burst



- Four consecutive symbol errors can result one two symbols and one single symbol errors



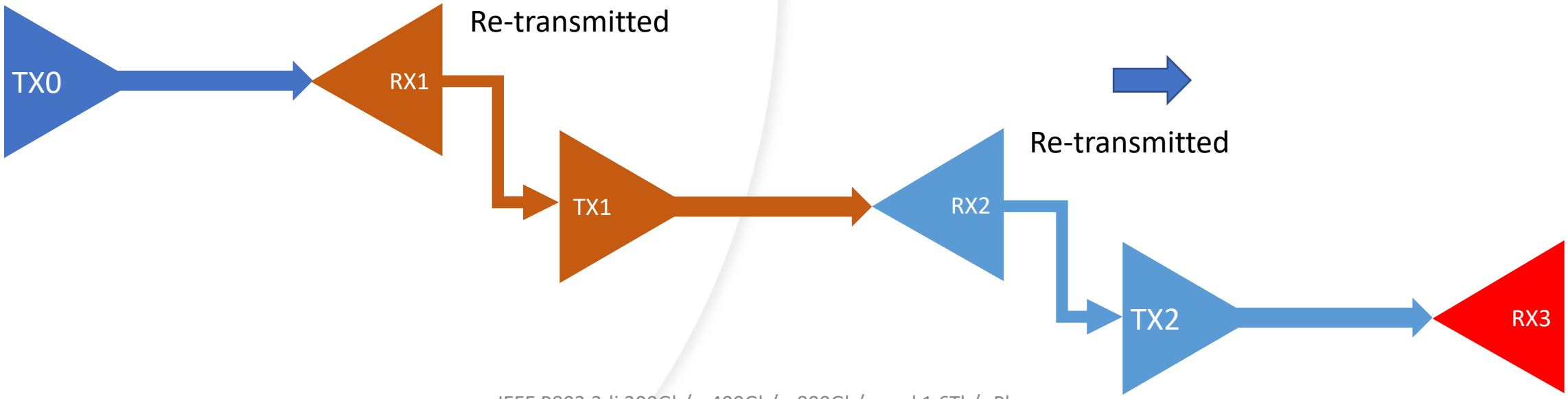
- Two consecutive symbol errors can result 3 single symbol errors



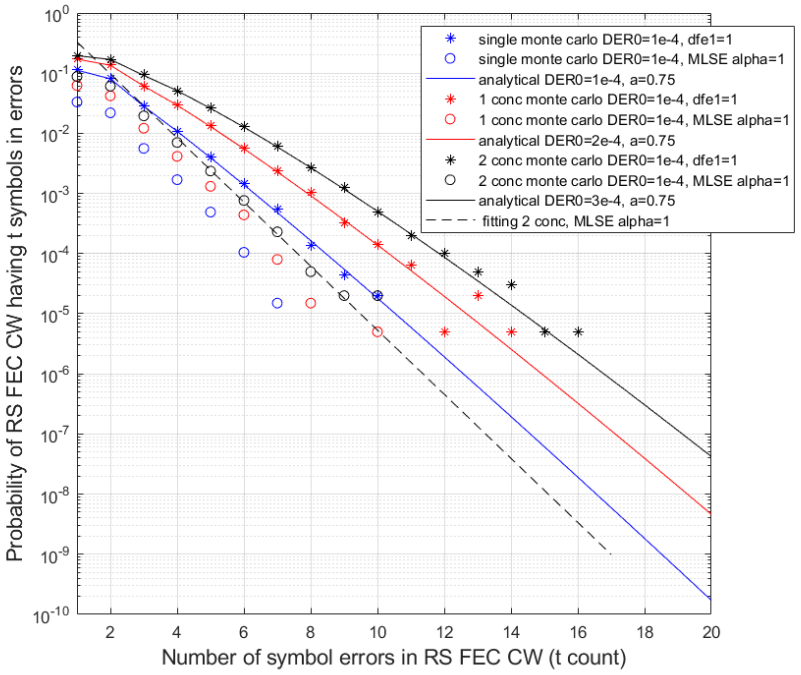
- Single symbol errors becomes single two symbol error
- After precoder both errors can be skipped error

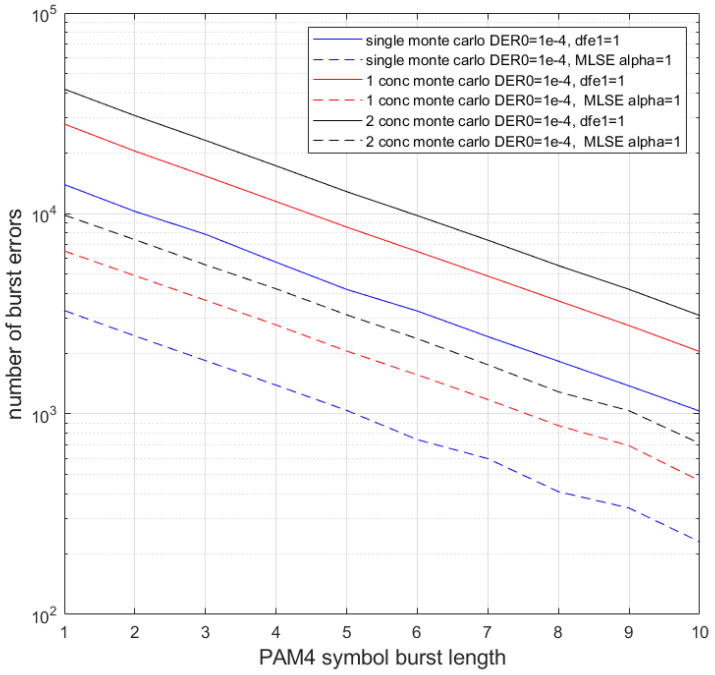
Concatenated sub-links

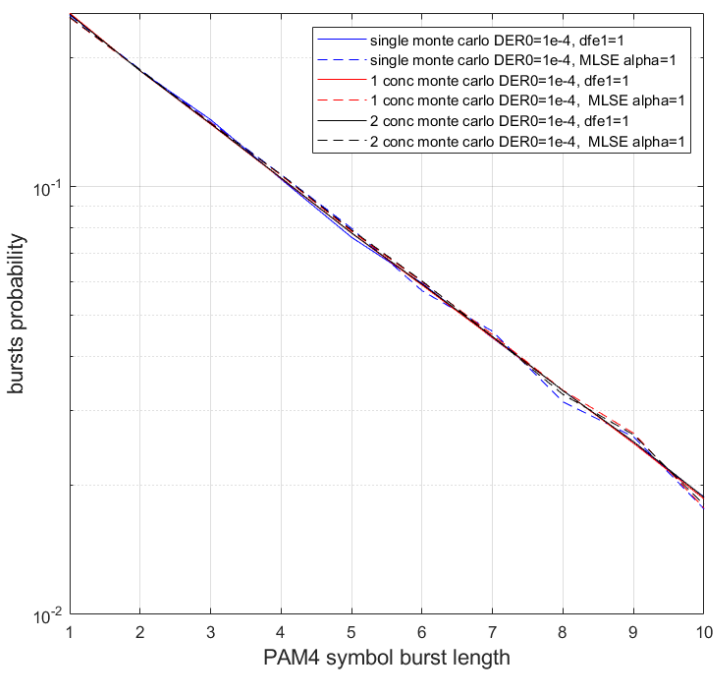
- Data is received and re-transmitted without error corrections
- Two Monte Carlo models are simulated:
  1. At each RX, DER0=1e-4, a=0.75
  2. At each RX, DER0=1e-4, DFE tap1=1
- RS 544 FEC at each sub-link
- 5.44e9 symbols simulated



Concatenated Sub-links: High level of skip level errors --- dfe1/alpha=1– precoding at all TXs and RXs **OFF**



