2014/10/29

FEC Performance of FOM Bitmux in Different User Cases

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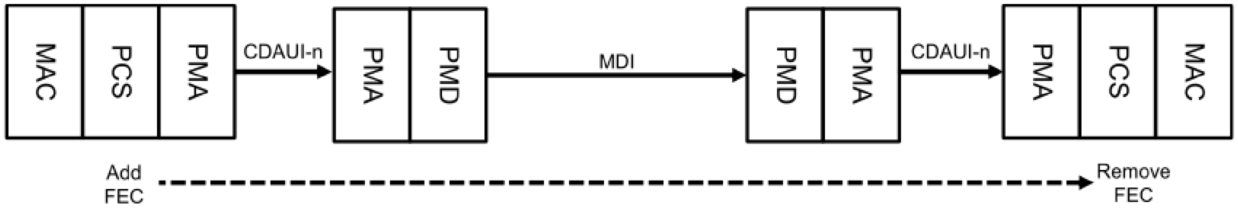
Background

- **FOM Bitmux (DF) has been proposed and analyzed since January meeting this year, the method and performance analysis can refer to**
  - wang_400_01a_0114
  - wang_t_3bs_01_0514
  - anslow_3bs_02_0714
  - anslow_3bs_02_0914
  - wang_t_3bs_01_0714

- **FEC Performance on Multi part links differs in 400GbE scenarios, e.g. xR8 w/CDAUI-8, xR8 w/CDAUI-16 , xR4 w/CDAUI-8, etc.**
- **We investigate the performance in all scenarios in this contribution.**

User Cases w/End to End FEC Architecture

- **Start analyze with end to end FEC architecture**



-- *gustlin_3bs_02_0714*

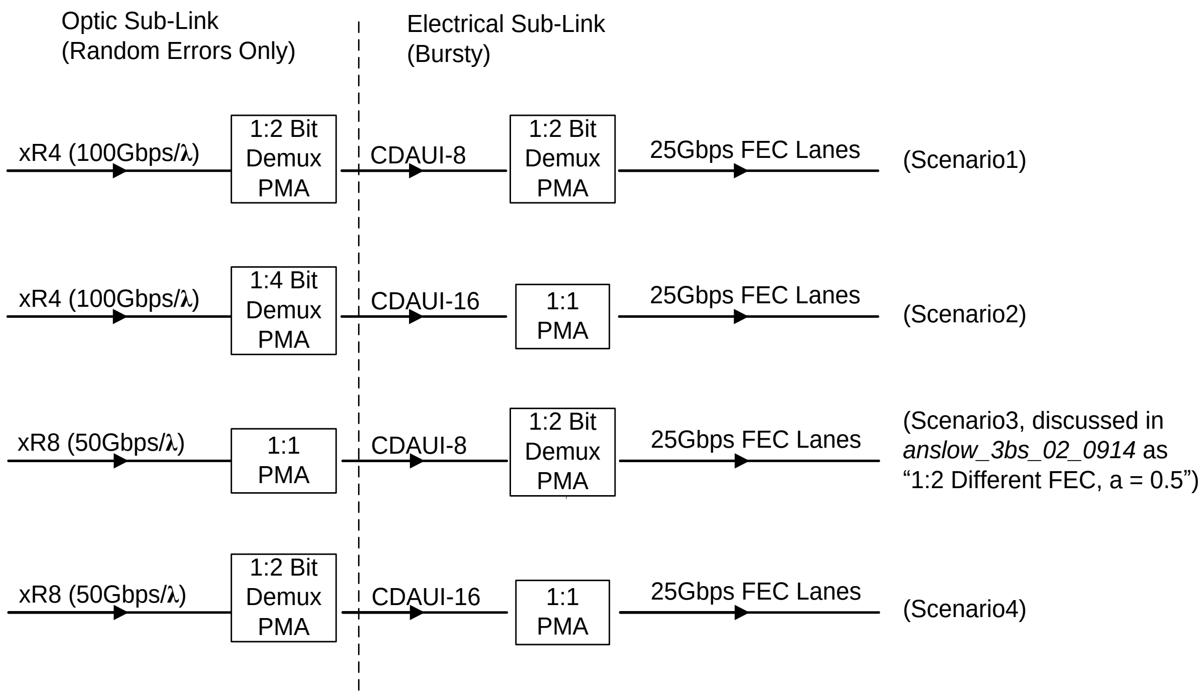
- **Electrical interface: CDAUI-16/8 spec are passed in Sep meeting**

Motion 4 (as modified by motion #5): 9:15 am.
Move to adopt 16 x 25Gb/s and 8 x 50Gb/s as the basis for the lane rates for any optional C2C and C2M electrical interfaces

- M: J. Goergen
- S: V. Parthasarathy
- Technical (>= 75%),
- Y: 102 , N: 0 , A: 4
- Result: passes!

