FEC Options for Extended Reach of 50/200/400GbE

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Background

- At least 2/10km reach SMF PMDs base on 56Gbps PAM4 per lane technology are included in 200/400GbE
- For 50GbE, it is most possible to accept at least 10km reach objective with 56Gbps PAM4 per lane
- This presentation gives some summary for higher coding gain FEC options comparing to RS(544,514) FEC to support extend reach of SMF PMD of 50/200/400GbE

Extend Reach of SMF PMDs in IEEE Ethernet Standard

- For 10GBASE-ER with up to 40km:

Table 52–15—10GBASE-E operating range

PMD Type	Nominal Wavelength (nm)	Minimum Range
10GBASE-E	1550	2 m to 30 km
		2 m to 40 km[a]

[a]Links longer than 30 km for the same link power budget are considered engineered links. Attenuation for such links needs to be less than the minimum specified for B1.1 or B1.3 single-mode fiber.

- For 100GBASE-ER4 with up to 40km:

Table 88–6—100GBASE–LR4 and 100GBASE–ER4 operating ranges

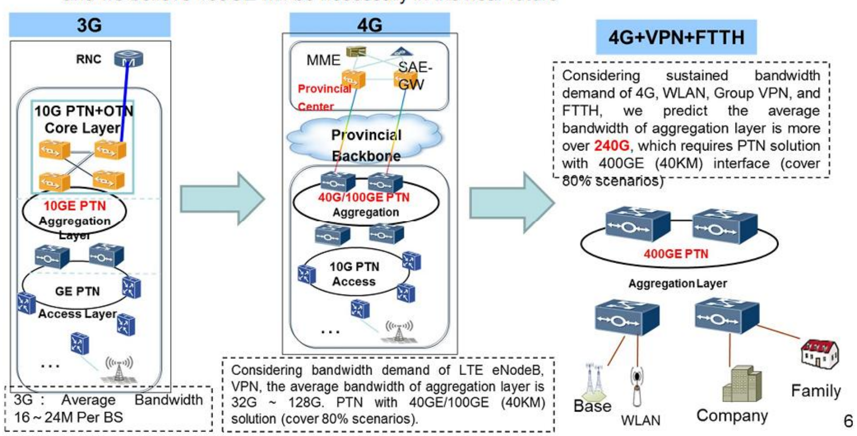
PMD type	Required operating range
100GBASE–LR4	2 m to 10 km
100GBASE–ER4	2 m to 30 km
	2 m to 40 km[a]

[a]Links longer than 30 km for the same link power budget are considered engineered links. Attenuation for such links needs to be less than the worst case specified for B1.1, B1.3, or B6_a single-mode fiber.

Extend Reach PMDs Application in 400GbE

▫ Link Scenario in Backhaul Network

- Based on Ethernet technology, we choose PTN to build the mobile backhaul networks of China Mobile
- Because backhaul network is in metro area, where is usually lack of OTN, most of link between PTN nodes are direct fiber connection
- With the large scale deployment of TD-LTE, PTN is evloving from 10GE to 40GE/100GE, and we believe 400GE will be necessary in the near future



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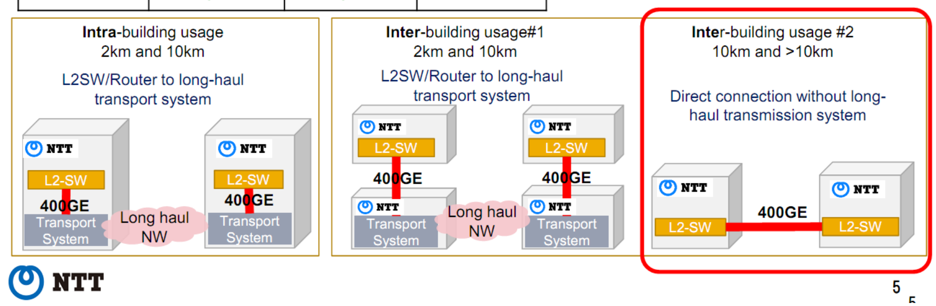
▫ 400GbE extended reach PMD

Extended reach(>10km) interface is essential for inter-building connections without long-haul transmission systems.

