FEC codeword interleaving schemes

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Introduction *

This document attempts to capture and evaluate some of the candidate methods of striping FEC codewords to PCS lanes in combination with muxing in the PMA for 400 Gb/s Ethernet.

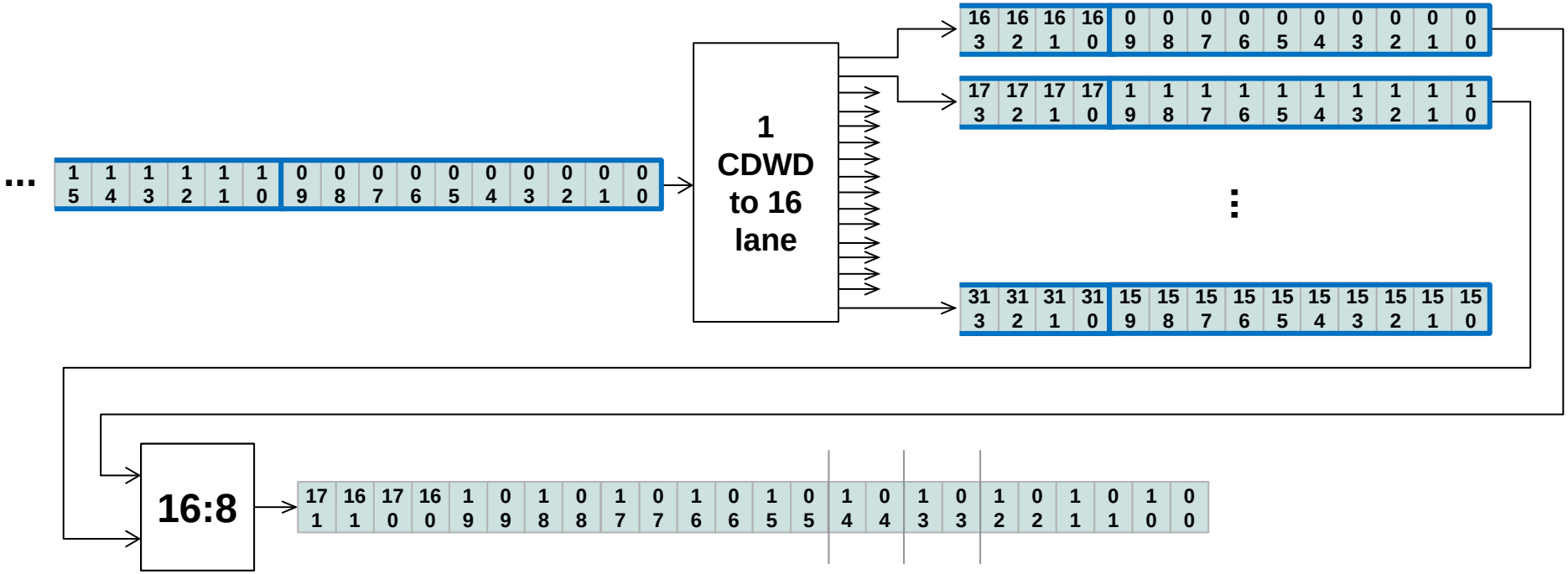
10 options are described and results are provided for 9 (in addition to the preceding results from anslow_3bs_04_0715).

Magesh Valliappan has pointed out that for options 1) and 2), a single burst that lasts for 75 PAM4 symbols has a high probability of causing errors in 16 FEC symbols (which is uncorrectable). With a = 0.75, the probability of a burst this long is 0.75^75 = 4.3E-10. When this is combined with the probability that the codeword has at least one error in it, a simple lower bound for the FLR can be calculated (see pages 4 and 6).

As the previous analysis did not include bursts as long as this, the results for options 1) and 2) have been updated.

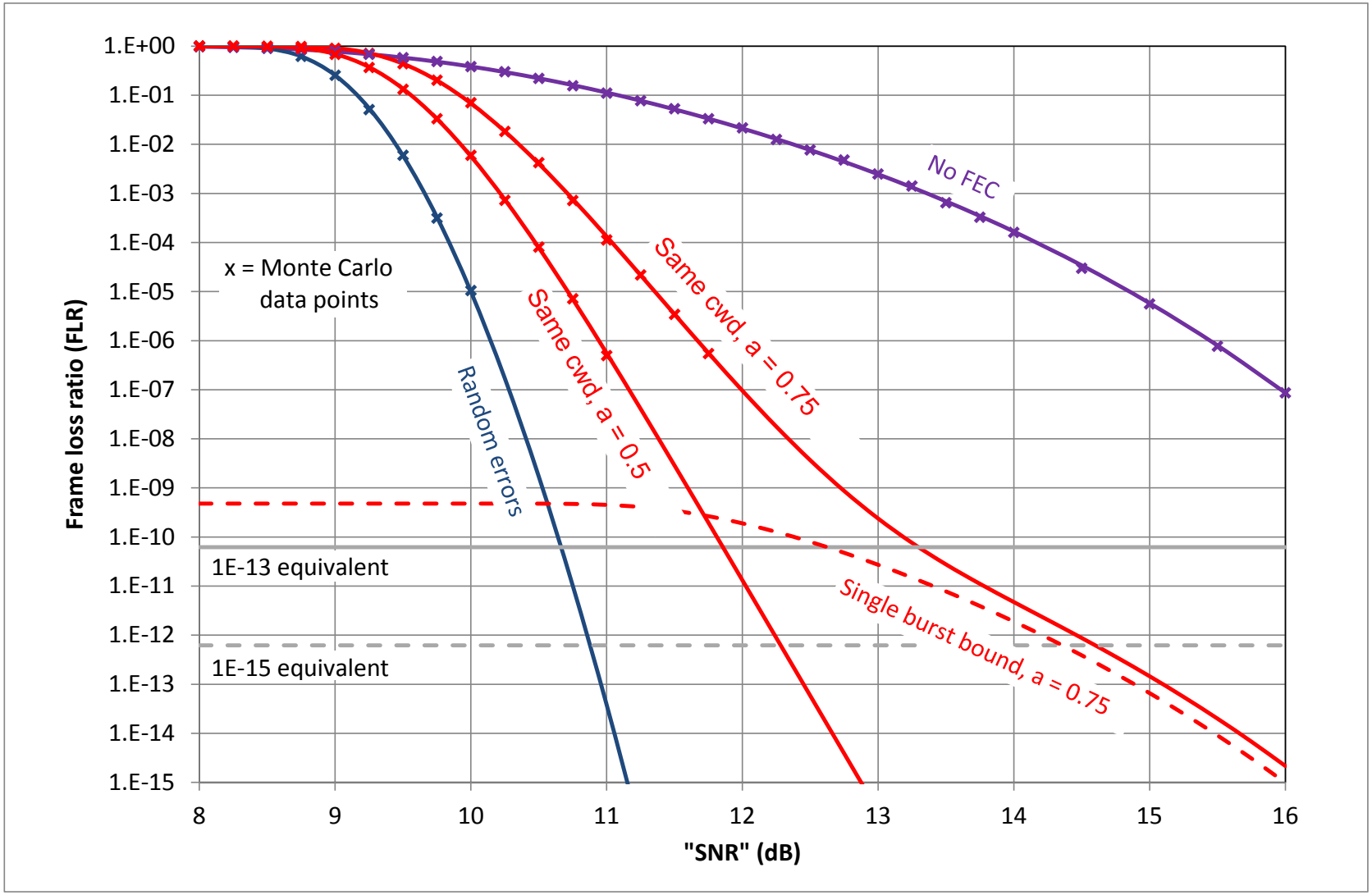
1. As per gustlin_3bs_02a_0715

Round robin distribution of FEC symbols to the PCS lanes. Bit multiplex in the PMA.



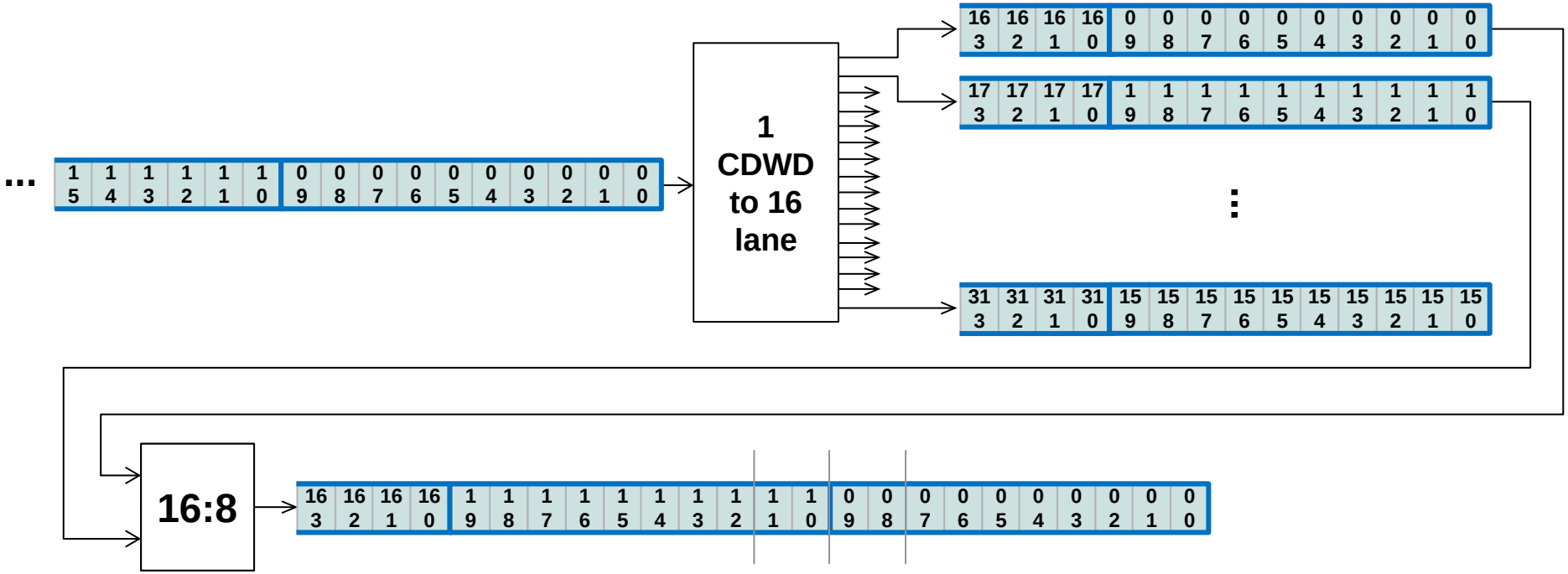
Robust for CDAUI-16, but for CDAUI-8 a 2 PAM-symbol burst can hit 2 FEC symbols from the same codeword.