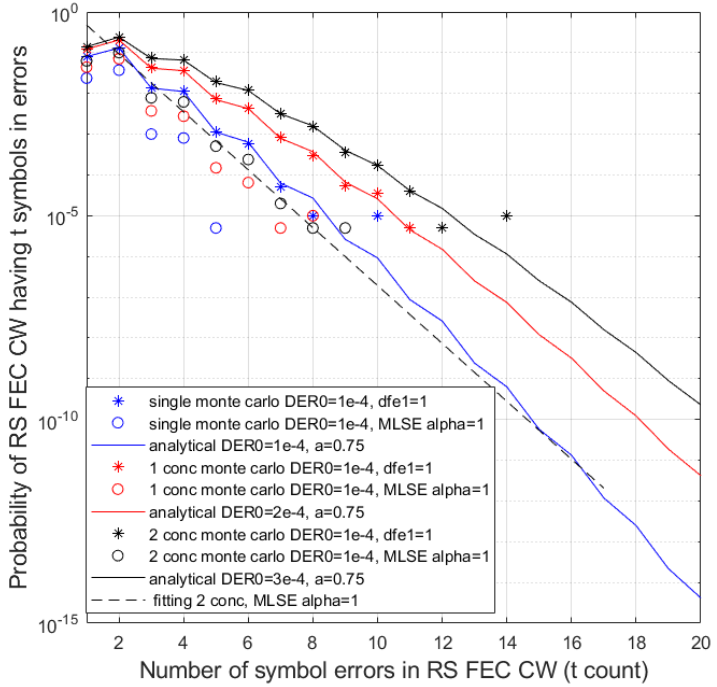


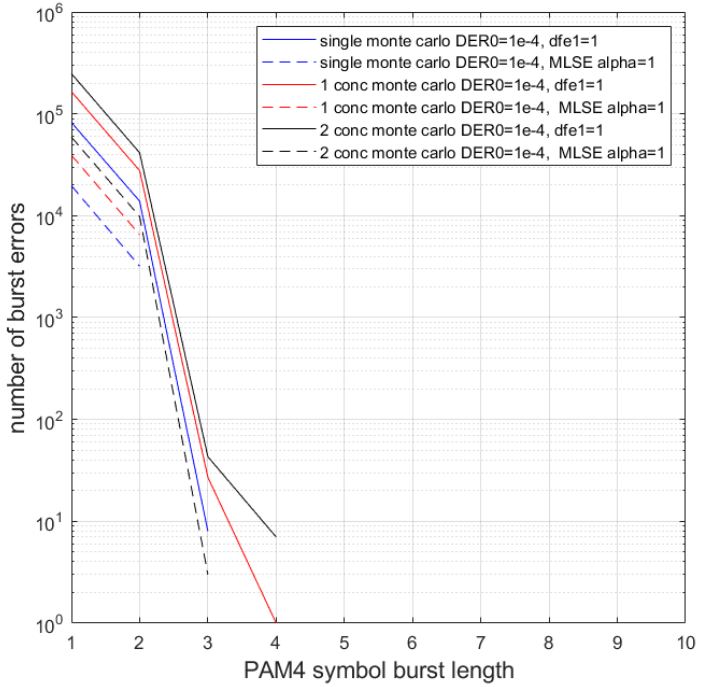


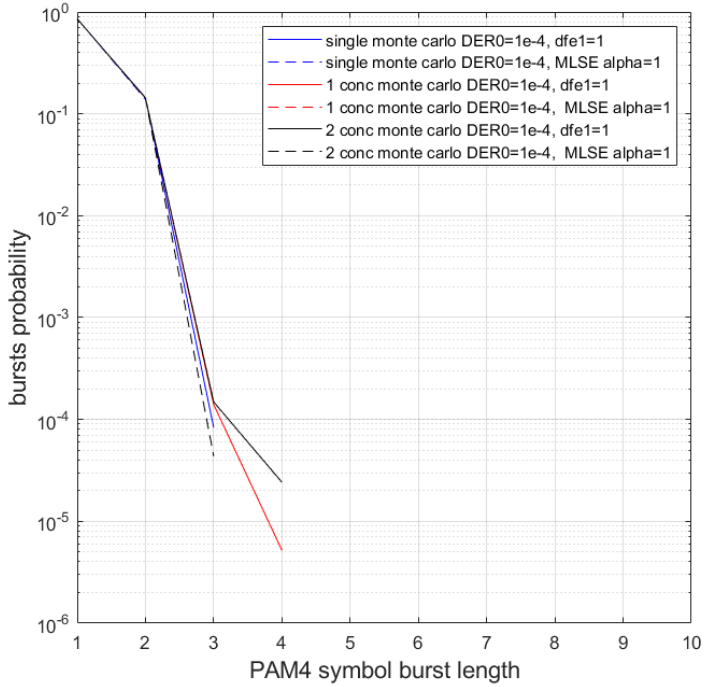
DFE1/alpha=1	precoder	DER0	DER DFE	DER MLSD	CER with DFE (analytical)	extrapolated CER with DFE	extrapolated CER with MLSD	average burst length with DFE (monte-carlo)	average burst length with MLSD (monte-carlo)
TX1/Rx1	**no/no**	1.00E-04	4.0E-04	9.0E-05	2.8E-08			3.99	3.99
TX2/Rx2	**no/no**	1.00E-04	8.0E-04	1.9E-04	5.0E-07			3.99	3.99
TX3/Rx3	**no/no**	1.00E-04	1.2E-03	2.8E-04	3.4E-06		3.4e-9	3.99	3.99

	PAM symb #
Monte Carlo	5.44E+08

Concatenated Sub-links: High level of skip level errors --- dfe1/alpha=1– precoding at all TXs and RXs **ON**