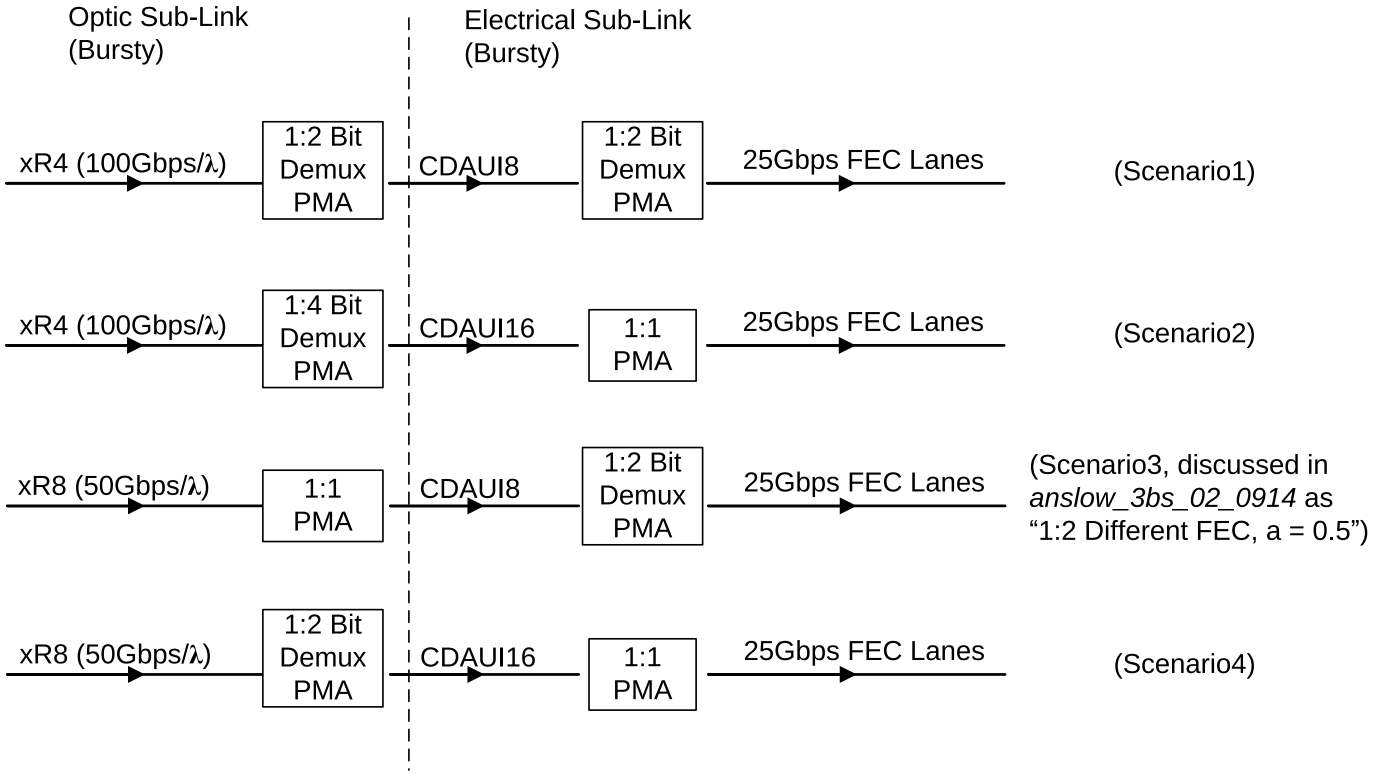
- **Optical interface: Both 50G and 100G bit rate per lane PMD are under investigation in task force.**
  - Refer to the SMF PMD Decision Tree (*cole_02_0814_smf*)