RS(544,514) Option 1 bit multiplex results



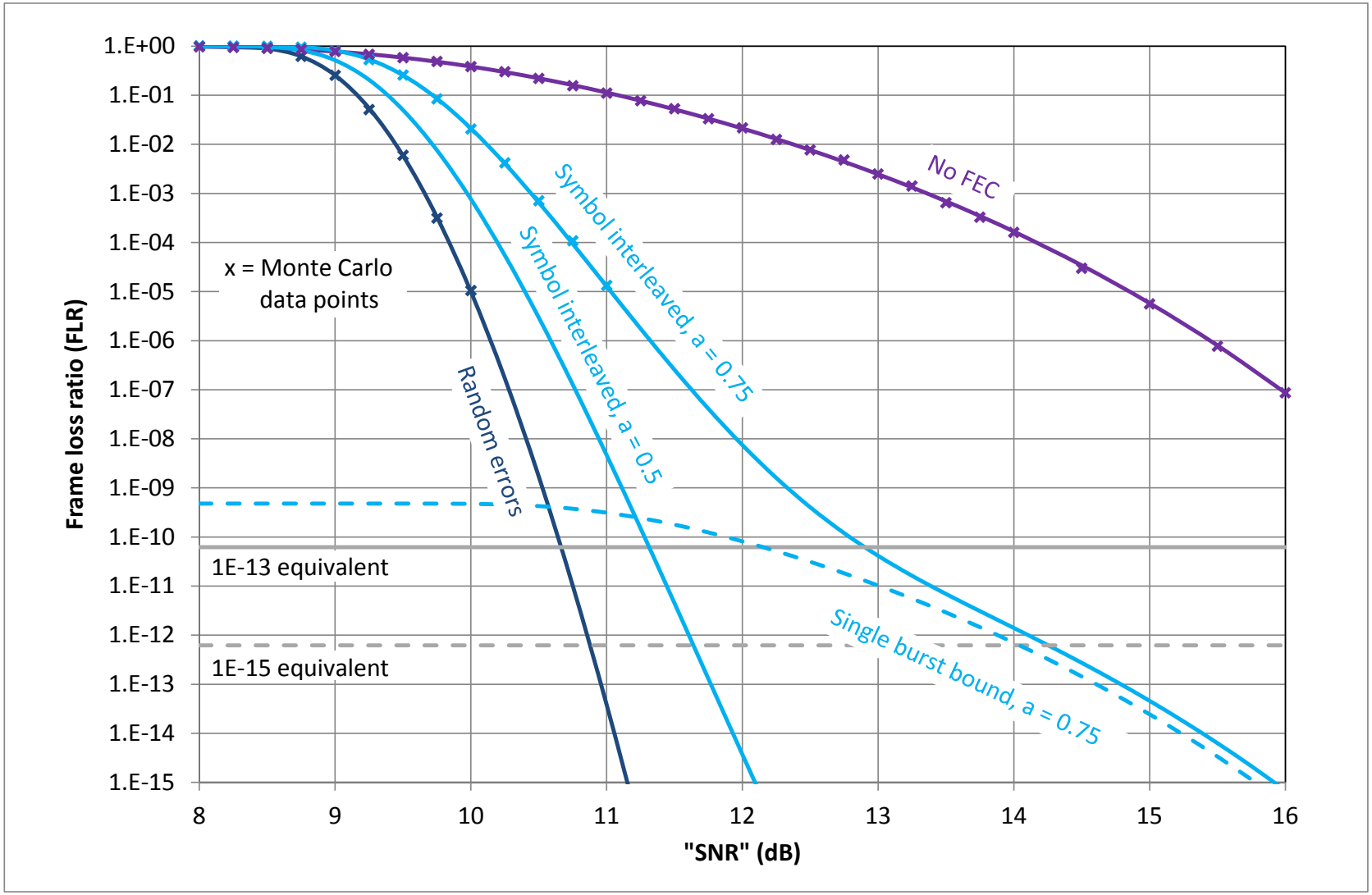
2. Symbol multiplexing

Round robin distribution of FEC symbols to the PCS lanes. Symbol multiplexing in the PMA.



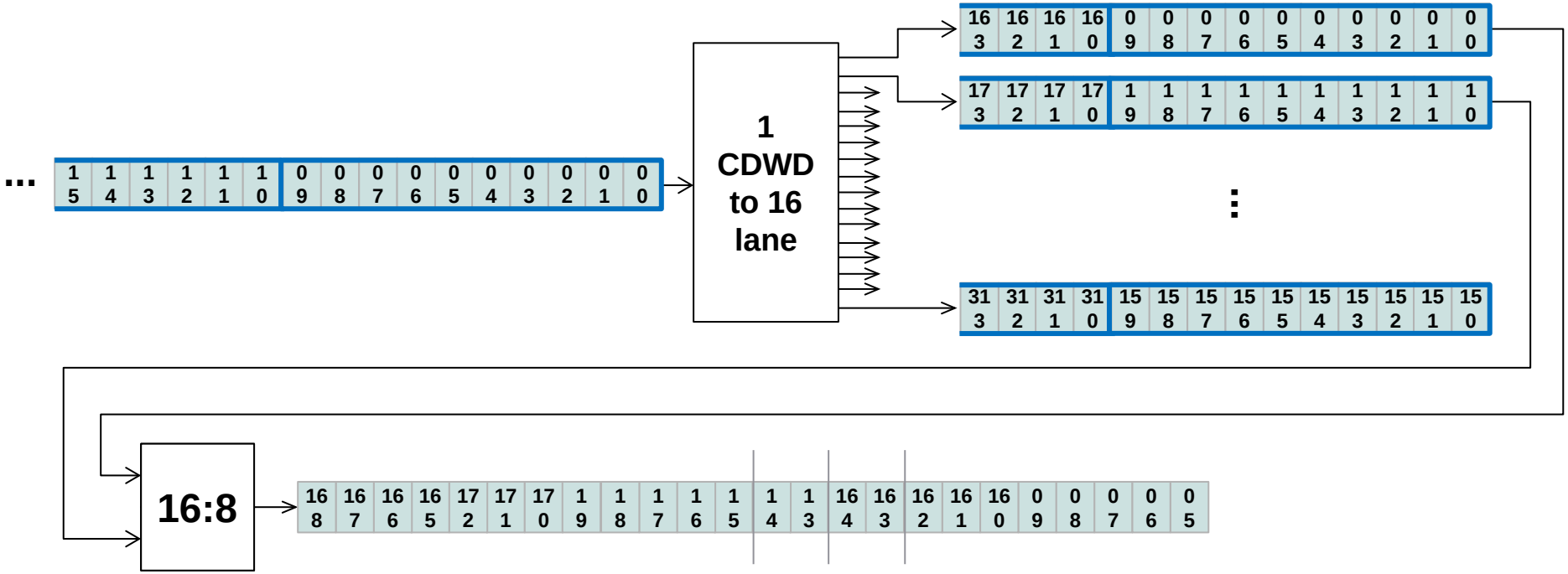
A CDAUI-16 based module must find FEC symbol boundaries.

RS(544,514) Option 2 symbol multiplex results



3. Blind 10-bit multiplexing

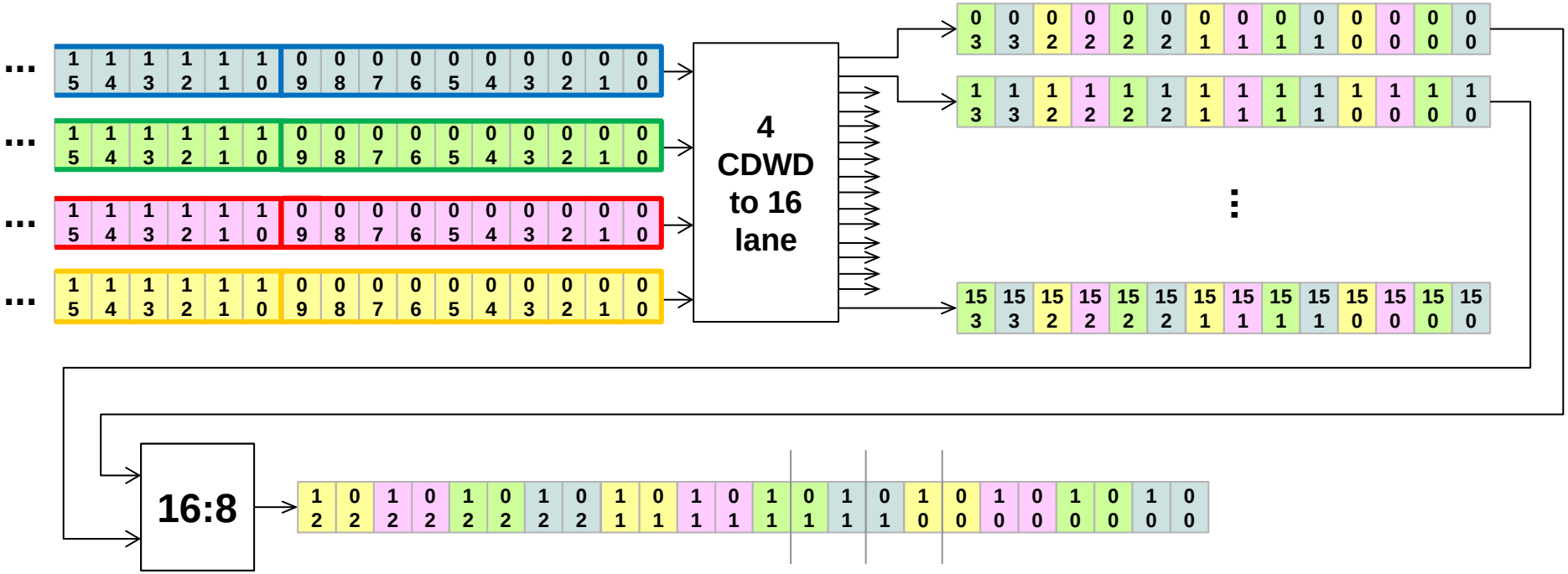
Round robin distribution of FEC symbols to the PCS lanes. Blind 10-bit multiplexing in the PMA.