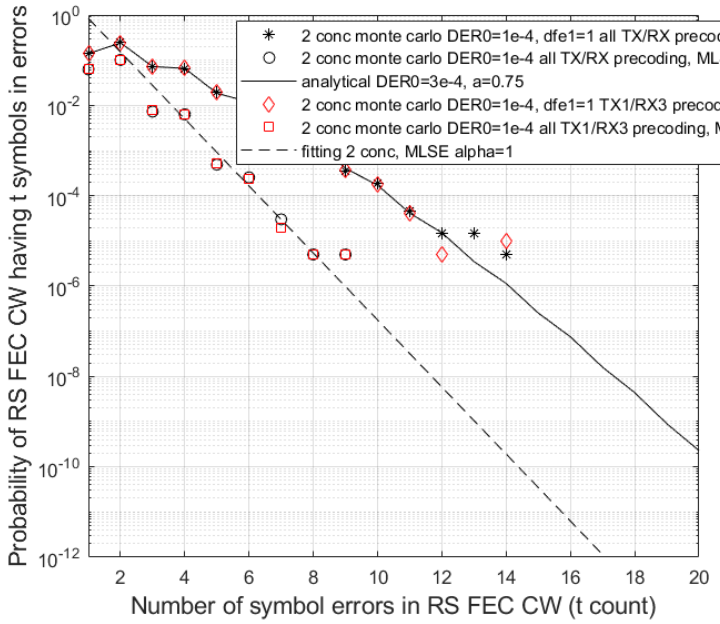


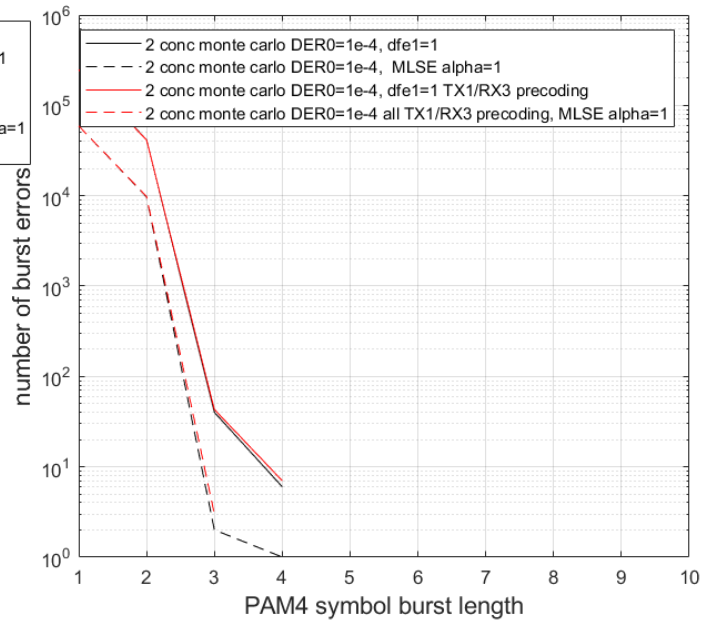


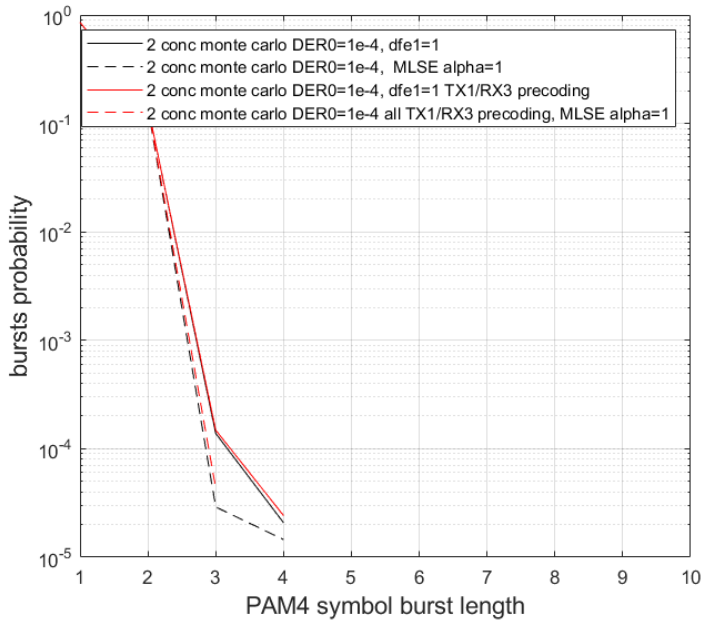
DFE1/alpha=1	precoder	DER0	DER DFE	DER MLSD	CER with DFE (analytical)	extrapolated CER with DFE	extrapolated CER with MLSD	average burst length with DFE (monte-carlo)	average burst length with MLSD (monte-carlo)
TX1/Rx1	**yes/yes**	1.00E-04	2.0E-04	4.0E-05	1.5E-11			1.14	1.14
TX2/Rx2	**yes/yes**	1.00E-04	4.0E-04	9.0E-05	3.8E-09			1.14	1.14
TX3/Rx3	**yes/yes**	1.00E-04	6.0E-04	1.4E-04	9.7E-08		1e-11	1.14	1.14

	PAM symb #
Monte Carlo	5.44E+08

Concatenated Sub-links: High level of skip level errors --- dfe1/alpha=1 ON





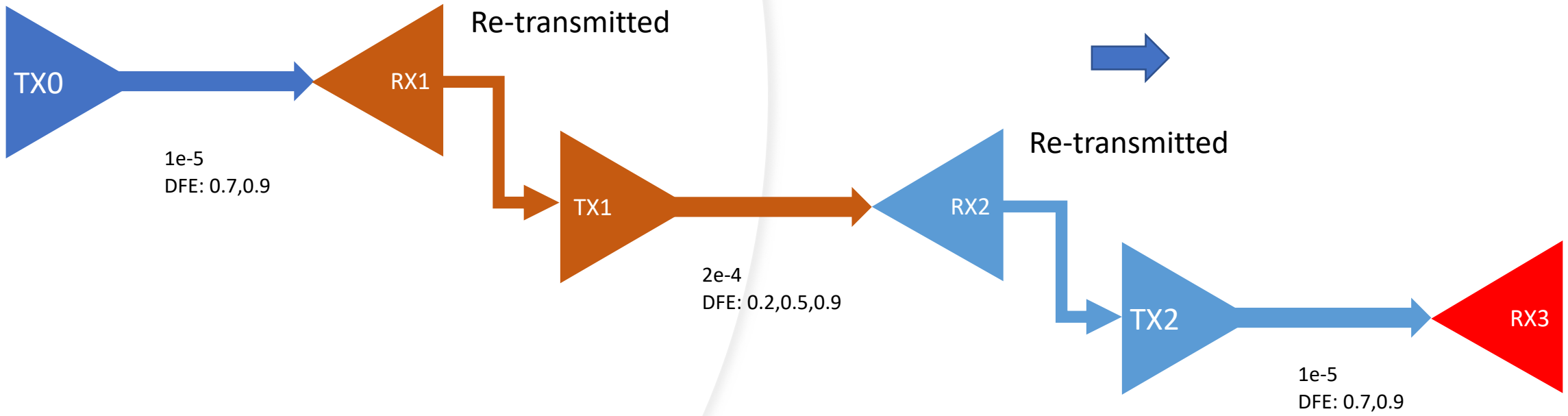


DFE1/alpha=1	precoder	DER0	DER DFE	DER MLSD	CER with DFE (analytical)	extrapolated CER with DFE	extrapolated CER with MLSD	average burst length with DFE (monte-carlo)	average burst length with MLSD (monte-carlo)
TX1/Rx1	yes/no	1.00E-04	2.0E-04	4.0E-05	1.5E-11			1.14	1.14
TX2/Rx2	no/no	1.00E-04	4.0E-04	9.0E-05	3.8E-09			1.14	1.14
TX3/Rx3	no/yes	1.00E-04	6.0E-04	1.4E-04	9.7E-08		7e-12	1.14	1.14

	PAM symb #
Monte Carlo	5.44E+08

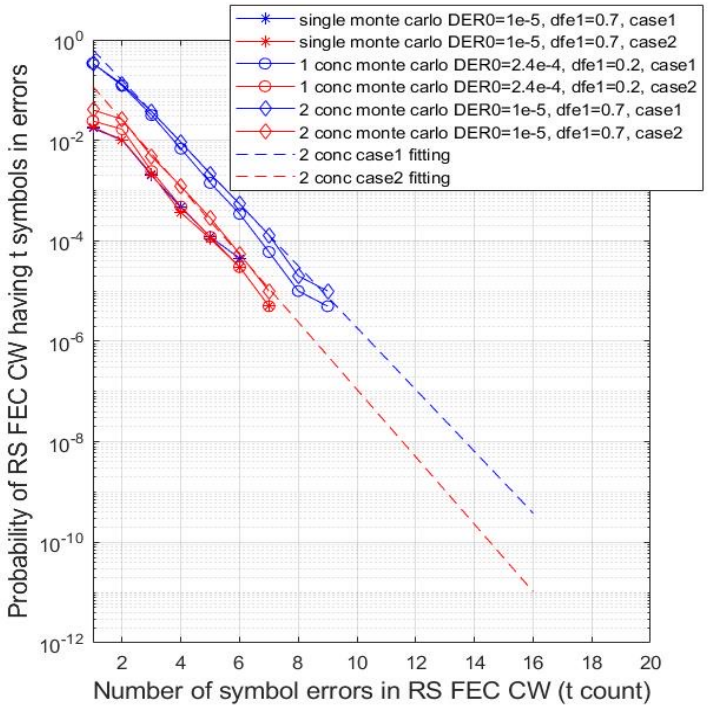
Concatenated sub-links : Inner BCH Code

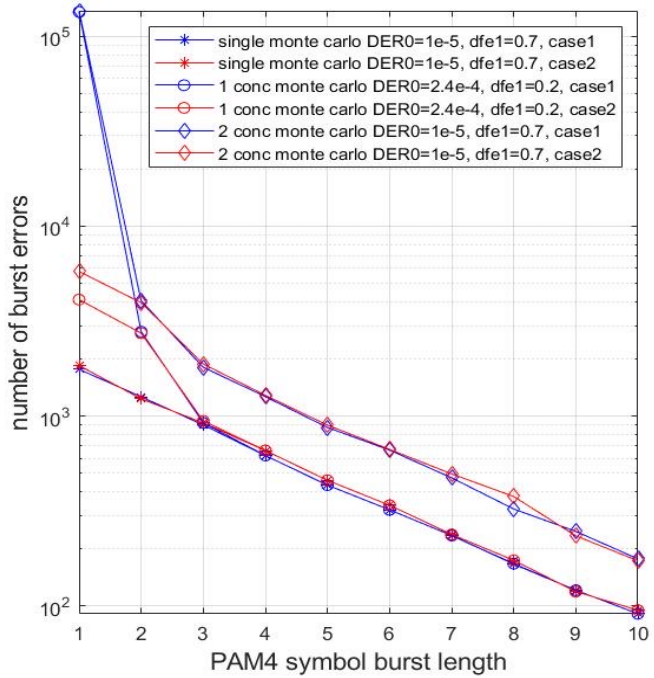
- Data is received and re-transmitted without error corrections
- End2End RS 544 FEC
- Inner FEC at middle sub-link BCH(144,136,1)
- 5.44e9 symbols simulated