FOM On Random + Burst Links



- Use receiver side to illustrate FOM demuxing on *Random* + *Burst* multipart link scenarios;
- Error model on optical sub links is either random or burst errors, as describe in *Anslow_3bs_02_0914*, and errors on electrical sub links are probably bursty. So for each scenarios, two kinds of error model on optical links are used to analyze the limiting BER on electrical links that cause 0.1dB penalty for optical links.
- For example in *Random+Burst* links, with limited BER on electrical links, KP4 FEC performance can be 0.1dB worse than “random error model” as in 100GbE, which requires BER_{in} = 3e-4 to meet 1e-13 objective .

FOM On Burst + Burst Links



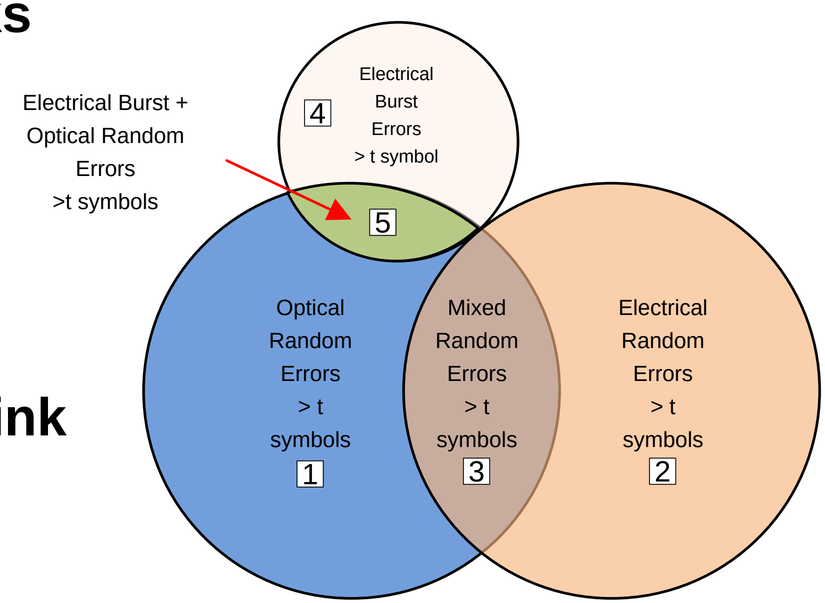
- Use receiver side to illustrate FOM demuxing on *Burst* + *Burst* multipart link scenarios.
- The following calculations use KP4 FEC to estimate limiting BER on electrical sub-links.

FEC Performance on Two Part Link (Random+Burst)

Random errors from two sub-links

$$\sum_{i=t+1}^{n} \binom{n}{i} SER^{i}(1-SER)^{n-i}$$

- Optical sub-link errors (1)
- Electrical sub-link errors (2)
- Optical + Electrical sub-link errors (3)



Burst errors from electrical sub-link

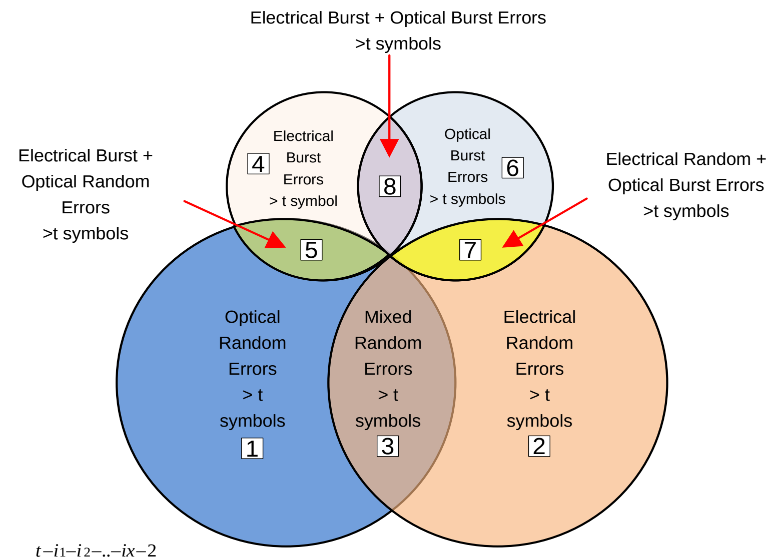
- One burst, two bursts, … seven bursts with total length > t symbols (4)