PCS must unravel blind 10-bit multiplexing and a CDAUI-16 based module can’t be tested with PRBS.

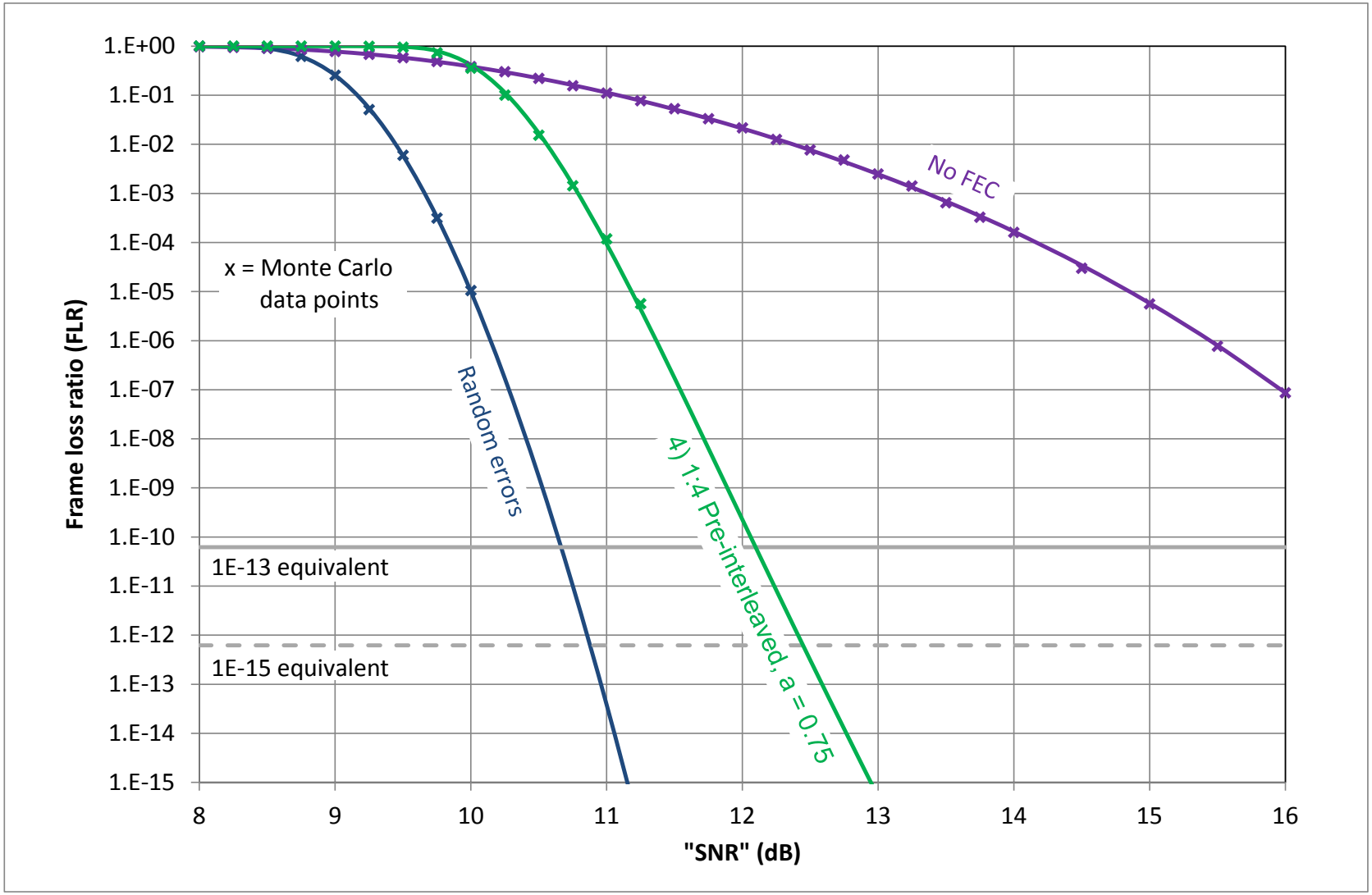
4. Pre-interleaved as per wang_t_3bs_01a_0115

Bit interleave from 4 FEC codewords, all bits from a given FEC symbol go down the same PCS lane. Bit multiplex in the PMA.



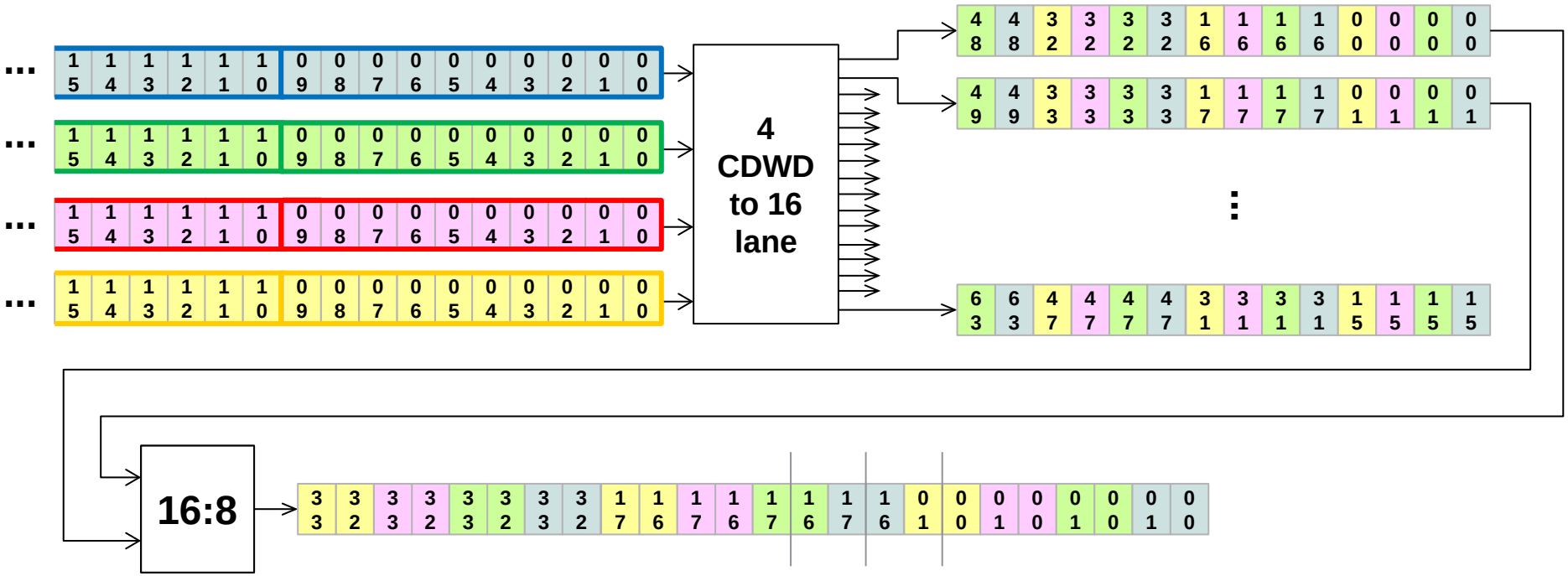
Robust for CDAUI-16. For CDAUI-8 a 2 PAM-symbol burst can hit 2 FEC symbols from the same codeword, but single bursts not an issue.

RS(544,514) Option 4 pre-interleaved results



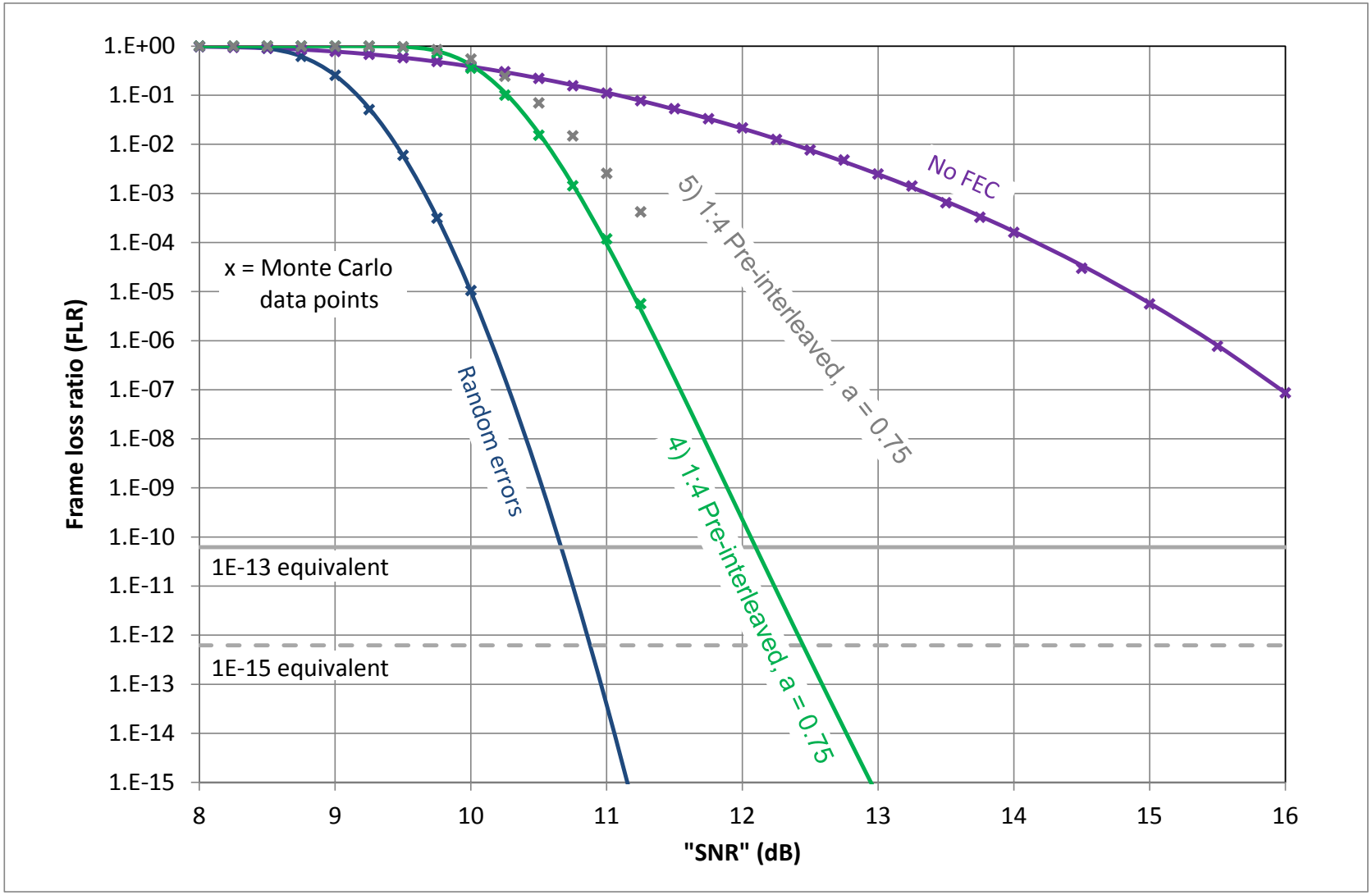
5. Pre-interleaved alternative 1

Bit interleave from 4 FEC codewords, each bit from a given FEC symbol goes down a different PCS lane. Bit multiplex in the PMA.