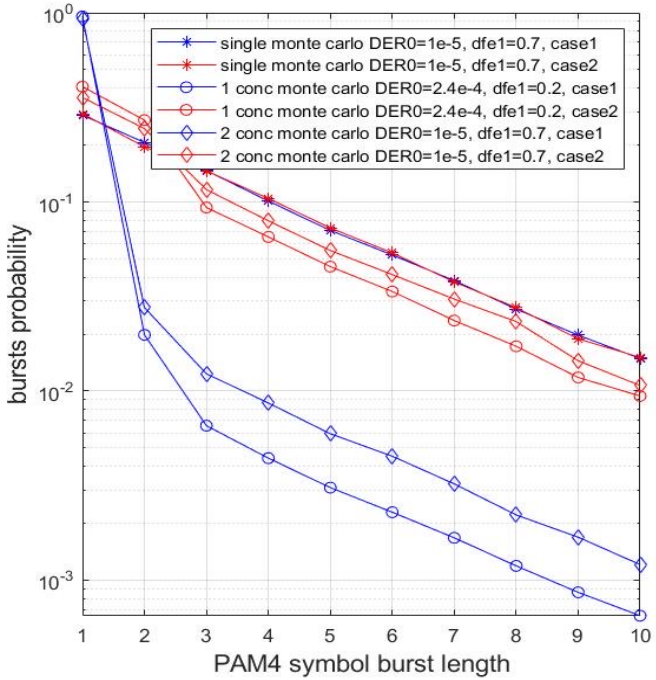


Concatenated sub-links: w/o vs w/ BCH correction at RX2---Precoding off at all TX/RX

RX1/RX3 DFE=0.7, RX2 DFE=0.2







	DFE	precoder	DER0	extrapolated CER with DFE for case 1	extrapolated CER with DFE for case 2	average burst length with DFE (w/ BCH)	average burst length with DFE (w/o BCH)
TX1/Rx1	0.7	no/no	1.00E-05			3.50	3.51
TX2/Rx2	0.2	no/no	2.40E-04			2.72	1.12
TX3/Rx3	0.7	no/no	1.00E-05	3.8E-10	1.0E-11	3.04	1.22

PAM symbols	5.44E+08
total number of BCH blocks	8.00E+06

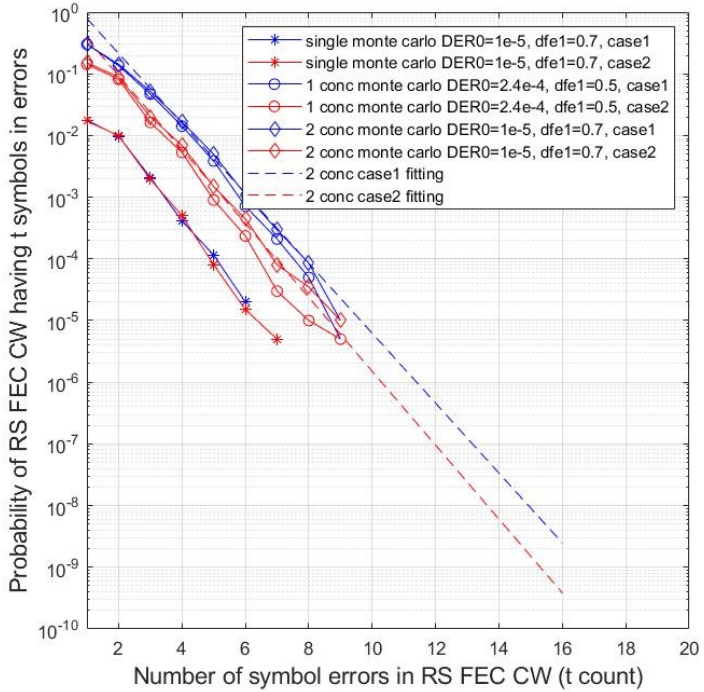
Case1--- no BCH correction

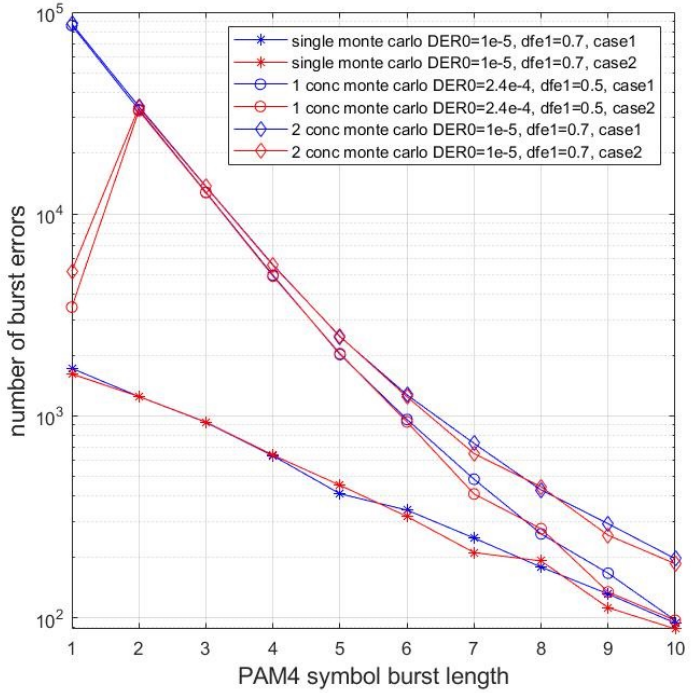
Case2--- BCH(144,136,1) correction at RX2

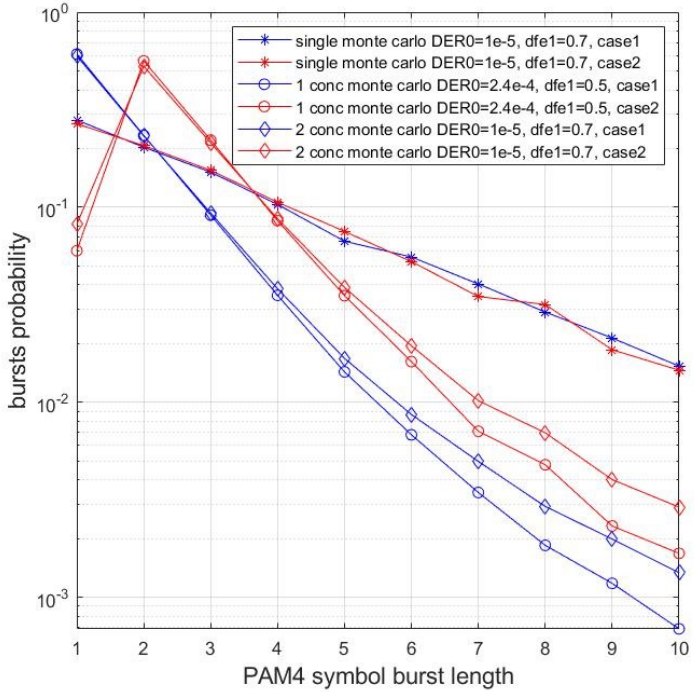
bits error per BCH block	dfe1 at RX2=0.2
1	136500
2	2646
3	51
4	0
5	0

Concatenated sub-links: w/o vs w/ BCH correction at RX2---Precoding off at all TX/RX

RX1/RX3 DFE=0.7, RX2 DFE=0.5







	DFE	precoder	DER0	extrapolated CER with DFE for case 1	extrapolated CER with DFE for case 2	average burst length with DFE (w/ BCH)	average burst length with DFE (w/o BCH)
TX1/Rx1	0.7	no/no	1.00E-05			3.58	3.54
TX2/Rx2	0.5	no/no	2.40E-04			2.64	1.68
TX3/Rx3	0.7	no/no	1.00E-05	2.5E-09	3.8E-10	2.73	1.76