$$Burst\ Error(x) = \binom{n}{1} * M(t+1) + \binom{n}{2} * \sum_{i=1}^{t} G(i) * M(t+1-i) + \ldots + \binom{n}{x} * \sum_{i_1=1}^{t} \ldots \sum_{i_{x-1}=1}^{t-i_1-i_2-\ldots-i_{x-2}} G(i_1) * G(i_2) * M(t+1-i_1-i_2-\ldots-i_{x-1})$$

Mixed burst errors and random errors

$$\sum_{i=1}^{t-1} \binom{n}{i} SER^{i}(1-SER)^{n-i} * Burst\ Error(t+1-i) \quad (5)$$

FEC Performance on Two Part Link (Burst + Burst)



Random errors from two sub-links

- Optical sub-link errors (1)
- Electrical sub-link errors (2)
- Optical + Electrical sub-link errors (3)

$$\sum_{i=t+1}^{n} \binom{n}{i} SER^{i}(1-SER)^{n-i}$$

Burst errors from both sub-links

- Electrical burst error longer than t symbols (4)
- Optical burst error longer than t symbols (6)

$$Burst\ Error(x) = \binom{n}{1} * M(t+1) + \binom{n}{2} * \sum_{i=1}^{t} G(i) * M(t+1-i) + \ldots + \binom{n}{x} * \sum_{i_1=1}^{t} \ldots \sum_{i_{x-1}=1}^{t-i_1-i_2-\ldots-i_{x-2}} G(i_1) * G(i_2) * M(t+1-i_1-i_2-\ldots-i_{x-1})$$

Mixed burst errors and random errors from both sub-links

- Burst from optic and random from electrical link(5)
- Burst from electrical and random from optic link(7)

$$\sum_{i=1}^{t-1} \binom{n}{i} SER^{i}(1-SER)^{n-i} * Burst\ Error(t+1-i)$$

Mixed burst errors from both sub-links

- Burst from both electrical and optic link (8)

$$\sum_{i=1}^{t-1} Burst_{optic}(i) * Burst_{electrical}(t+1-i)$$

Scenario 1 (xR4 +CDAUI-8)