Less robust for both CDAUI-16 and CDAUI-8.

RS(544,514) Option 5 pre-interleaved results

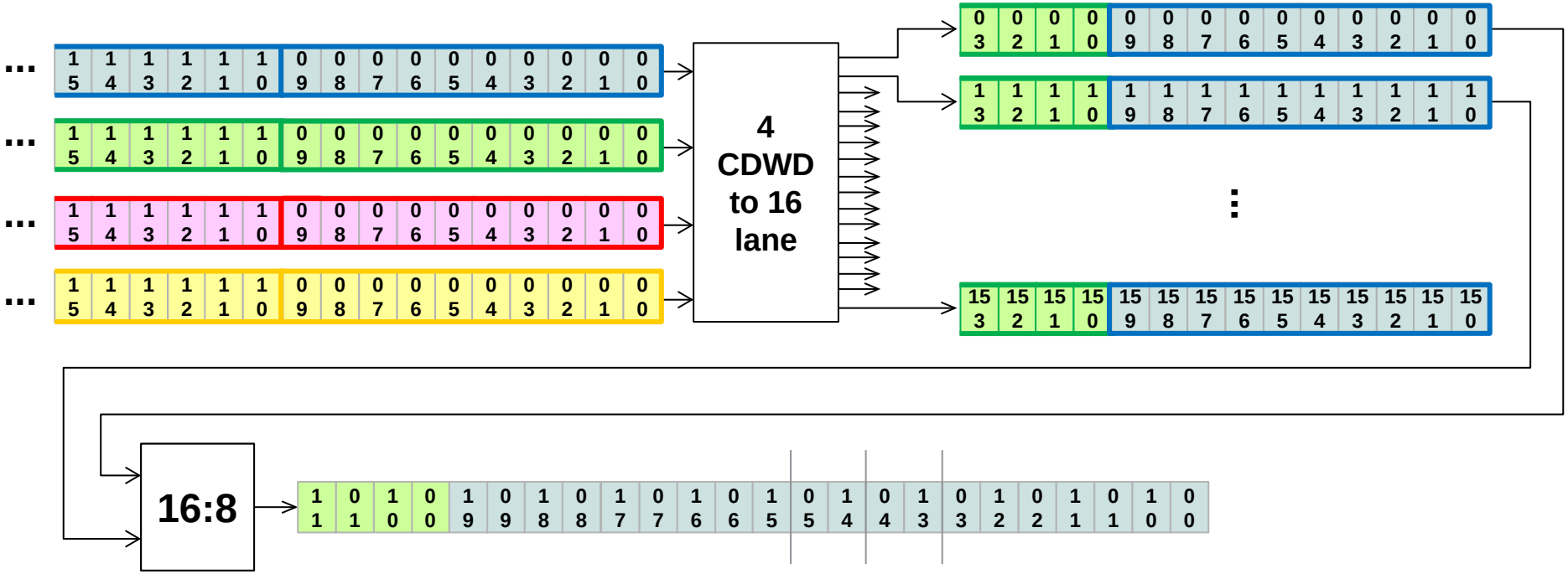


Simulated case

4	3	4	3	4	3	4	3	2	1	2	1	2	1	2	1	1	0	1	0	1	0	1	0
2	2	2	2	2	2	2	2	6	6	6	6	6	6	6	6	0	0	0	0	0	0	0	0

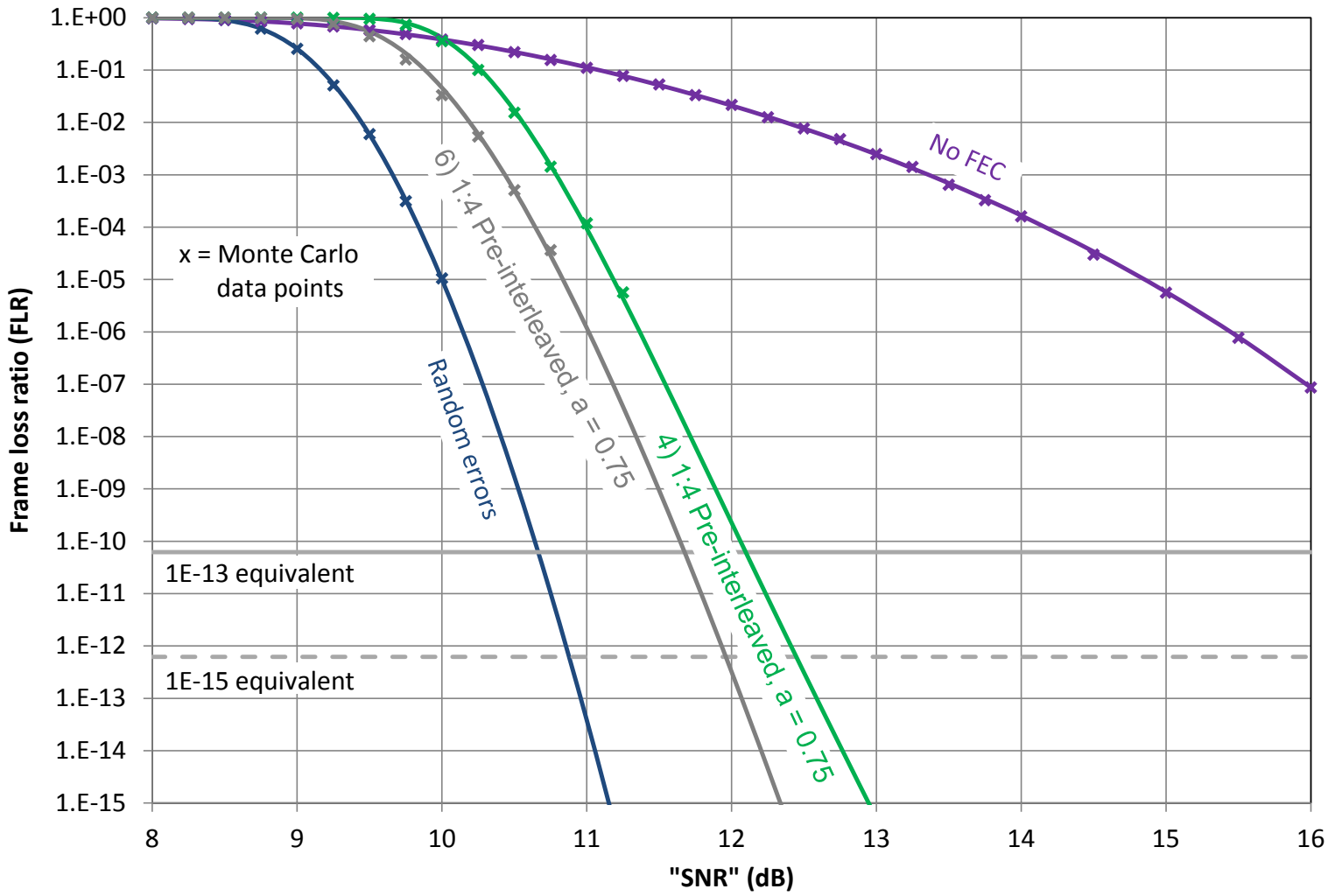
6. Pre-interleaved alternative 2

Symbol interleave from 4 FEC codewords. Bit multiplex in the PMA.



Better performance than scheme 1 and single bursts not an issue.
Two bookend skew values analysed, worst case taken forward.

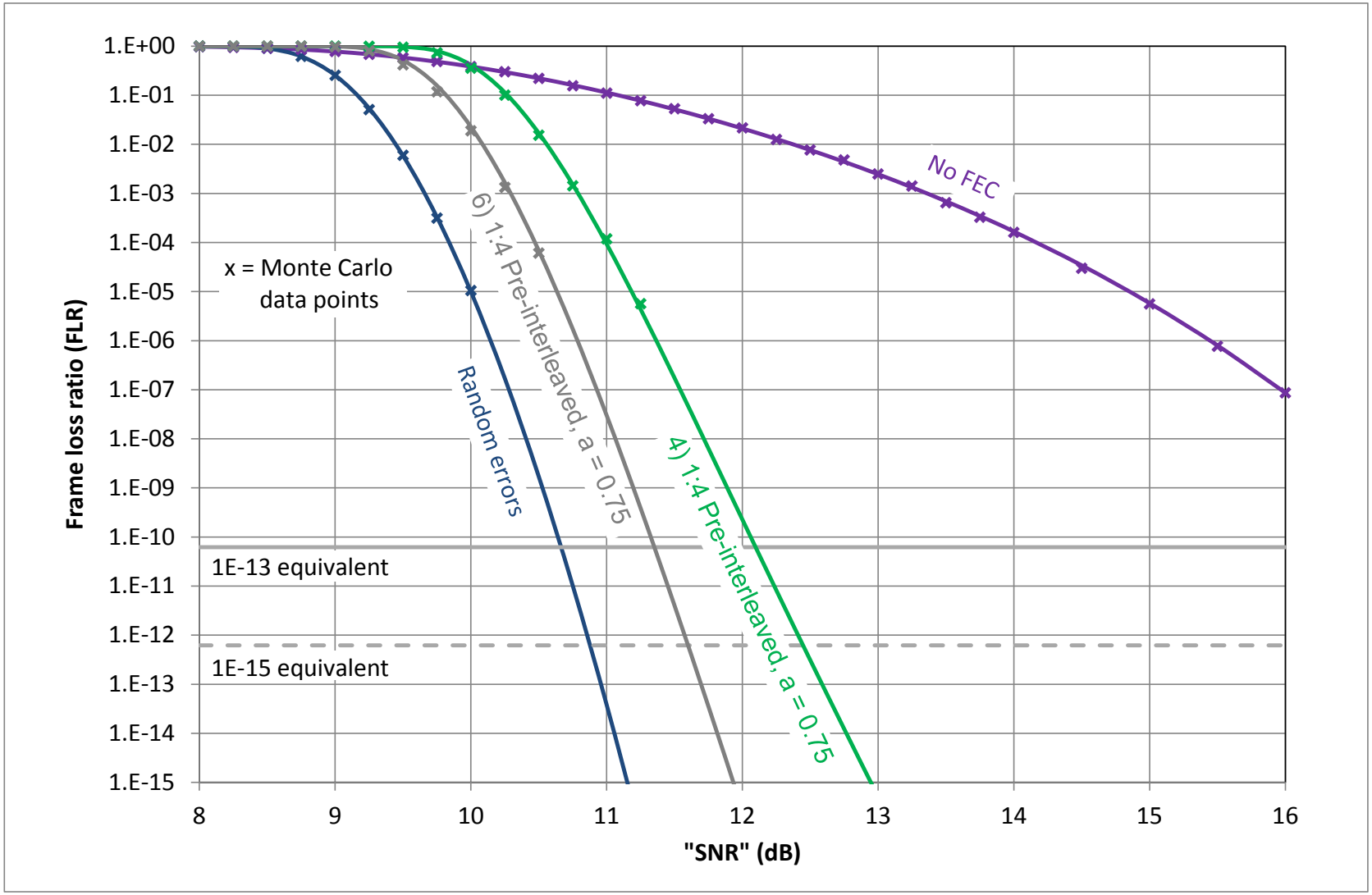
RS(544,514) Option 6 pre-interleaved results 1