PAM symbols	5.44E+08
total number of BCH blocks	8.00E+06

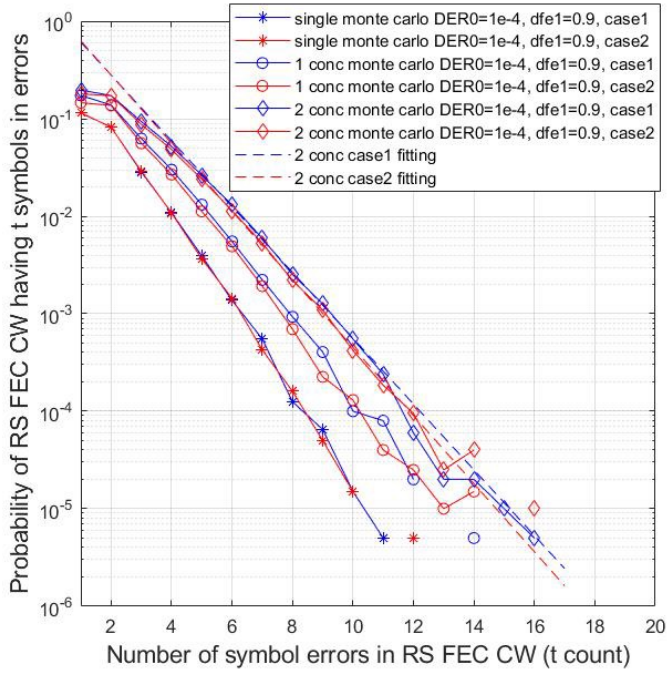
Case1--- no BCH correction

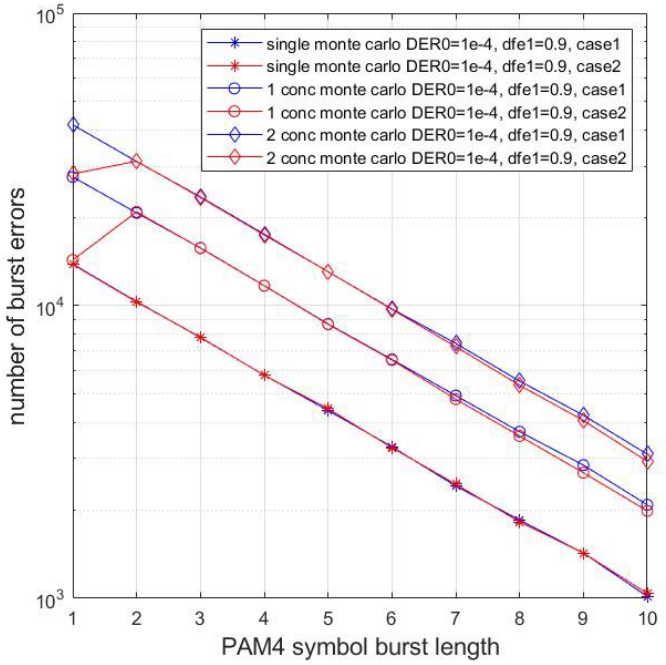
Case2--- BCH(144,136,1) correction at RX2

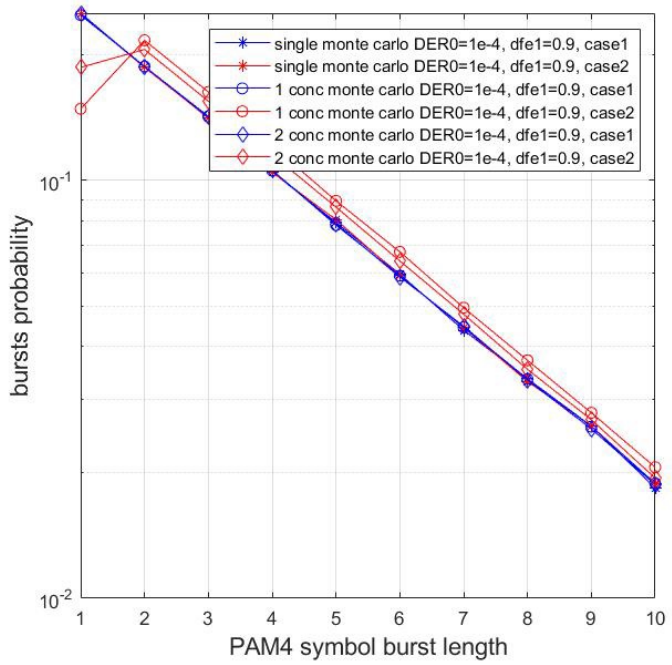
bits error per BCH block	dfe1 at RX2=0.5
1	88409
2	31558
3	12041
4	4443
5	1664

Concatenated sub-links: link w/o vs w/ BCH correction at RX2---Precoding off at all TX/RX

RX1/RX3 DFE=0.7, RX2 DFE=0.9







	DFE	precoder	DER0	extrapolated CER with DFE for case 1	extrapolated CER with DFE for case 2	average burst length with DFE (w/ BCH)	average burst length with DFE (w/o BCH)
TX1/Rx1	0.7	no/no	1.00E-05			3.56	3.59
TX2/Rx2	0.9	no/no	2.40E-04			4.68	3.94
TX3/Rx3	0.7	no/no	1.00E-05	1.6E-06	2.4E-06	3.40	3.92

bits error per BCH block	dfe1 at RX2=0.9
1	39022
2	26224
3	19373
4	14174
5	10604

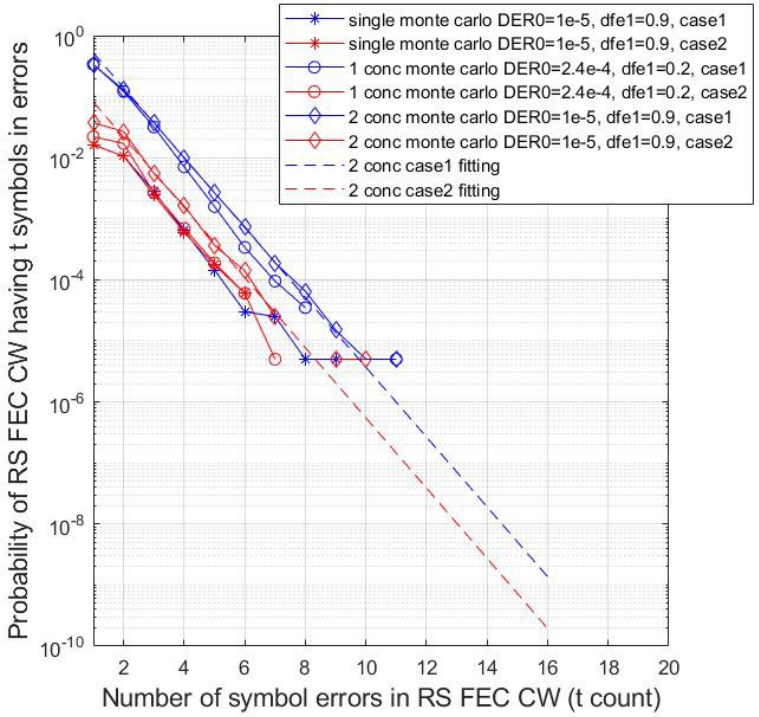
PAM symbols	5.44E+08
total number of BCH blocks	8.00E+06

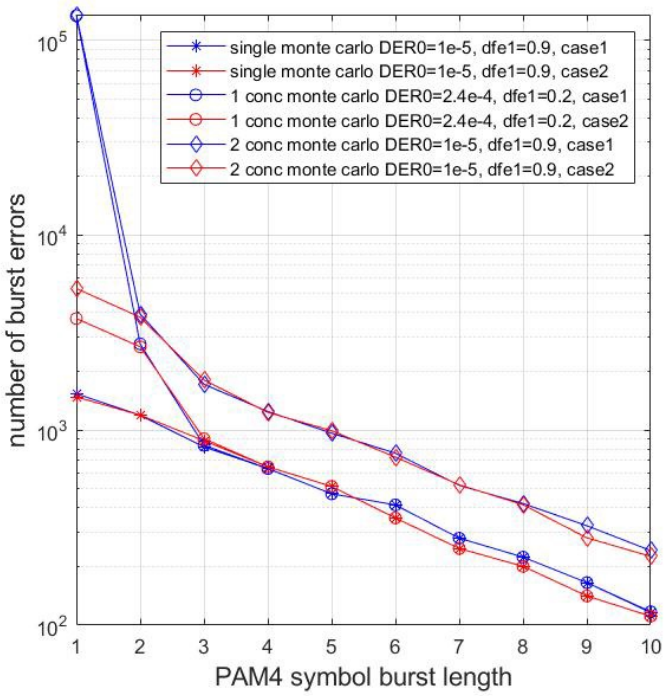
Case1--- no BCH correction

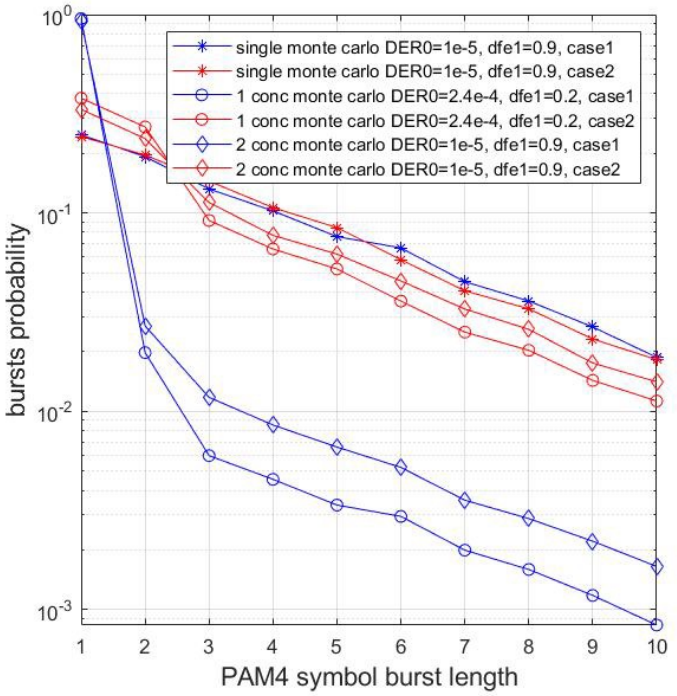
Case2--- BCH(144,136,1) correction at RX2