Media	Duplex single mode fiber		
Transmission distance	2km	10km	40km
Application	Intra-building; Inter-building usage #1	Intra-building; Inter-building usage #1; Inter-building usage #2	Inter-building usage #2
802.3bs Objectives	✔	✔	-

Route-to-transport application

10km reach:
Covers 50% of inter-building links
40km reach(For example):
Covers almost 100% of inter-building links



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Review of FEC in IEEE Ethernet Standard

- In clause 74, shortened cyclic code (2112, 2080) is defined for 10GBASE-R, 40GBASE-R, and 100GBASE-R and 25GBASE-R
  - Provide 2.0~2.5dB coding gain
  - Encodes 2080 bits of payload (or information symbols) and adds 32 bits of overhead (or parity symbols)
  - Guaranteed to correct an error burst of up to 11 bits per block
- In clause 91, Reed-Solomon Forward Error Correction (RS-FEC) is defined for 100GBASE-R
  - RS(528,514) with ~5.28dB net coding gain is defined for 100GBASE-KR4/SR4 and 25GBASE-R
  - RS(544,514) with ~6.39dB net coding gain is defined for 100GBASE-KP4 and 802.3bs 400GbE

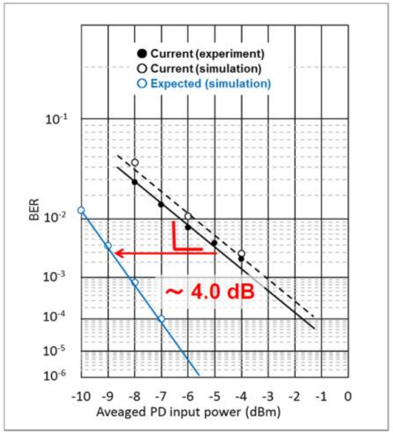
Higher Gain RS FEC Option

- In “wang_x_3bs_01a_0115”, ~7.53dB net coding gain with ~9.09% overhead will be available for RS(864,771,46,10);
- Assuming ~16% overhead, RS(888,744,72,10) will get ~8.1dB net coding gain
- Assuming ~16% overhead, RS(592,496,48,10) will get ~7.9dB net coding gain
- Assuming ~23% overhead, RS(912,720,96,10) will get ~8.2dB net coding gain

RS FEC(n,k,t,m)	CG	NCG*	BERin	Overhead	SerDes Rate	Block Time	Latency**	Area Ratio
Group 1 : Similar RS FEC as KR4 FEC								
RS(528,514,7,10)	5.39	5.28	3.92E-05	0%	25.78125	51.2ns	~87ns	1X
RS(544,514,15,10)	6.64	6.39	3.09E-04	3.03%	26.5625	51.2ns	~112ns	2.9X
RS(560,514,23,10)	7.3	6.93	7.60E-04	6.06%	27.34375	51.2ns	~208ns	14.5X
RS(576,514,31,10)	7.76	7.26	1.30E-03	9.09%	28.125	51.2ns	~258ns	33.4X
Group 2 : Large Block RS FEC								
RS(1056,1028,14,11)	6.07	5.95	1.29E-04	0%	25.78125	102.4ns	~172ns	2.6X
RS(1088,1028,30,11)	7.12	6.88	6.06E-04	3.03%	26.5625	102.4ns	~315ns	16.7X
RS(1120,1028,46,11)	7.7	7.33	1.20E-03	6.06%	27.34375	102.4ns	~414ns	54.8X
RS(1152,1028,62,11)	8.11	7.61	1.90E-03	9.09%	28.125	102.4ns	~514ns	129.5X
Group 3 : RS(255,239) Like RS FEC								
RS(255,239,8,8)	6.12	5.83	1.39E-04	6.7%	27.5	18.9ns	~49ns	1.1X
RS(510,478,16,9)	6.85	6.57	4.21E-04	6.7%	27.5	42.5ns	~162ns	5.3X
RS(1020,956,32,10)	7.34	7.06	7.95E-04	6.7%	27.5	93.1ns	~304ns	27.2X
Group 4 : 256/257b coding friendly RS FEC***								
RS(800,771,14,10)	6.29	6.13	1.83E-04	1.01%	26.04	76.8ns	~140ns	2.6X
RS(816,771,22,10)	6.95	6.71	4.84E-04	3.03%	26.5625	76.8ns	~232ns	9.4X
RS(840,771,34,10)	7.58	7.22	1.10E-03	6.06%	27.34375	76.8ns	~306ns	30.6X
RS(864,771,46,10)	8.02	7.53	1.80E-03	9.09%	28.125	76.8ns	~379ns	72.1X