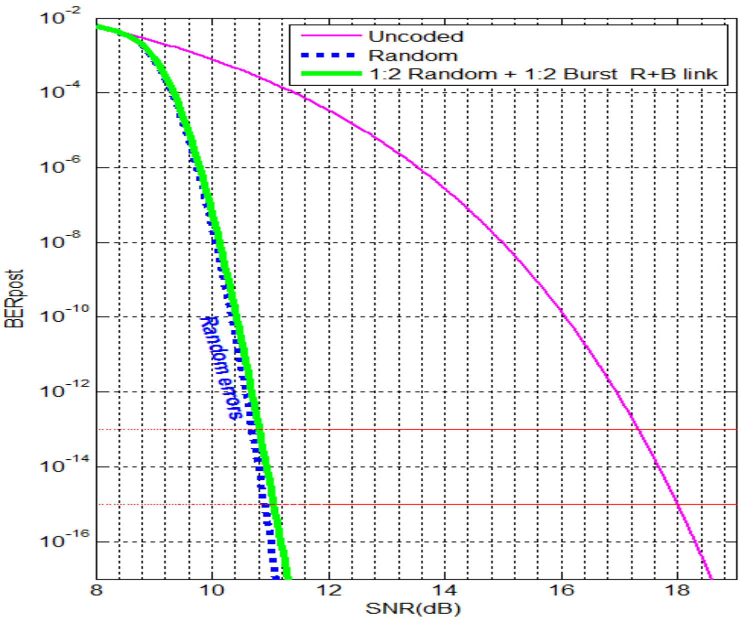


Figure 1: Random on Optical w/ Burst(a=0.5) on Electrical links

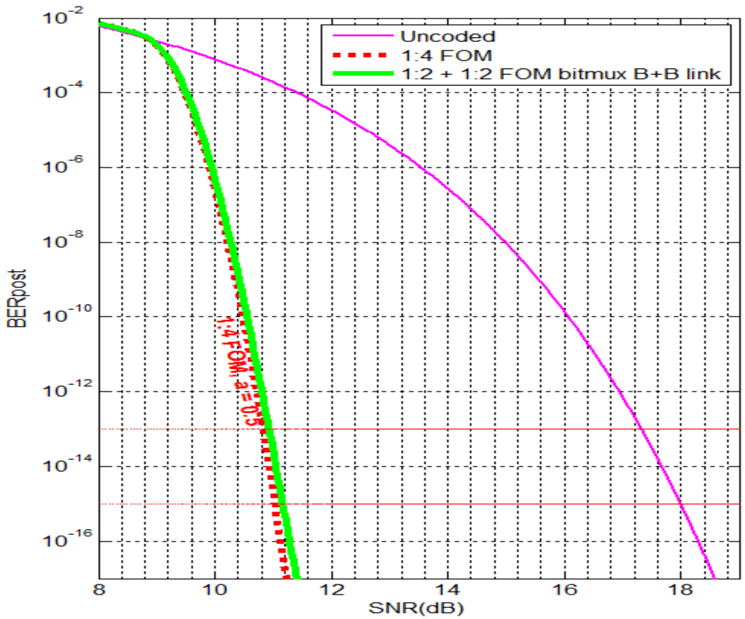


Figure 2: Burst on Optical w/ Burst(a=0.5) on Electrical links

	Error on Electrical	Error on Optical	FLR=6.2e-11	FLR=6.2e-13
BER on electrical link for 0.1 dB penalty on the optical link	Burst(a=0.5)	Random	2.7e-5*	1.9e-5*
	Burst(a=0.5)	Burst(a=0.5)	2.3e-5*	1.5e-5*
	Burst(a=0.5)	Burst(a=0.2)	2.3e-5*	1.7e-5*

- The green curve is FEC performance on mutli-part link;
- For random+burst links, the best FEC performance is as good as having random errors only, as Figure 1 shows.
- For xR4, The best FEC performance for burst+burst links is 1:4 FOM(a=0.5/0.2) as in Figure 2.

** Note – All these values do not include the additional errors due to the bursts.*

Scenario 2 (xR4 + CDAUI-16)