Concatenated sub-links:

RX1/RX3 DFE=0.9, DFE=0.2







	DFE	precoder	DER0	extrapolated CER with DFE for case 1	extrapolated CER with DFE for case 2	average burst length with DFE (w/ BCH)	average burst length with DFE (w/o BCH)
TX1/Rx1	0.9	no/no	1.00E-05			3.94	4.03
TX2/Rx2	0.2	no/no	2.40E-04			2.97	1.15
TX3/Rx3	0.9	no/no	1.00E-05	1.4E-09	1.9E-10	3.35	1.27

bits error per BCH block	dfe1 at RX2=0.2
1	136463
2	2618
3	51
4	1
5	0

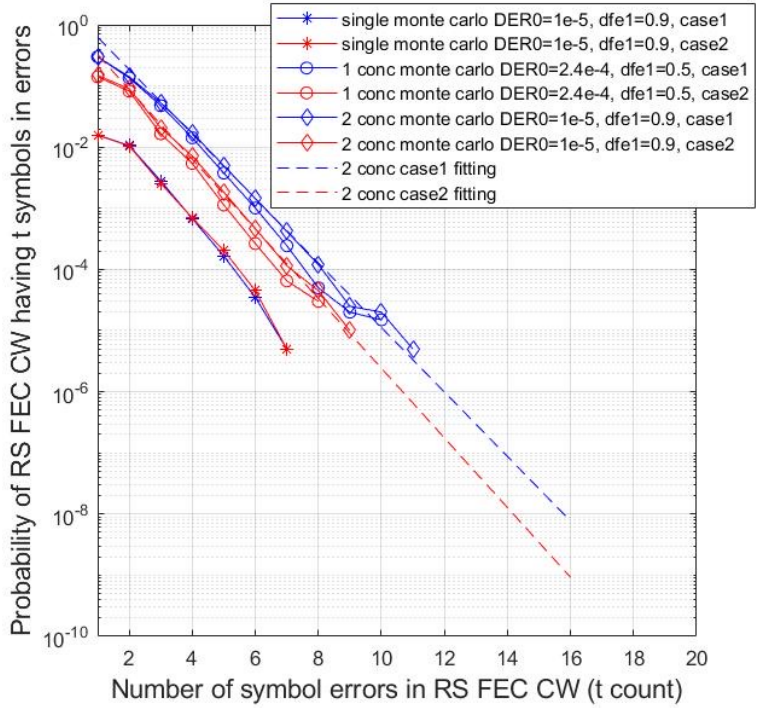
PAM symbols	5.44E+08
total number of BCH blocks	8.00E+06

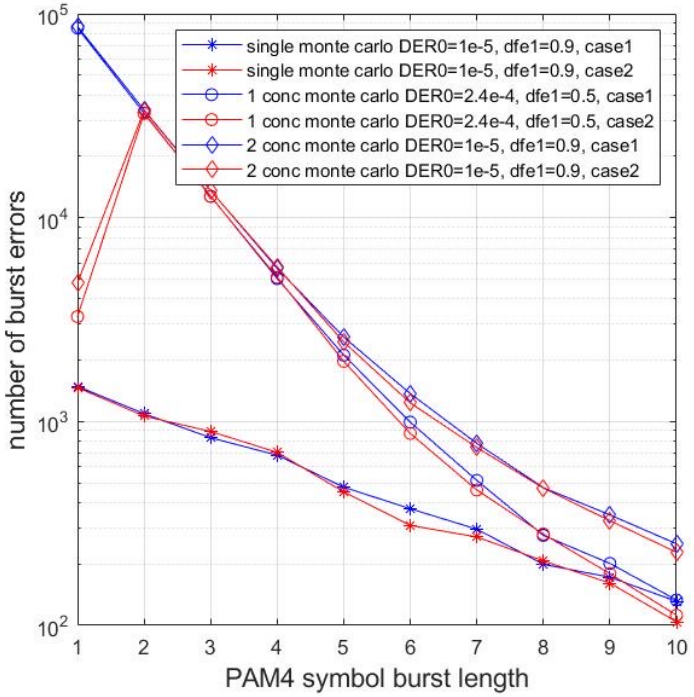
Case1--- no BCH correction

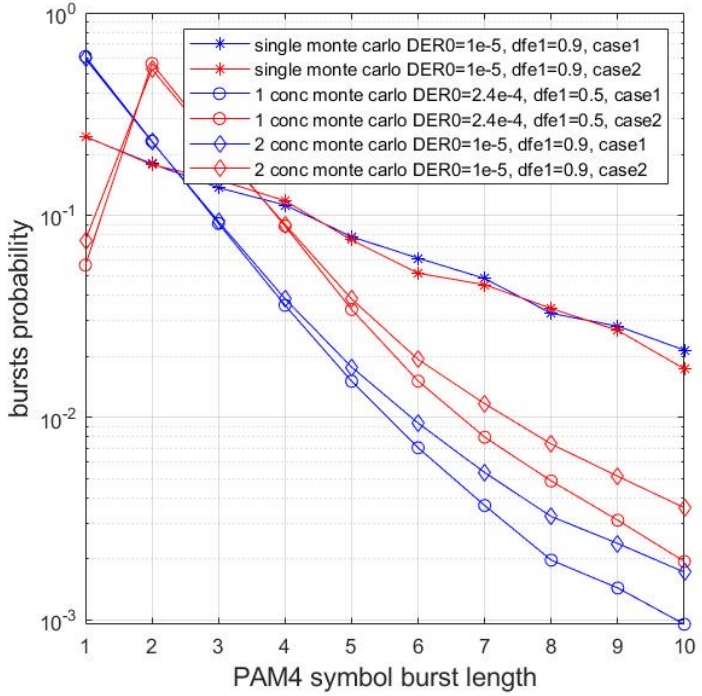
Case2--- BCH(144,136,1) correction at RX2

Concatenated sub-links: w/o vs w/ BCH correction at RX2---Precoding off at all TX/RX

RX1/RX3 DFE=0.9, RX2 DFE=0.5







	DFE	precoder	DER0	extrapolated CER with DFE for case 1	extrapolated CER with DFE for case 2	average burst length with DFE (w/ BCH)	average burst length with DFE (w/o BCH)
TX1/Rx1	0.9	no/no	1.00E-05			4.04	4.08
TX2/Rx2	0.5	no/no	2.40E-04			2.68	1.71
TX3/Rx3	0.9	no/no	1.00E-05	7.7E-09	9.2E-10	2.81	1.80