Simulated case

11	01	10	00	19	09	18	08	17	07	16	06	15	05	14	04	13	03	12	02	11	01	10	00

RS(544,514) Option 6 pre-interleaved results 2

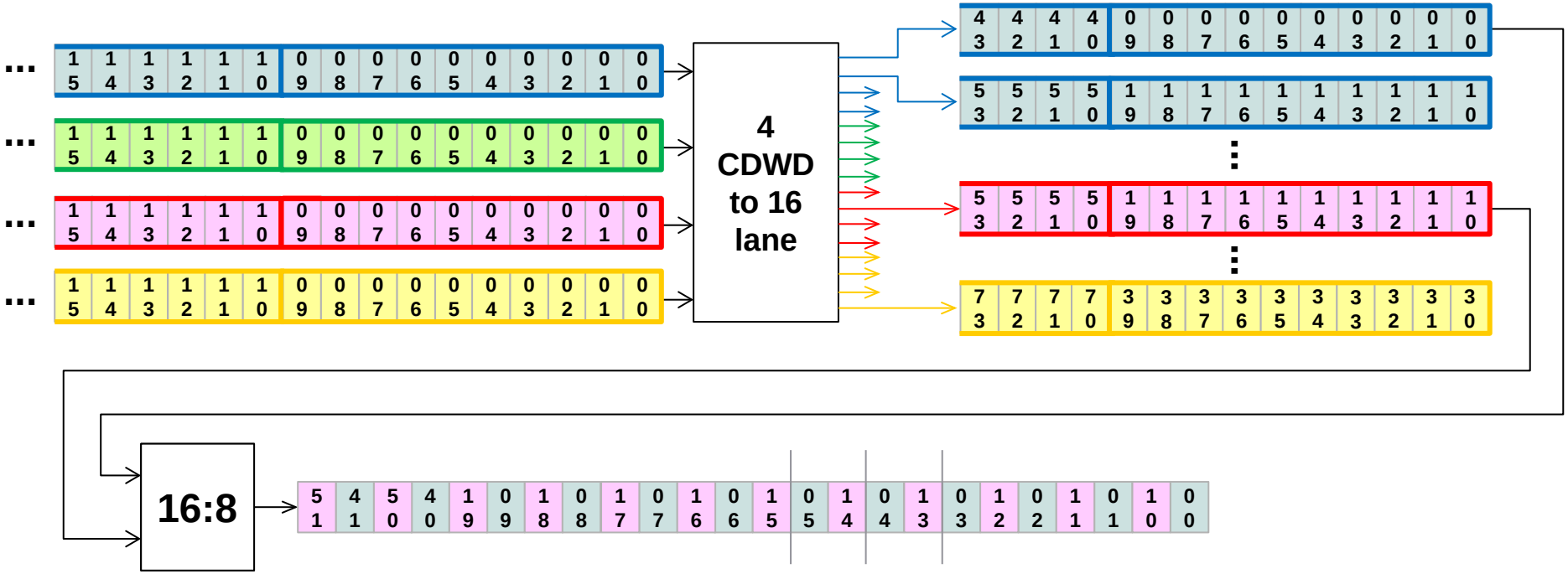


Simulated case

1 1	0 1	1 0	0 0	1 9	0 9	1 8	0 8	1 7	0 7	1 6	0 6	1 5	0 5	1 4	0 4	1 3	0 3	1 2	0 2	1 1	0 1	1 0	0 0

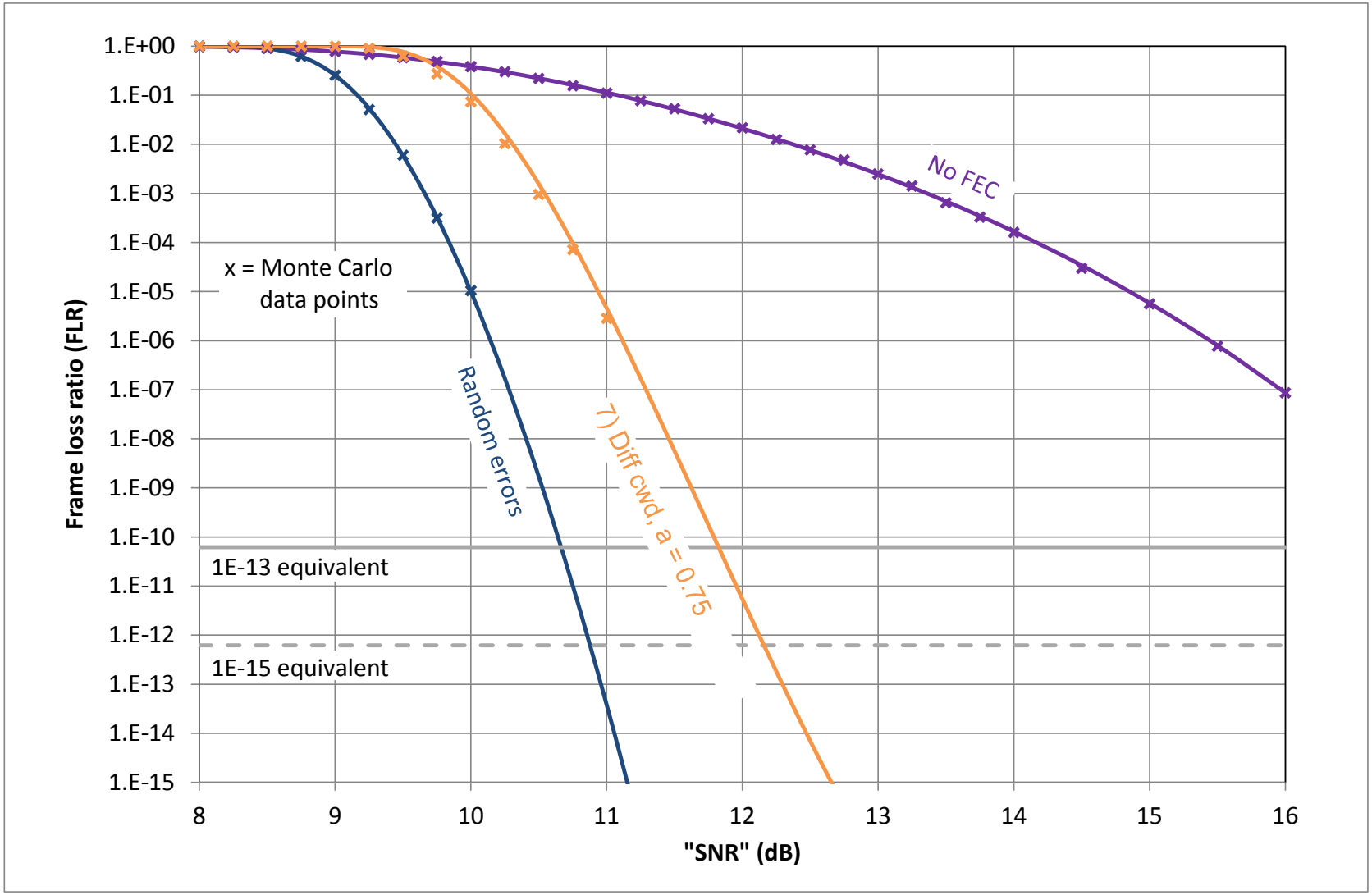
7. 1:2 Different codeword bit interleave (FOM)

Round robin distribution of FEC symbols from one codeword to 4 PCS lanes. Bit multiplex PCS lanes from different codewords in the PMA.