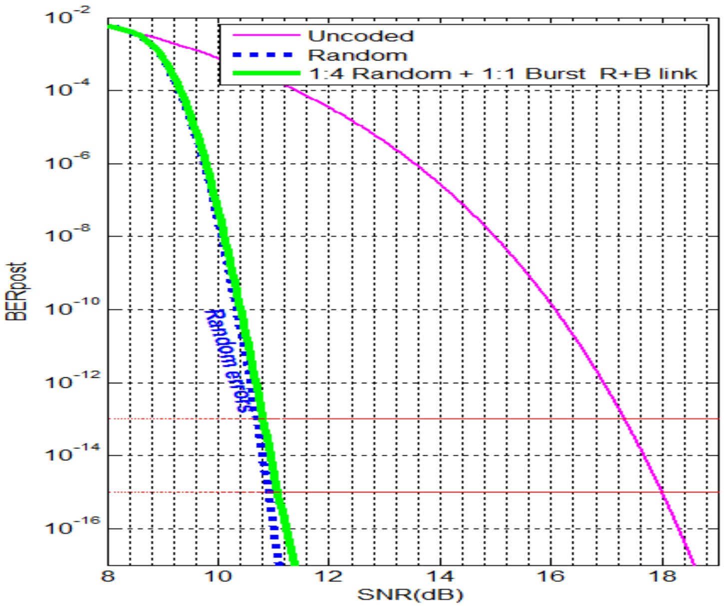


Figure 3: Random on Optical w/ Burst(a=0.5) on Electrical links

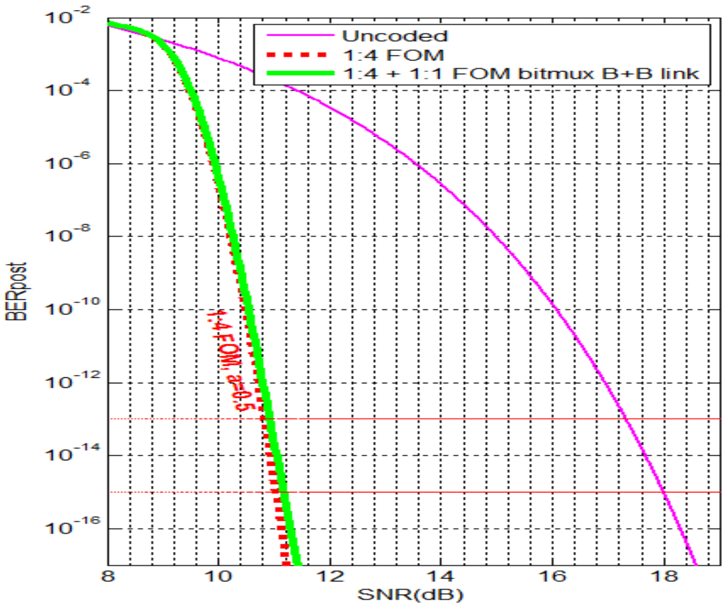


Figure 4: Burst on Optical w/ Burst(a=0.5) on Electrical links

	Error on Electrical	Error on Optical	FLR=6.2e-11	FLR=6.2e-13
BER on electrical link for 0.1 dB penalty on the optical link	Burst(a=0.5)	Random	2.5e-5*	1.6e-5*
	Burst(a=0.5)	Burst(a=0.5)	2.0e-5*	1.3e-5*
	Burst(a=0.5)	Burst(a=0.2)	2.7e-5*	1.9e-5*

- Limiting BER is larger when error propagation parameter (a) is smaller.
- Limiting BER on CDAUI-16 is more strict than on CDAUI-8, as no FOM muxing is used on 25Gbps electrical lanes.

** Note – All these values do not include the additional errors due to the bursts.*

Scenario 3 (xR8 + CDAUI-8)