BCH FEC Proposal in 802.3bs

- In "cole_3bs_02b_0914", BCH (2858, 2570, t=24) with 7.6dB net coding gain is presented for post BER at 1E-12
- In "takahara_3bs_01a_0914", BCH (9193, 8192) with 12.5% overhead can provide ~8.1dB net coding gain



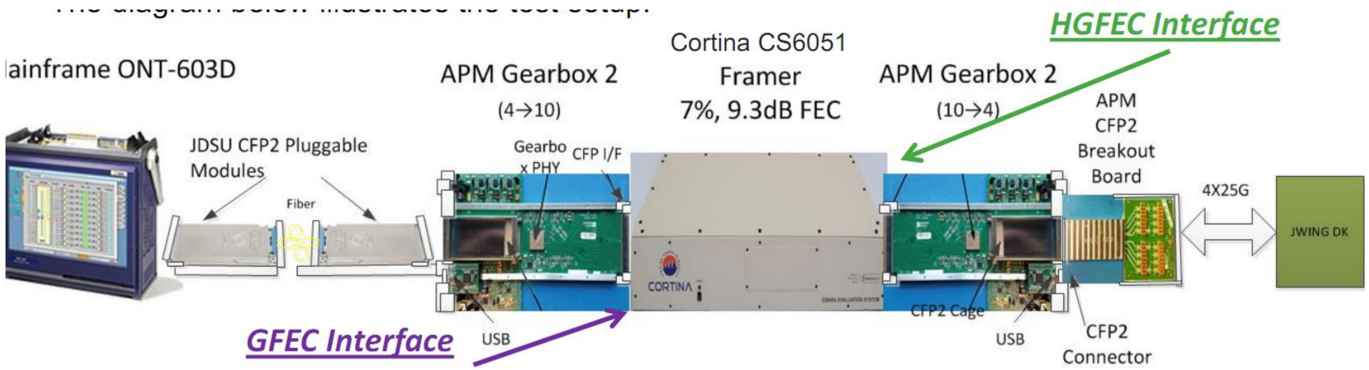
116 Gbps
SC: 256
Target BER 3.3E-3
BCH(9193,8192)

- For >10km extended reach SMF PMDs, it is most possible to use advanced receiver equalization technology, for example DFE or MLSE, and lead burst error
- BCH FEC capability will degrade for facing burst error and require to compensate with cost of large latency and logic resource

High Gain FEC Proposal in 802.3bs

- In "corbeil_01_1114_smf", staircase FEC is tested with DMT modulation SMF link

The framer used was a Cortina CS6051 which has a (9.39dB NCG) staircase FEC with ITU-G.975.1 compatible, 7% overhead a latency of <20us and a 1E-15 FEC threshold of 4.62E-3



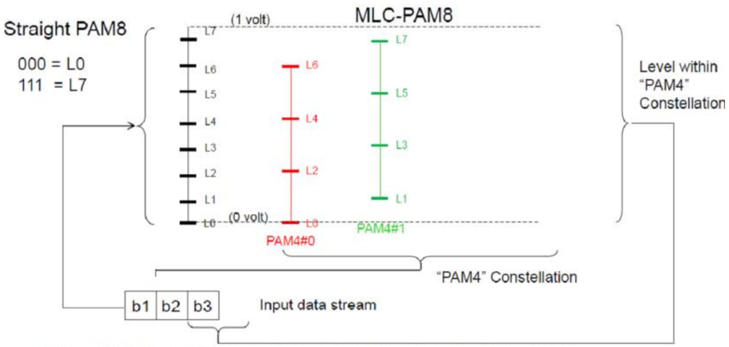
- For ~7% over head, NCG=~8.37dB with Pre-BER=~4.7E-3 and Post-BER=1E-12