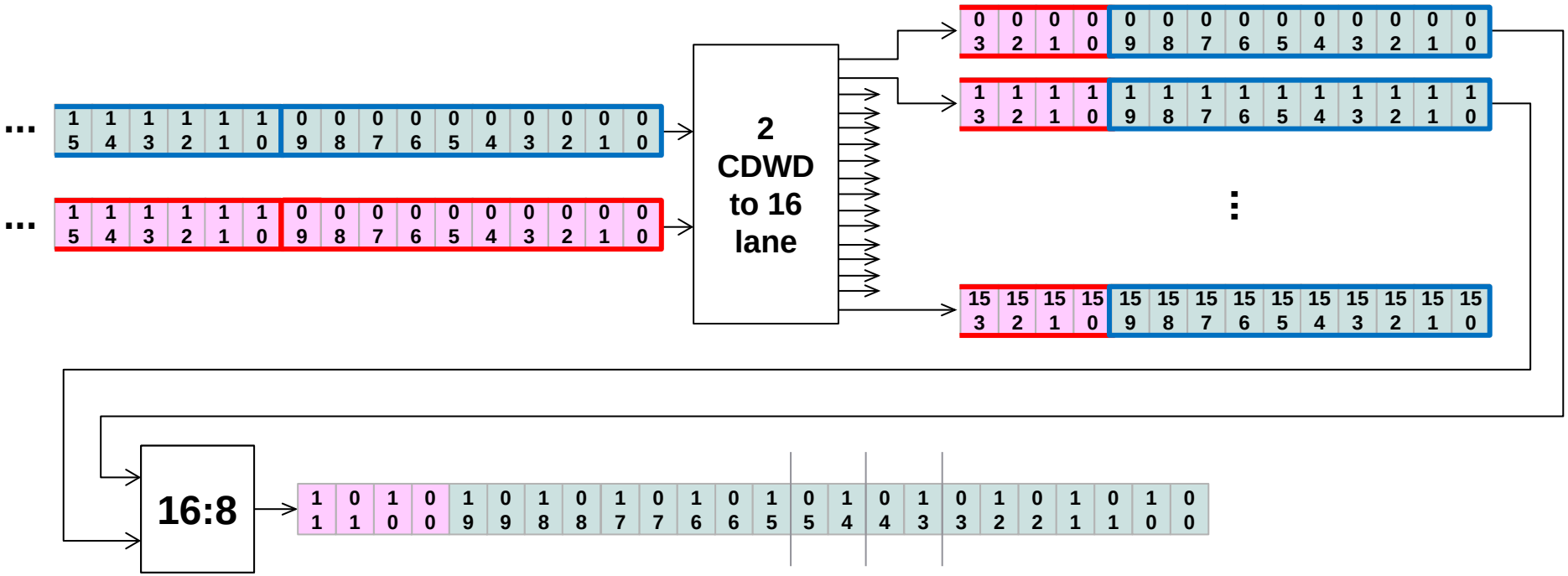
Robust for CDAUI-16 and CDAUI-8 but lose lane independence and worse performance if lane BERs are not identical.

RS(544,514) Diff cwd (FOM) results



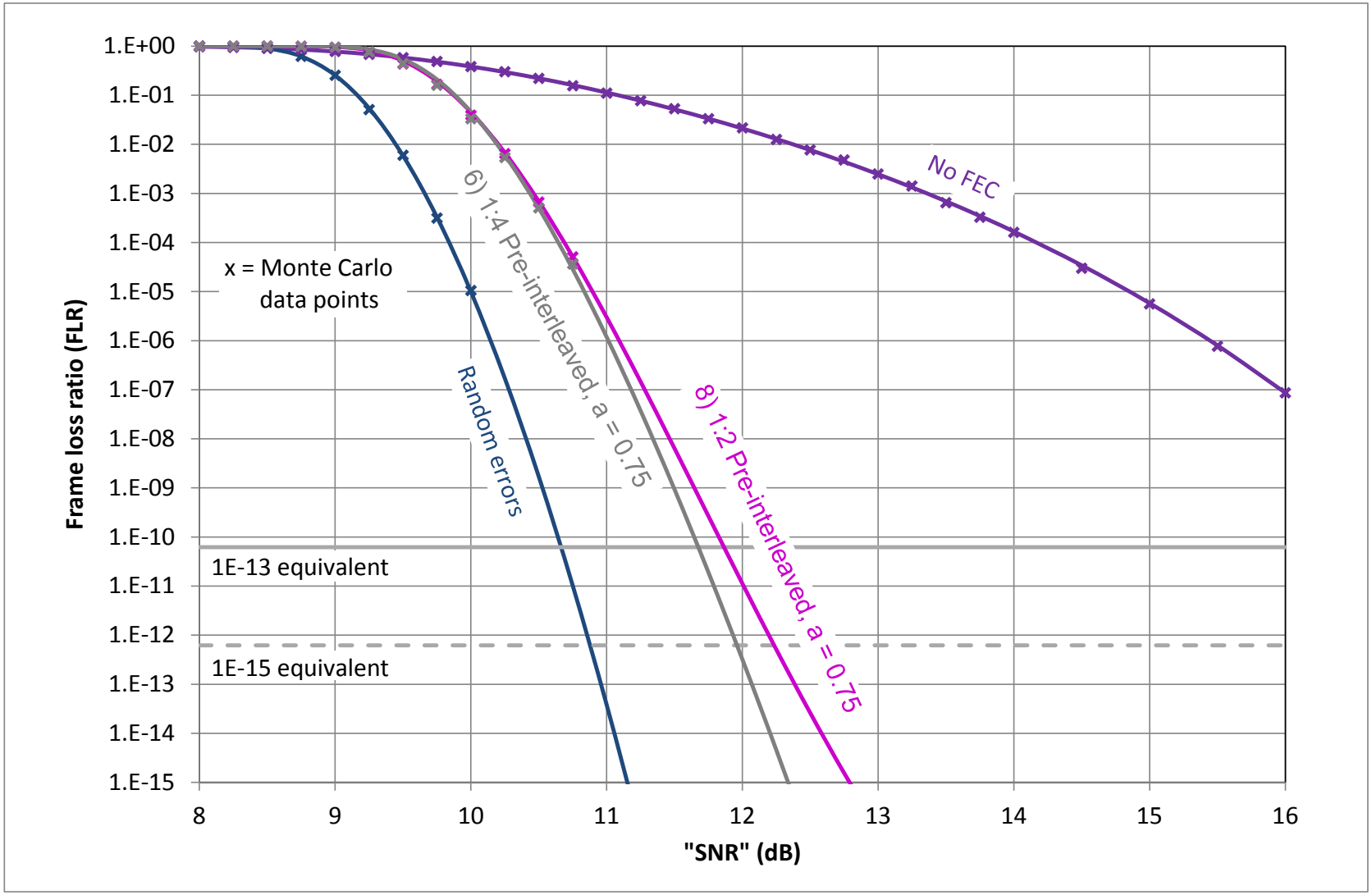
8. Pre-interleaved from 2 codewords

Symbol interleave from 2 FEC codewords. Bit multiplex in the PMA.



Slightly reduced performance.

RS(544,514) Option 8 pre-interleaved results

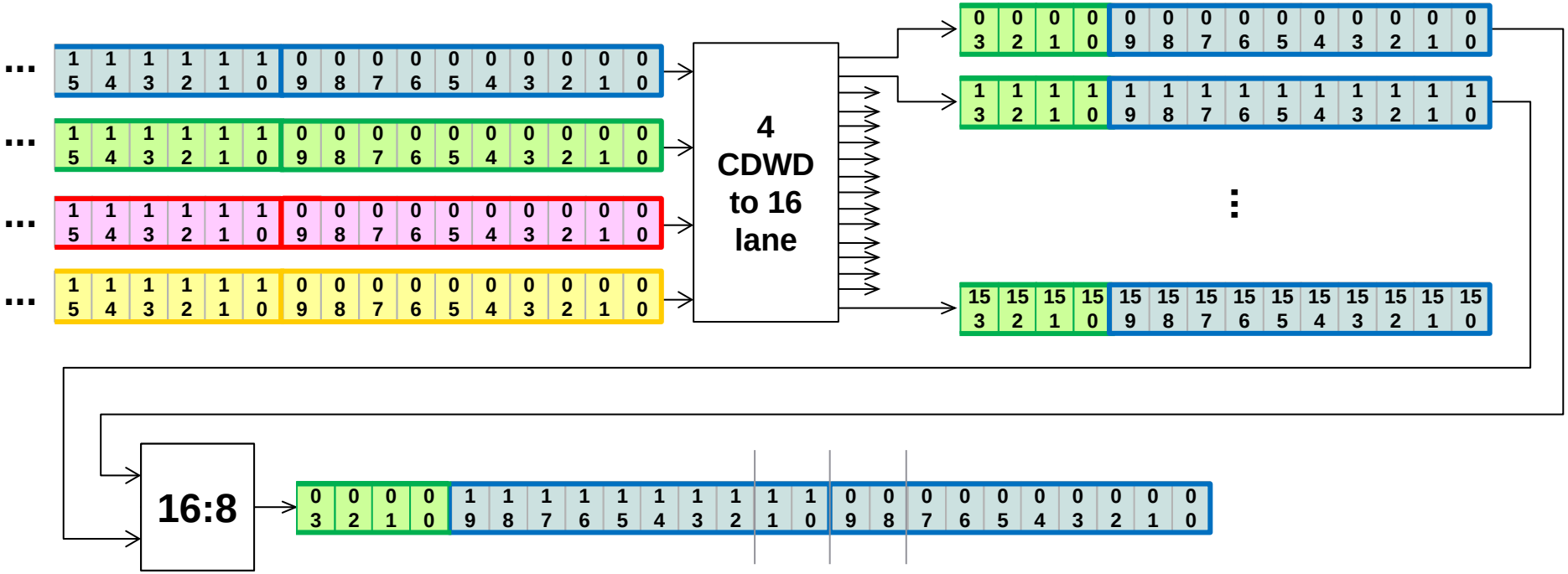


Simulated case

11	01	10	00	19	09	18	08	17	07	16	06	15	05	14	04	13	03	12	02	11	01	10	00

9. Pre-interleaved 4:1 symbol mux

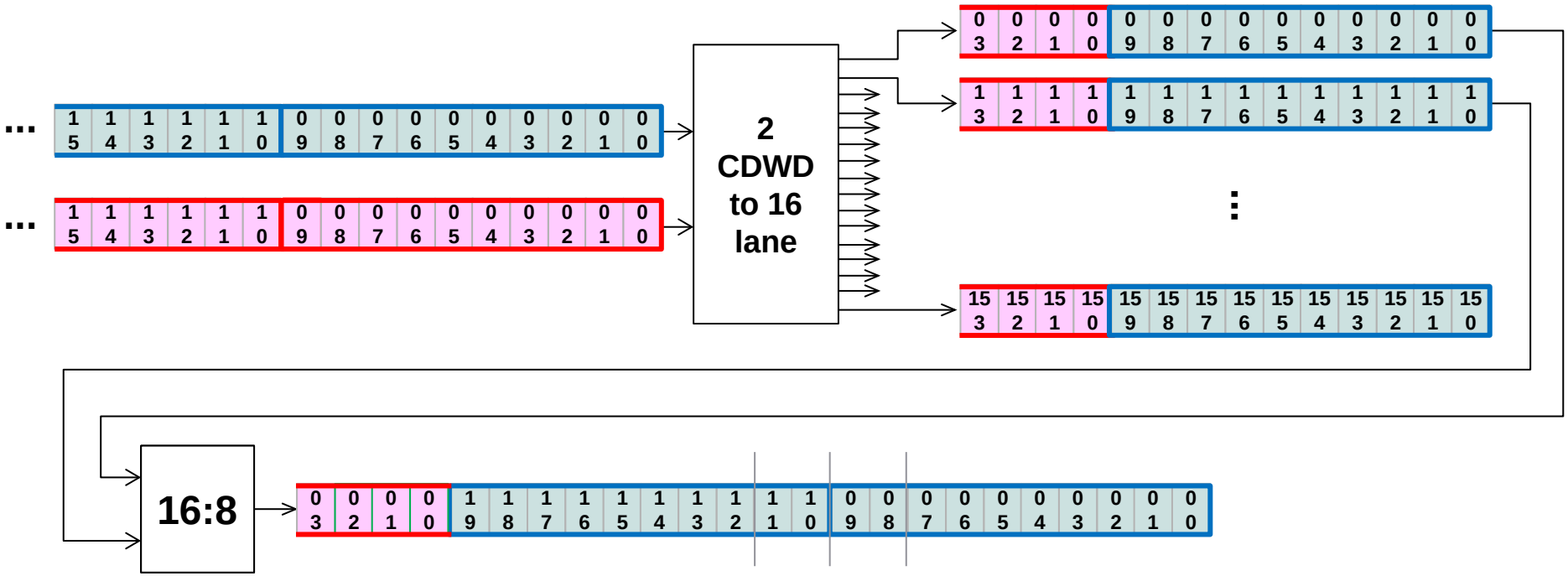
Symbol interleave from 4 FEC codewords. Symbol multiplex in the PMA.