PAM symbols	5.44E+08
total number of BCH blocks	8.00E+06

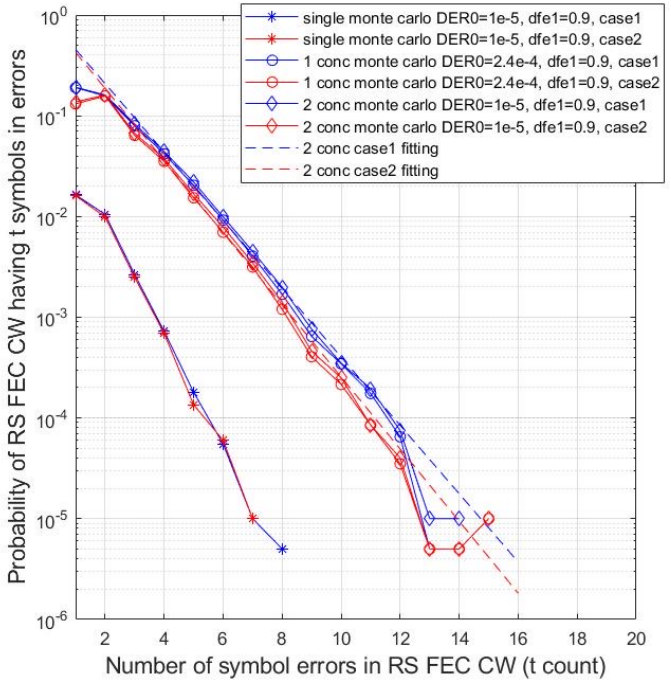
Case1--- no BCH correction

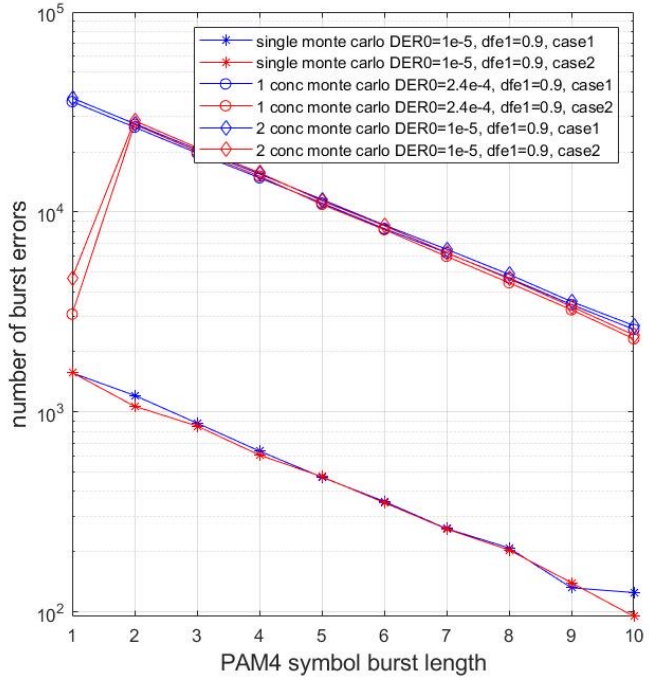
Case2--- BCH(144,136,1) correction at RX2

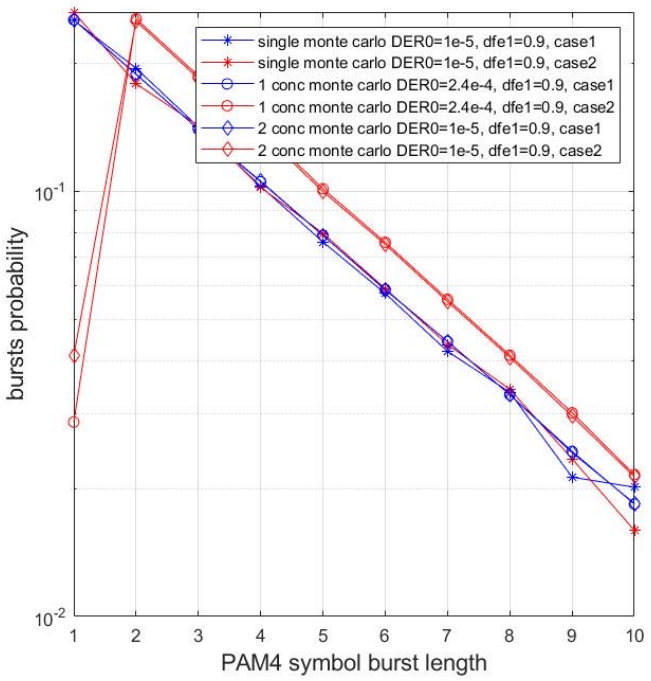
bits error per BCH block	dfe1 at RX2=0.5
1	88510
2	31655
3	12029
4	4542
5	1614

Concatenated sub-links: w/o vs w/ BCH correction at RX2---Precoding off at all TX/RX

RX1/RX3 DFE=0.9, RX2 DFE=0.9







	DFE	precoder	DER0	extrapolated CER with DFE for case 1	extrapolated CER with DFE for case 2	average burst length with DFE (w/ BCH)	average burst length with DFE (w/o BCH)
TX1/Rx1	0.9	no/no	1.00E-05			3.95	3.96
TX2/Rx2	0.9	no/no	2.40E-04			4.71	3.97
TX3/Rx3	0.9	no/no	1.00E-05	3.7E-06	1.8E-06	4.67	3.97

bits error per BCH block	dfe1 at RX2=0.9
1	38956
2	26259
3	19327
4	14558
5	10532

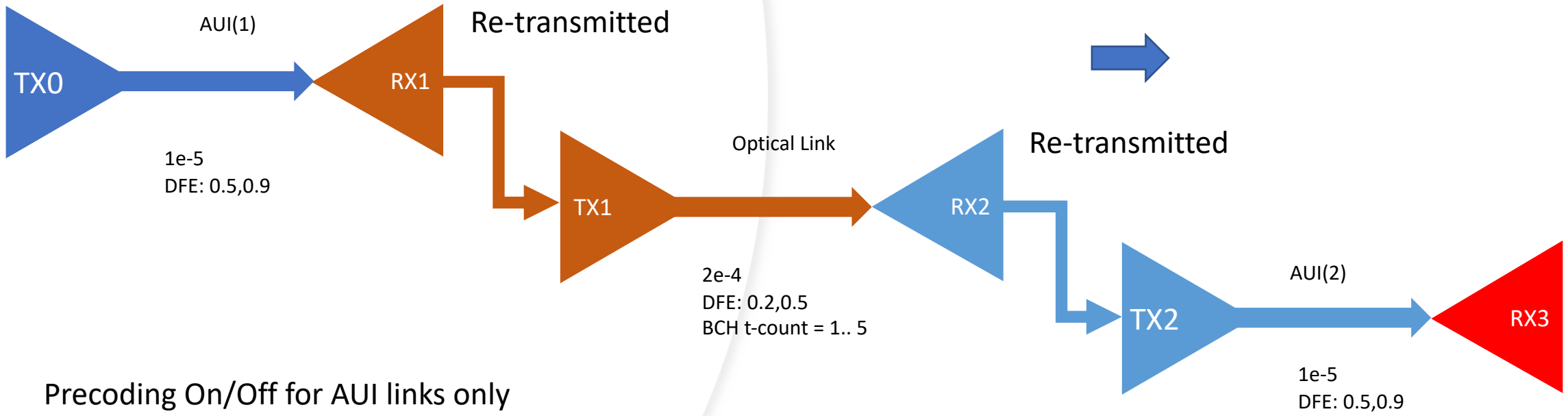
PAM symbols	5.44E+08
total number of BCH blocks	8.00E+06