Latency	BERi for BERo=1E-12	Net Coding Gain @1E-12	BERi for BERo=1E-15	Net Coding Gain @1E-15
2.25Mb	4.70e-3	8.37dB	4.62e-3	9.41dB
2Mb	4.66e-3	8.36dB	4.55e-3	9.39dB
1.75Mb	4.62e-3	8.35dB	4.50e-3	9.38dB
1.5Mb	4.20e-3	8.25dB	3.80e-3	9.19dB

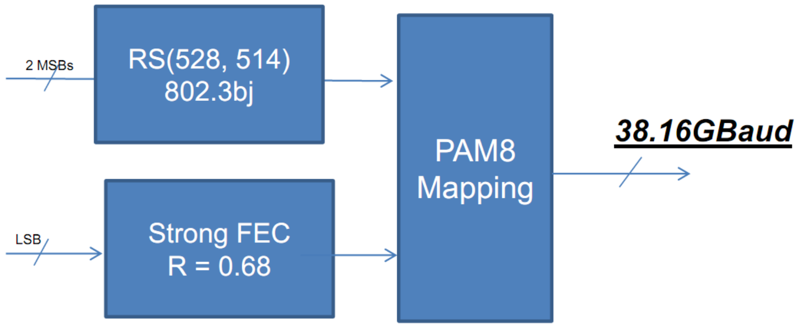
Refer to : http://www.stupi.se/Standards/100G-long-haul4.pdf

Multi Level Coding FEC in 802.3

- In “farhood_01_0713_optx” and “bhoja_01a_1112_optx”, MLC FEC is proposed in PAM8 solution

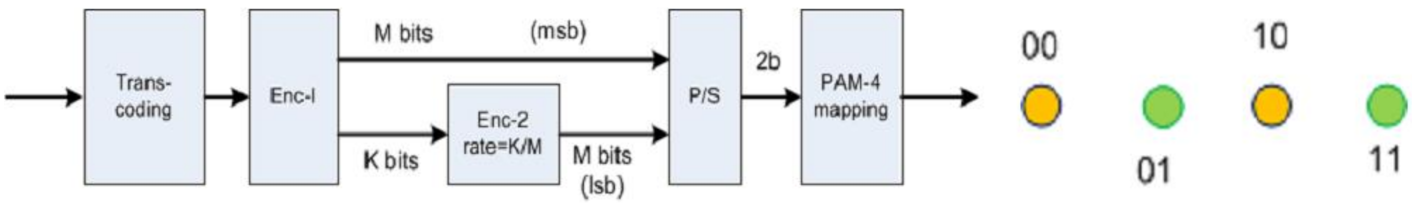


- MLC – Not all bits are equal. Focus FEC overhead/gain where it adds most value
- Treat one bit b1 as "PAM8". Treat lower two bits (b2,b3) as "PAM4"
- Target all FEC overhead/gain to protecting the upper bit, and no FEC to lower two bits
- Enables higher FEC coding gain without bumping up the symbol (data) rate
- A 10% overhead FEC (on aggregate) results in 30% overhead FEC on upper bit



- Combined rate: (2 * 514/528 + 0.6836) / 3 = 0.8769
- Ethernet Rate = 100/3 * 257/256 * 1/0.8769 = 38.16 GBaud

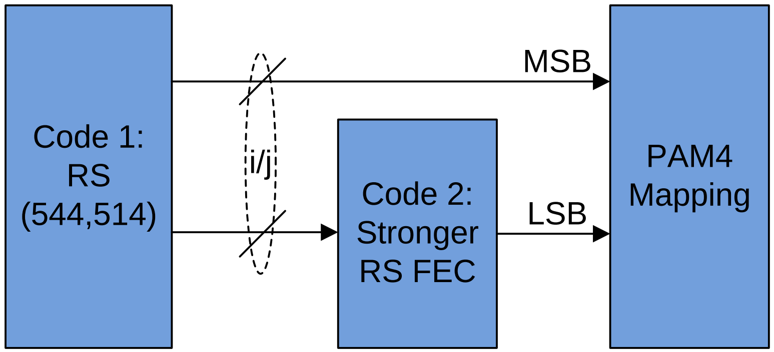
- In “parthasarathy_3bs_01a_1114”, MLC FEC proposal is also presented based on RS(528,514) for PAM4 solution