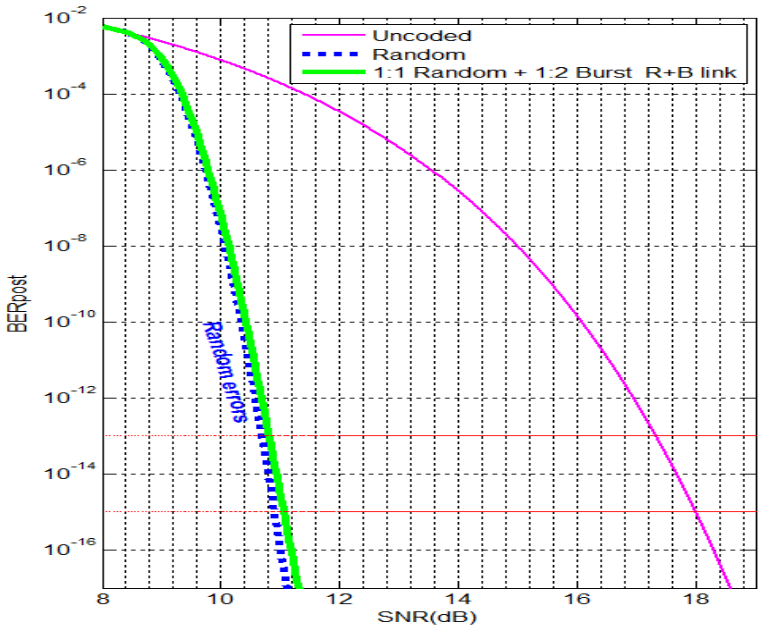


Figure 5: Random on Optical w/ Burst(a=0.5) on Electrical links

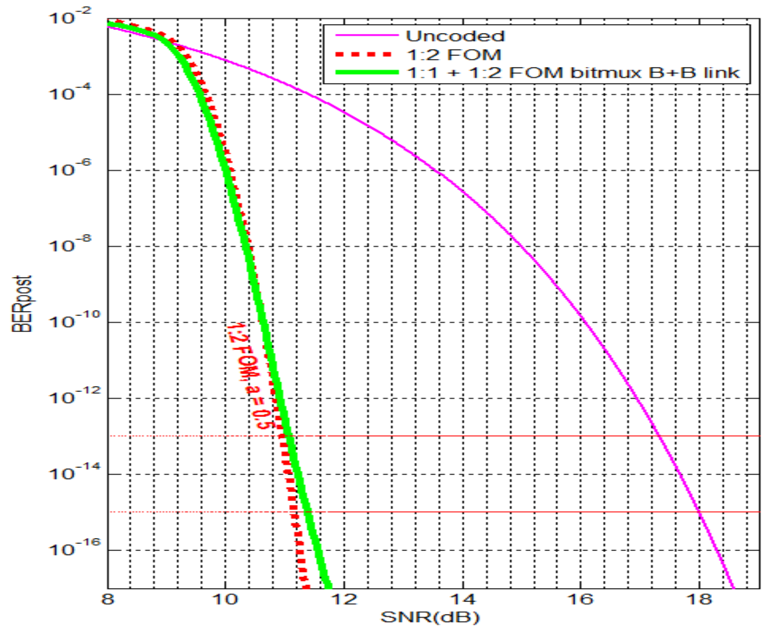


Figure 6: Burst on Optical w/ Burst(a=0.5) on Electrical links

	Error on Electrical	Error on Optical	FLR=6.2e-11	FLR=6.2e-13
BER on electrical link for 0.1 dB penalty on the optical link	Burst(a=0.5)	Random	2.7e-5*	1.9e-5*
	Burst(a=0.5)	Burst(a=0.5)	3.6e-5*	2.1e-5*
	Burst(a=0.5)	Burst(a=0.2)	3.8e-5*	2.4e-5*

- For xR8, The best FEC performance for burst+burst links is 1:2 FOM(a=0.5/0.2) as in Figure 6.

** Note – All these values do not include the additional errors due to the bursts.*

Scenario 4 (xR8 + CDAUI-16)