Case1--- no BCH correction

Case2--- BCH(144,136,1) correction at RX2

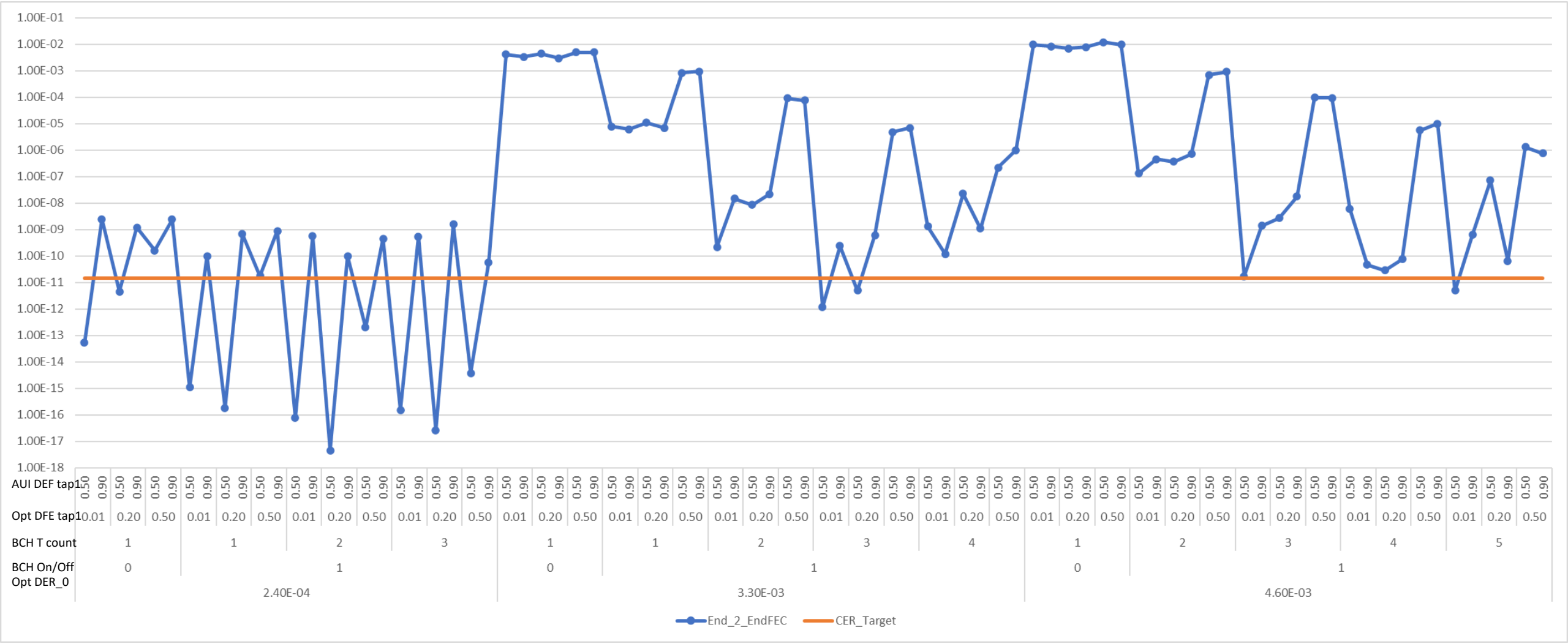
Concatenated sub-links : Inner BCH Code

- Data is received and re-transmitted without error corrections
- End2End RS 544 FEC
- Inner FEC at middle sub-link BCH(144,136,1)
- 5.44e9 symbols simulated

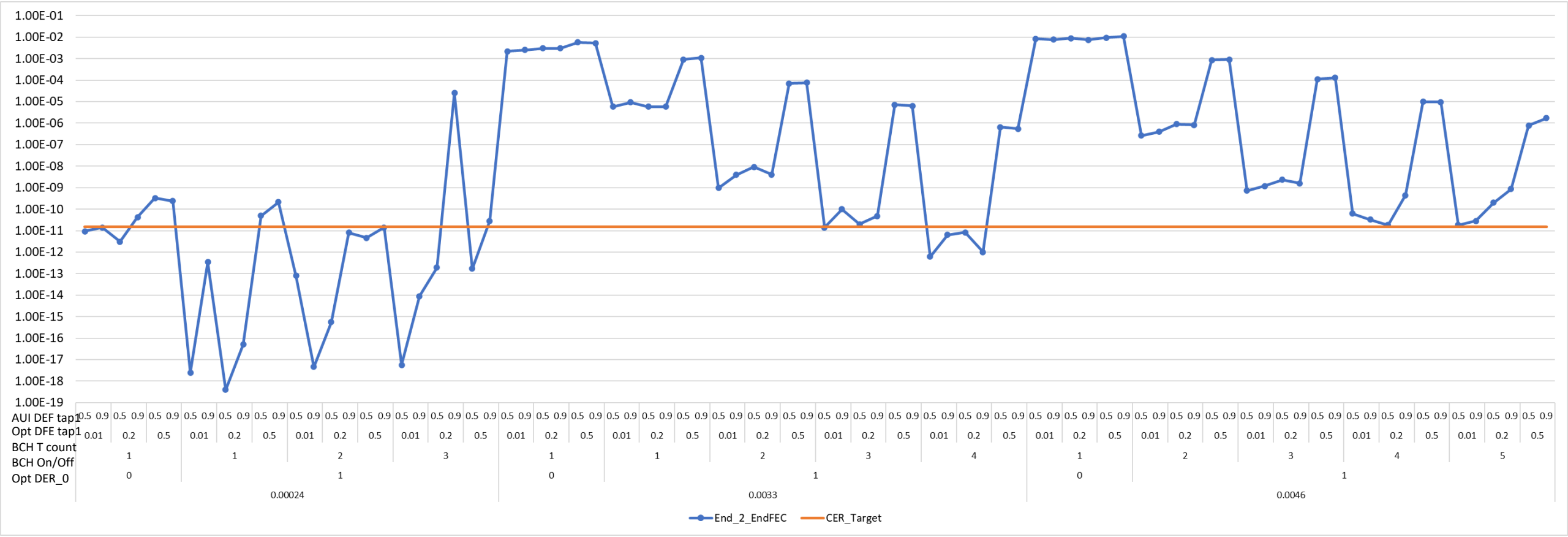


Precoding On/Off for AUI links only
Add RSFEC CI(4)

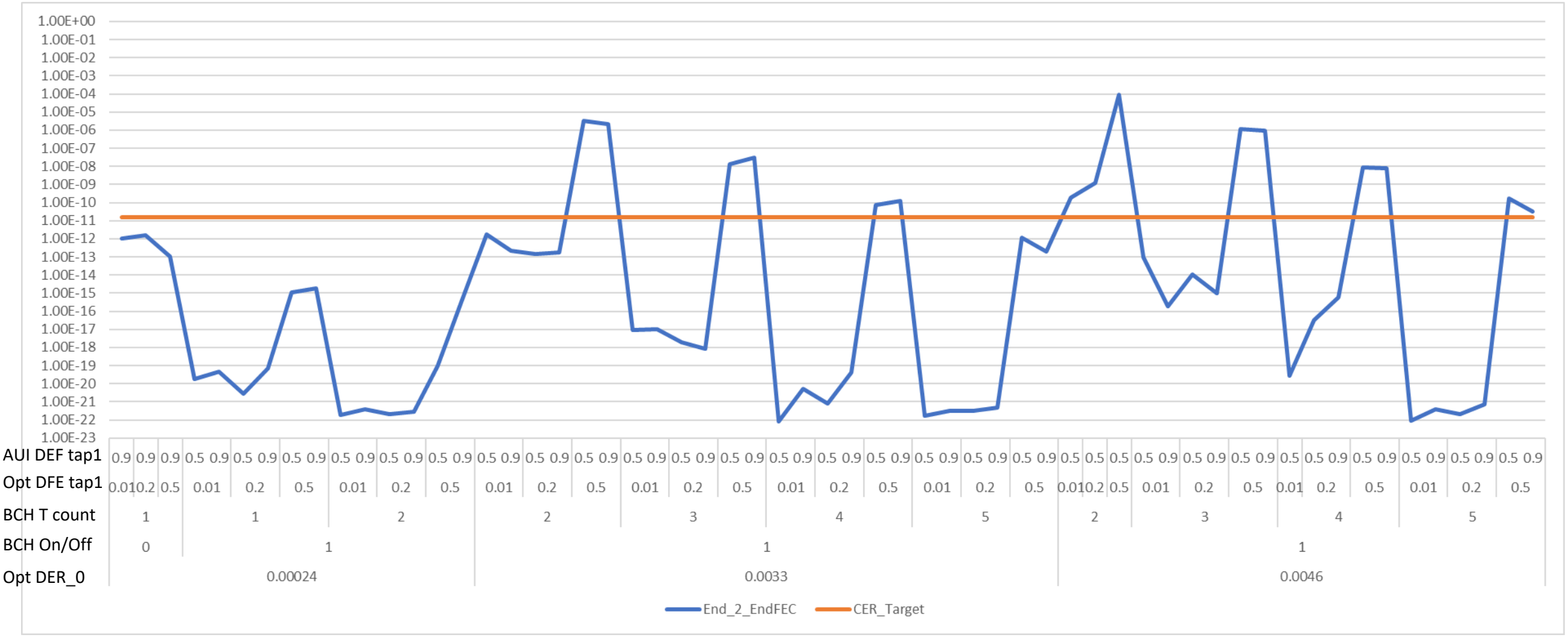
Concatenated sub-links: -Precoding off at all sub-links and CI(4) Off



Concatenated sub-links: -Precoding on at AUI sub-links and CI(4) Off



Concatenated sub-links: -Precoding on at AUI sub-links and CI(4)



Summary

- Precoding When Skip level error present
  - After decoding pre-code, the data stream have higher bit errors compared to when there are no skip level errors
  - No significant impact to error rate as skip level errors are relatively a few even for DFE tap1 = 1
- Inner FEC code (BCH(144,136,t):

  - Shown how many BCH bit error corrections are needed for various levels of correlated errors and Optical link target DER_0s (2.4e-4, 3.3e-3, 4.6e-3)

- Precoding on AUI links and 4 Codeword RSFEC interleave are very helpful

Next steps
Look into Multipart links : 2 AUI sub-links on both sides of Optical sub-link for find solution space for different FEC strategies

- End2End RS 544 FEC
- Segmented FEC
- Concatenated FEC – End2End FEC with optical sub-link with Inner FEC code like BCH(144,136,t)