HUAWEI

MLC FEC with RS FEC

- Assuming RS(544,514) as a baseline for 50/200GbE to cover 2/10km SMF reach, same as code 1 in MLC FEC, cascade another stronger RS(n,k,t) FEC as code 2 to get higher coding gain

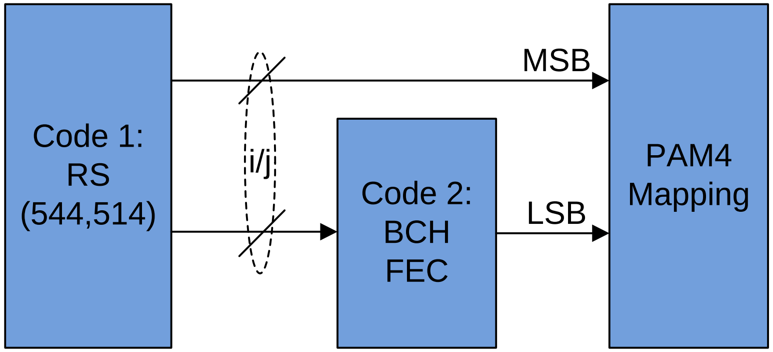


Ratio on Code 1:2	Code2(n,k,t) m=10	Code2 CG	Code2 OH	Code2 Delay	MLC CG	MLC NCG	MLC OH	MLC BERin
i/j=78/58	(624,464,80)	9.3db	34%	318ns	8.6db	7.9db	18%	3.10E-03
	(936,696,120)	9.5db	34%	477ns	8.7db	8.0db	18%	3.60E-03
i/j=76/60	(304,240,32)	8.4db	26%	134ns	7.9db	7.3db	15%	1.50E-03
	(608,480,64)	8.9db	26%	266ns	8.3db	7.7db	15%	2.30E-03
i/j=74/62	(296,248,24)	7.9db	19%	107ns	7.5db	7.0db	12%	9.00E-04
	(592,496,48)	8.5db	19%	213ns	7.9db	7.4db	12%	1.50E-03
i/j=72/64	(576,512,32)	7.8db	12%	160ns	7.4db	7.0db	9%	8.50E-04
i/j=70/66	(560,528,16)	6.7db	6%	107ns	6.7db	6.5db	6%	3.00E-04