Best performance.

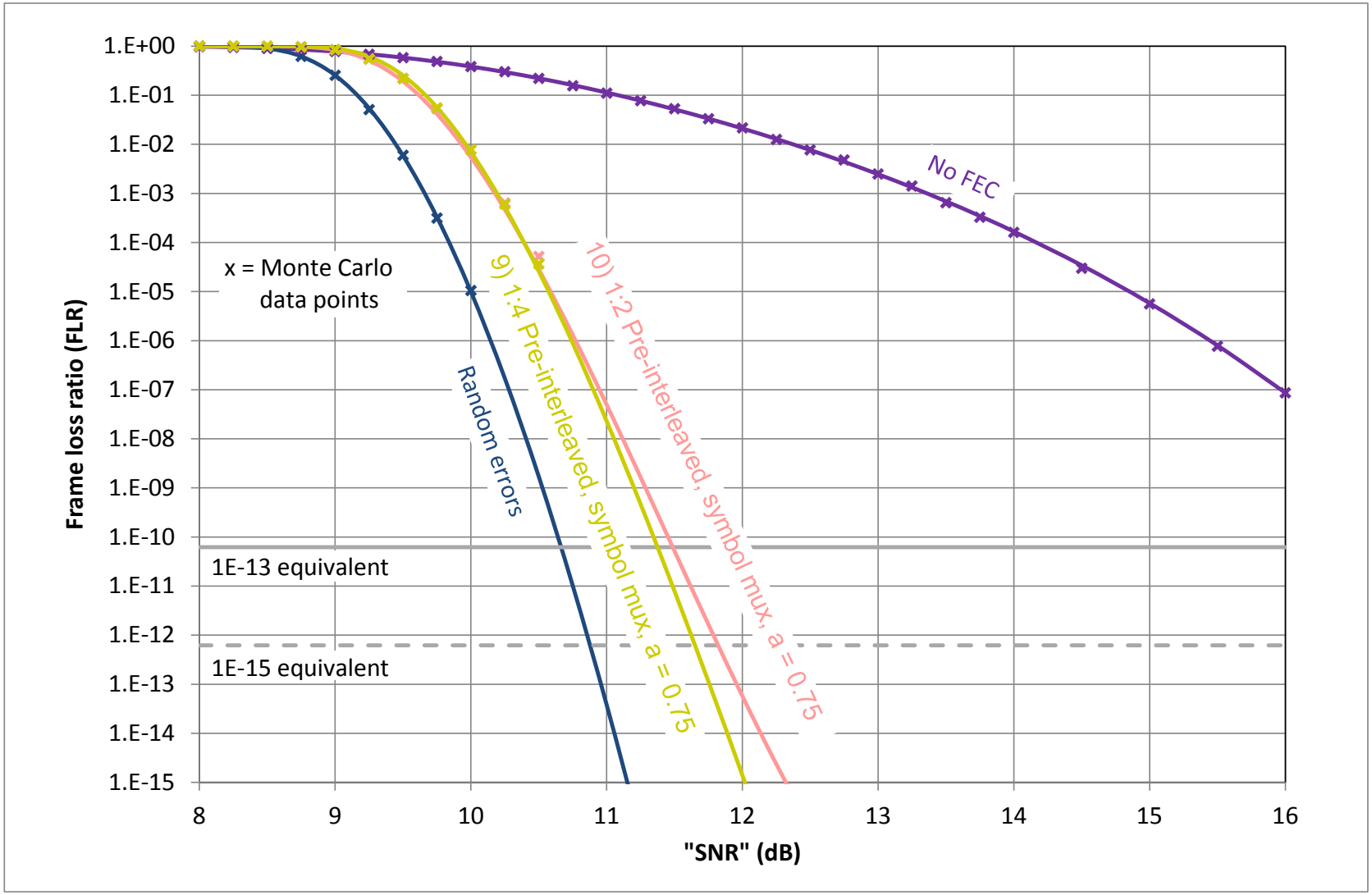
10. Pre-interleaved 2:1 symbol mux

Symbol interleave from 2 FEC codewords. Symbol multiplex in the PMA.



Slightly reduced performance.

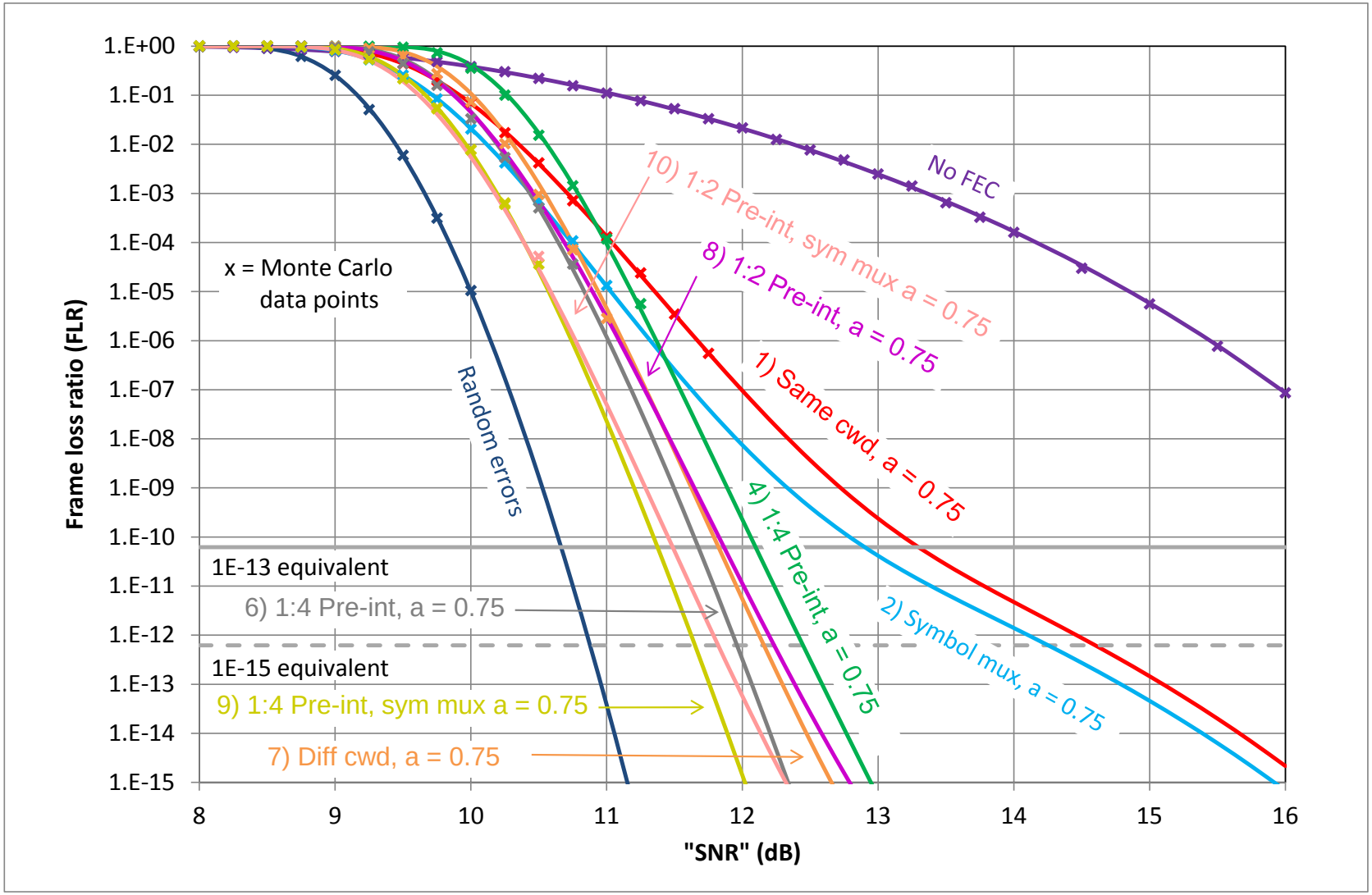
RS(544,514) Options 9,10 pre-interleaved results