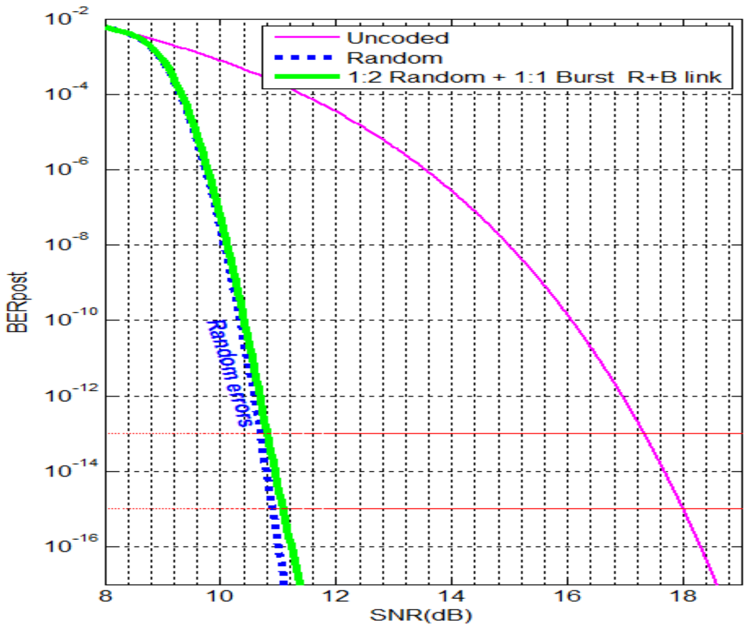


Figure 7: Random on Optical w/ Burst(a=0.5) on Electrical links

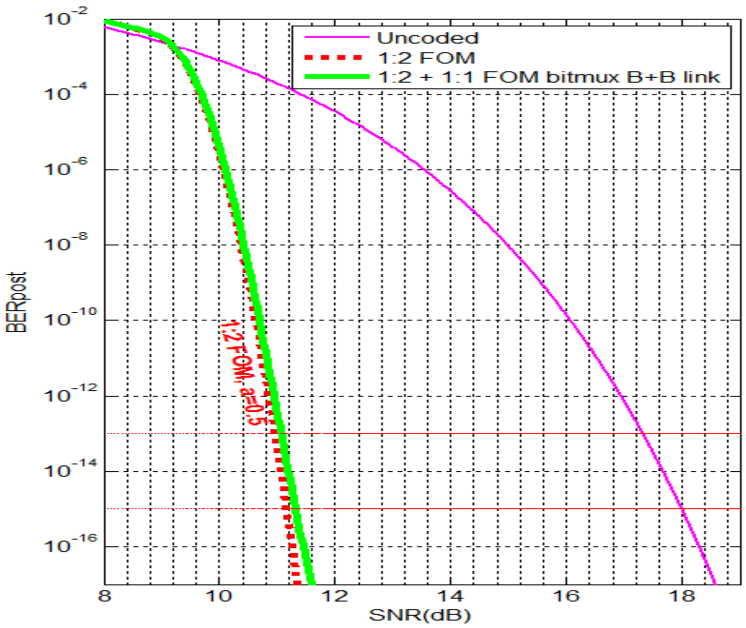


Figure 8: Burst on Optical w/ Burst(a=0.5) on Electrical links

	Error on Electrical	Error on Optical	FLR=6.2e-11	FLR=6.2e-13
BER on electrical link for 0.1 dB penalty on the optical link	Burst(a=0.5)	Random	2.5e-5*	1.6e-5*
	Burst(a=0.5)	Burst(a=0.5)	2.3e-5*	1.3e-5*
	Burst(a=0.5)	Burst(a=0.2)	2.4e-5*	1.4e-5*

- Limiting BER on CDAUI-16 is more strict than on CDAUI-8, as no FOM muxing is used on 25Gbps electrical lanes.

** Note – All these values do not include the additional errors due to the bursts.*

Use Precoding in Bursty Links

- **Precoding Characteristics**
  - Help reduce ISI by coding at source
  - "Pre-coding [17] reduces the effect of DFE error propagation for a 1-tap DFE by breaking up DFE error bursts so that each error burst turns into two single errors after decoding. Pre-coding is less effective in breaking error bursts generated by multi-tap DFEs"*

    -- R. Cideciyan et al. 《Next Generation Backplane and Copper Cable Challenges》, Dec 2013
- **FOM Bitmux**
  - "Divide and conquer" errors
  - No dependence on DFE Tap numbers, comparing to precoding.

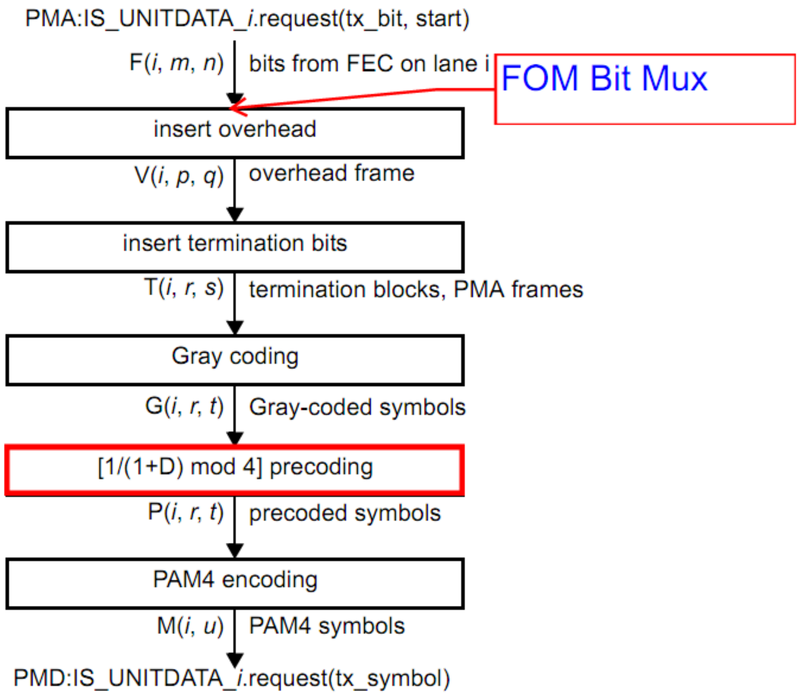


Figure 94–2—Transmit adaptation process diagram

- **Precoding can be enabled with FOM bitmux method to improve FEC performance.**

Summary

- **Based on FOM bitmux method analysis, KP4 FEC performance for possible user cases in near future has been explored.**
- **Limiting BER on Electrical links can be relaxed with smaller probability of burst errors on optical interface.**
- **Limiting BER on CDAUI-16 is more strict than on CDAUI-8, as no FOM muxing is used on 25Gbps electrical lanes.**
- **Precoding can be used with FOM bitmux together to help reducing burst errors.**

Thank you