*:latency of code2 based on ~200Gbps data path

MLC FEC with BCH FEC

- Change Code 2 to BCH(n,k,t) FEC to get higher coding gain



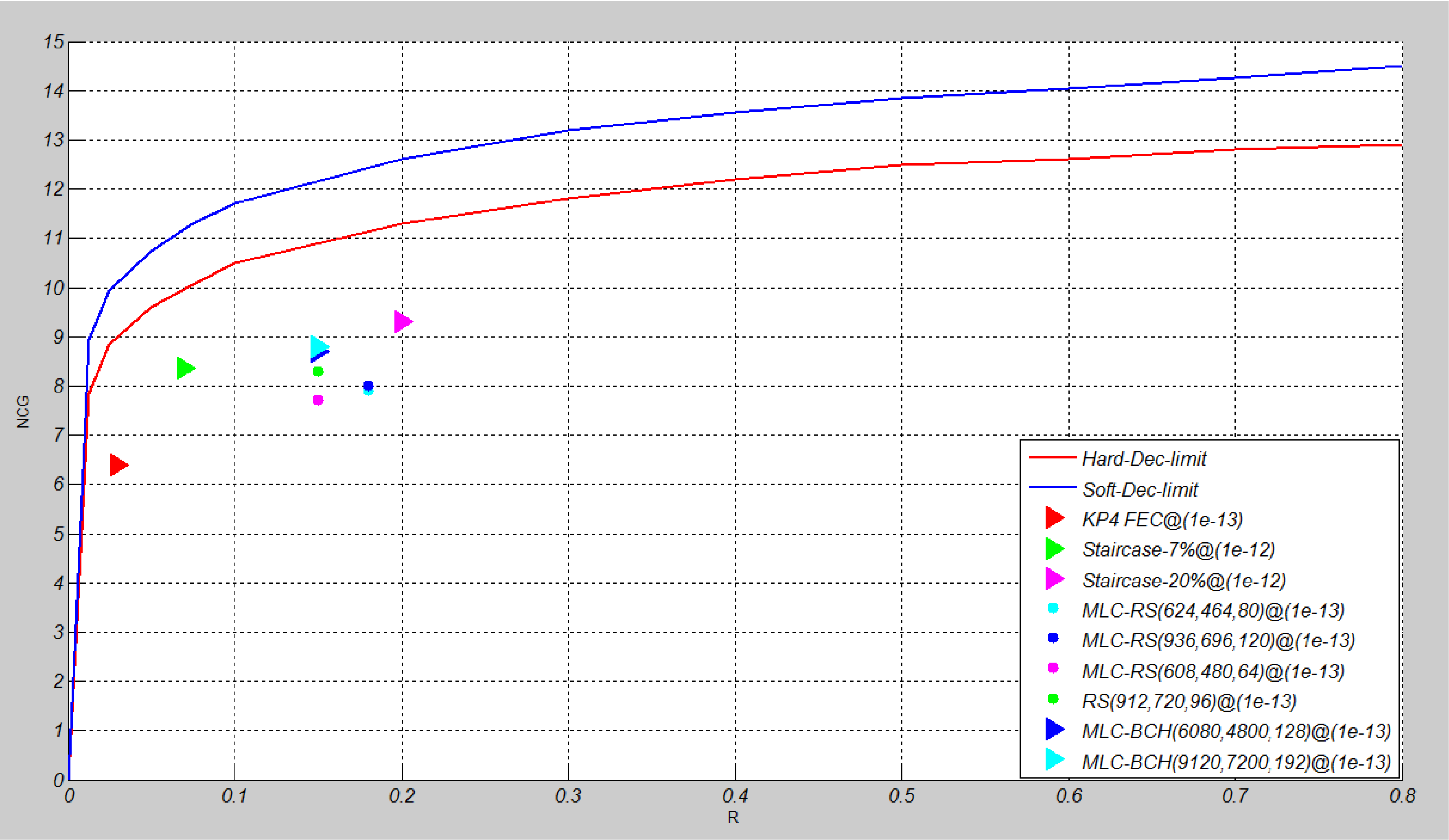
Ratio on Code 1:2	Code2(n,k,t) BCH-FEC	Code2 CG	Code2 OH	MLC CG	MLC NCG	MLC OH	MLC BERin
i/j=(76:60)	(3040,2400,64)	9.7db	26%	8.9db	8.3db	15%	4.2E-3
	(6080,4800,128)	10.1db	26%	9.3db	8.7db	15%	5.7E-3
	(9120,7200,192)	10.3db	26%	9.4db	8.8db	15%	6.4E-3
i/j=(74:62)	(2960,2480,48)	9.2db	19%	8.5db	8.0db	12%	2.75E-3
	(5920,4960,96)	9.6db	19%	8.8db	8.3db	12%	3.9E-3
i/j=(72:64)	(2880,2560,32)	8.4db	12%	7.9db	7.5db	9%	1.5E-3
	(5760,5120,64)	8.9db	12%	8.3db	7.9db	9%	2.3E-3

*:latency of code2 based on ~200Gbps data path

Further Analysis on MLC FEC

- MLC FEC is convenient with PAMn solution, in which data bits are parted corresponding to different PAMn levels
- Based on RS(544,514) FEC in 2/10km reach SMF PMDs, MLC FEC architecture with partial cascading strong FEC can further improve net coding gain to 8.0~9.5dB, at the expense of large overhead up to 20% and more logic resource
- However, coding gain of MLC FEC is still limited by theoretical threshold of hard-decision FEC
- Code 2 in MLC can be either RS FEC or BCH and thus be influenced by burst error in different degree.
- For MLC FEC, code 2 candidates are:
  - RS (624,464,80) and RS (936,696,120) are preferred, if burst error exists.
  - BCH(6080,4800,128) and BCH (9120,7200,192) are preferred, if burst error on optical links are less

Summary of High Gain FEC Options



NCG for HG FEC options, Assuming post BER@1E-13 objective.

Summary

- For further higher gain FEC required from extended reach, several candidate MLC-FEC are investigated from coding gain, overhead and technical feasibility perspective
- To enable extend reach 50/200/400GbE standard, more comprehensive work is needed to lower optical loss to cooperate with FEC in this presentation or with other potential solutions

Thank You