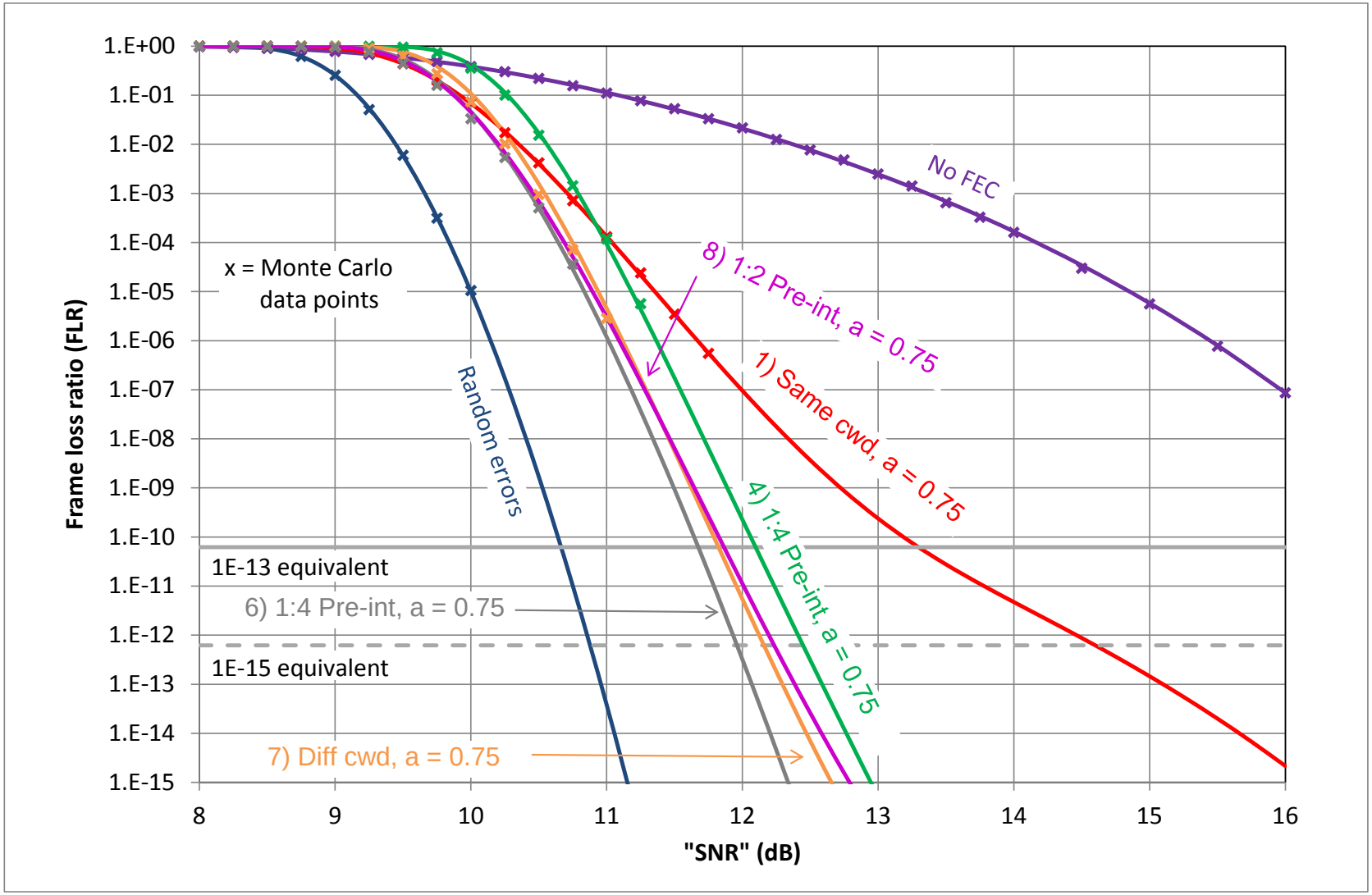
Simulated case

1 1	0 1	1 0	0 0	1 9	0 9	1 8	0 8	1 7	0 7	1 6	0 6	1 5	0 5	1 4	0 4	1 3	0 3	1 2	0 2	1 1	0 1	1 0	0 0

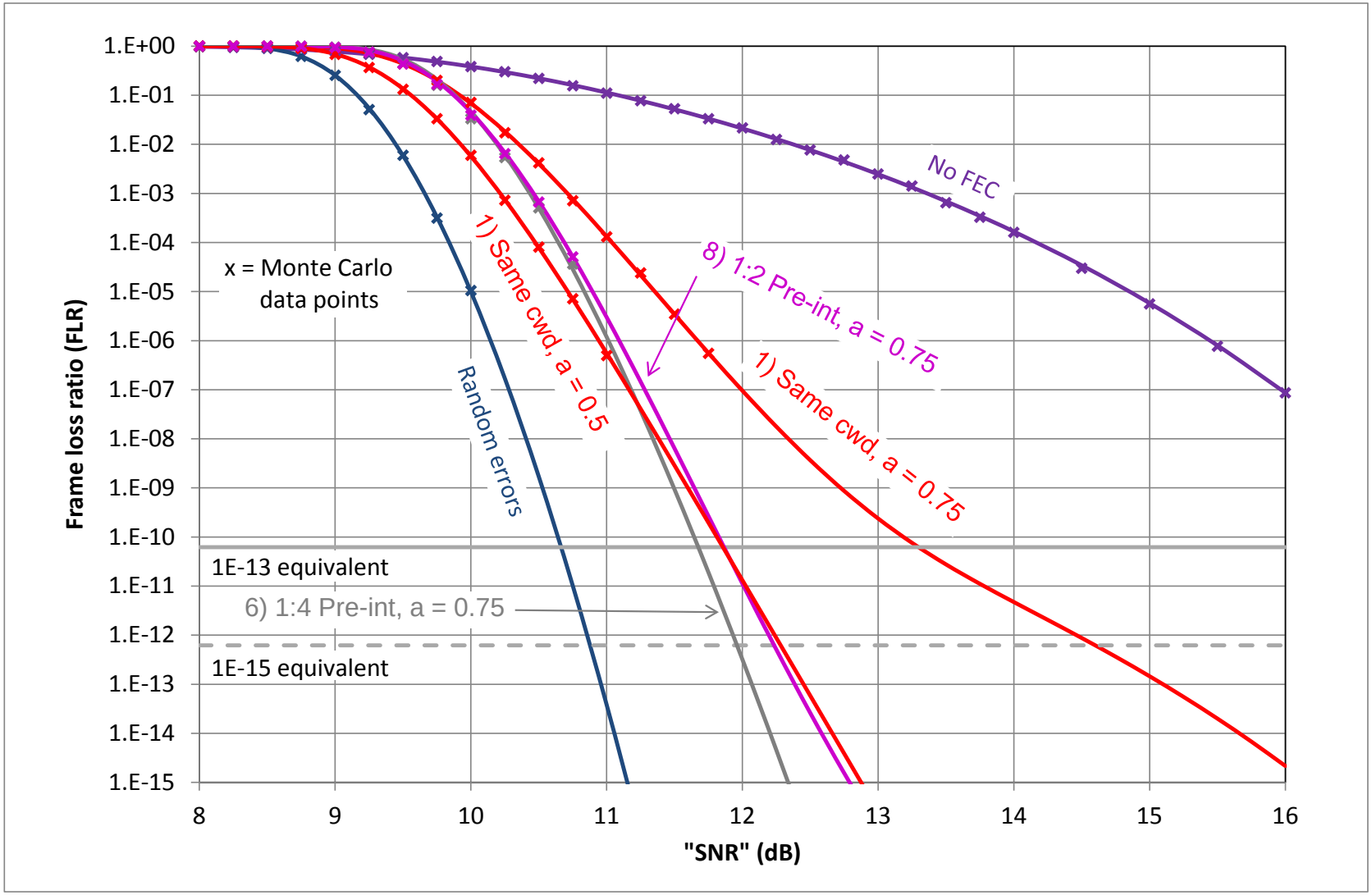
RS(544,514) All 1:2 multiplexing results



RS(544,514) All 1:2 bit mux results



RS(544,514) Options 1, 6 and 8



Results for RS(544,514) 50G, all gain used for PAM4

For reference, if all of the coding gain were to be used for the 50G PAM4 link, the BERs at the slicer output and FEC input required to give FLRs equivalent to that of a BER of 1E-13 and 1E-15 are:

	At slicer output		At FEC input	
	FLR = 6.2E-11	FLR = 6.2E-13	FLR = 6.2E-11	FLR = 6.2E-13
No FEC	1E-13	1E-15	1E-13	1E-15
Same cwd (1), a = 0.75			7.6E-6*	1.6E-7*
Same cwd, symb inter (2), a = 0.75			2E-5*	4.9E-7*
Same cwd (1), a = 0.5			9E-5*	3.9E-5*
1:4 Pre-interleaved (4), a=0.75			1.1E-4*	5.5E-5*
1:2 Pre-interleaved (8), a=0.75			1.8E-4*	8.6E-5*
Diff cwd (FOM) (7), a = 0.75			1.9E-4*	1E-4*
Same cwd precoded, a=0.75	2.3E-4*	1.3E-4*	1.1E-4	6.3E-5
1:4 Pre-interleaved (6), a=0.75			2.5E-4*	1.5E-4*
1:2 Pre-int, sym mux (10), a=0.75			3.5E-4*	1.9E-4*
1:4 Pre-int, sym mux (9), a=0.75			4.2E-4*	2.6E-4*
Random errors			3.2E-4	2.3E-4

Note – these values are the BER **including** the additional errors due to the bursts. To account for burst errors, the values marked with "*" have been multiplied by 4 when a = 0.75 and 2 when a = 0.5.

Multi-part link results

The BER of the electrical sub-links for a penalty of ~0.1 dB optical in the optical sub-link are shown in the table below.

	At slicer output for FLR = 6.2E-11			
	Total electrical		Optical	
Same cwd (1), a = 0.75	Burst	2.9E-7*	Random	2.4E-4
Same cwd, symbol interleave (2), a = 0.75	Burst	7.5E-7*	Random	2.4E-4
Same cwd (1), a = 0.5	Burst	1.6E-5*	Random	2.4E-4
1:4 Pre-interleaved (4), a=0.75	Burst	2.2E-5*	Random	2.4E-4
1:2 Pre-interleaved (8), a=0.75	Burst	3.5E-5*	Random	2.4E-4
Diff cwd (FOM) (7), a = 0.75	Burst	4E-5*	Random	2.4E-4
Same cwd elec only precoded, a=0.75	Burst	5.1E-5*	Random	2.4E-4
Same cwd end-to-end precoded, a=0.75	Burst	6.9E-5*	Random	4.9E-5
1:4 Pre-interleaved (6), a=0.75	Burst	5.7E-5*	Random	2.4E-4
1:2 Pre-int, sym mux (10), a=0.75	Burst	7.6E-5*	Random	2.4E-4
1:4 Pre-int, sym mux (9), a=0.75	Burst	1E-4*	Random	2.4E-4
Random errors	Random	8.2E-5	Random	2.4E-4

Note – these values are the BER **including** the additional errors due to the bursts. To account for burst errors, the values marked with "*" have been multiplied by 4 when a = 0.75 and 2 when a = 0.5.

Thanks!