End-to-end FEC for 200G per lane based 200GbE, 400GbE, 800GbE and 1.6TbE

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IEEE P802.3df 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force.

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Adopted physical layer objectives

All for Data Center Network (DCN) applications, latency and power consumption are critical.

Ethernet Rate	Signaling Rate	Electrical			Optical					
		AUI	Backplane TBD **	**Copper Cable**	**MMF 50m**	**MMF 100m**	**SMF 500m**	**SMF 2km**	SMF 10km	SMF 40km
200Gbps	**200Gbps**	Over 1 lane 200GAUI-1	Over 1 lane 200GBASE-KR1	Over 1 pair 200GBASE-CR1			Over 1 pair 200GBASE-DR1	Over 1 pair 200GBASE-FR1	TBD * 200GBASE-LR1	
400Gbps	100Gbps							Over 4 pairs 400GBASE-DR4-2		
	200Gbps	Over 2 lanes 400GAUI-2	Over 2 lanes 400GBASE-KR2	Over 2 pairs 400GBASE-CR2			Over 2 pairs 400GBASE-DR2		TBD * 400GBASE-LR2	
800Gbps	100Gbps	Over 8 lanes 800GAUI-8	Over 8 lanes 800GBASE-KR8	Over 8 pairs 800GBASE-CR8	Over 8 pairs 800GBASE-VR8	Over 8 pairs 800GBASE-SR8	Over 8 pairs 800GBASE-DR8	Over 8 pairs 800GBASE-DR8-2		
	200Gbps	Over 4 lanes 800GAUI-4	Over 4 lanes 800GBASE-KR4	Over 4 pairs 800GBASE-CR4			Over 4 pairs 800GBASE-DR4	Over 4 pairs 800GBASE-DR4-2 Over 4 lambdas 800GBASE-FR4	TBD * 800GBASE-LR4	
	TBD *								Over single SMF in each direction ?	Over single SMF in each direction ?
1.6Tbps	100Gbps	Over 16 lanes 1.6TAUI-16								
	200Gbps	Over 8 lanes 1.6TAUI-8		Over 8 pairs 1.6TGBASE-CR8			Over 8 pairs 1.6TBASE-DR8	Over 8 pairs 1.6TBASE-DR8-2		

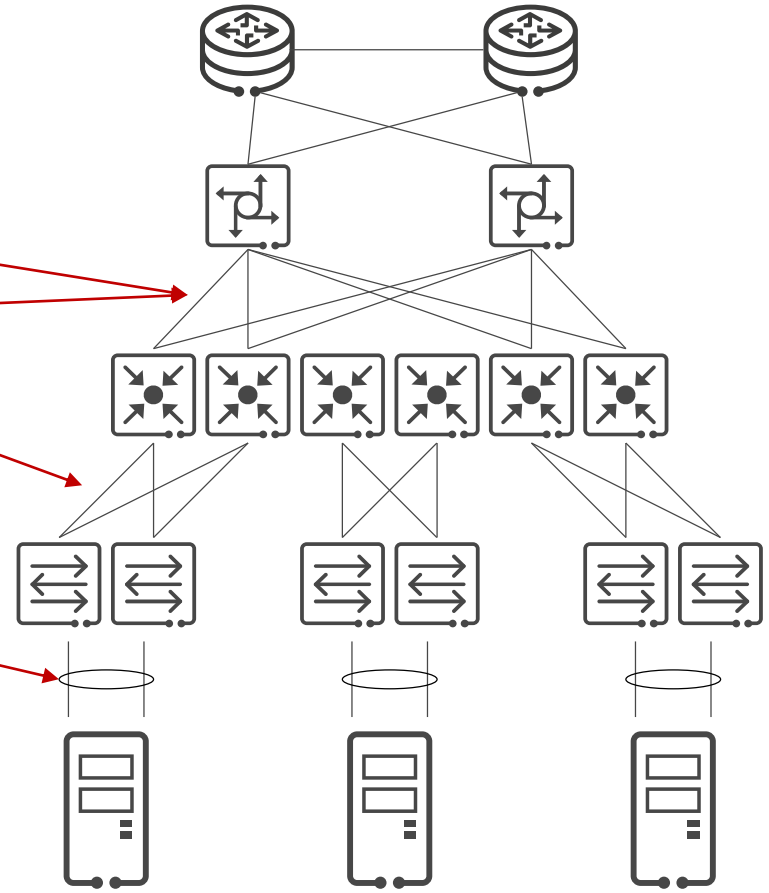
https://www.ieee802.org/3/df/proj_doc/objectives_P802d3df_220317.pdf

* If 4*200G 10km is adopted, 2*200G and 1*200G 10km may also be considered for 400GE and 200GE, respectively.

** Should be adopted as long as the signaling & modulation & insertion loss objectives for CR/KR channels are determined.

Application scenarios for 200G/lane Ethernet

Ethernet Rate	Electrical		Optical		
	AUI	Copper Cable	SMF 500m	SMF 2km	SMF 10km
1.6Tbps	Over 8 lanes 1.6TAUI-8	Over 8 pairs 1.6TGBASE-CR8	Over 8 pairs 1.6TBASE-DR8	Over 8 pairs 1.6TBASE-DR8-2	
800Gbps	Over 4 lanes 800GAUI-4	Over 4 pairs 800GBASE-CR4	Over 4 pairs 800GBASE-DR4	Over 4 pairs 800GBASE-DR4-2 Over 4 lambdas 800GBASE-FR4	800GBASE-LR4
400Gbps	Over 2 lanes 400GAUI-2	Over 2 pairs 400GBASE-CR2	Over 2 pairs 400GBASE-DR2		400GBASE-LR2
200Gbps	Over 1 lane 200GAUI-1	Over 1 pair 200GBASE-CR1	Over 1 pair 200GBASE-DR1	Over 1 pair 200GBASE-FR1	200GBASE-LR1

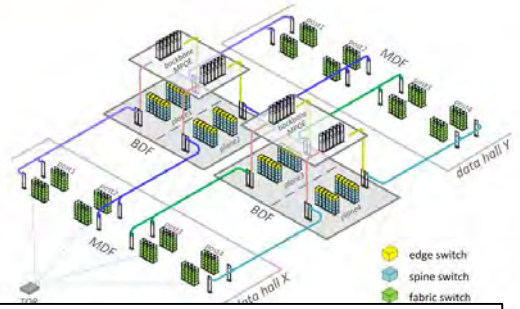


- Latency, power consumption, and cost are critical for CRx and DRx links, they make up the majority of all data center network links.
- End-to-end RS(544, 514) FEC should be sufficient for C2C and DRx links, because they are relatively “easier” than FR (3dB+ loss) and LR (6.6dB+ loss) links. If not, FR and LR links might become infeasible, since stronger FEC provides less than 3dB net coding gain (NCG) over RS(544, 514).
- End-to-end FEC can be used for C2C, Near-Package-Optics (NPO) and Co-Package Optics (CPO) and the linear drive pluggable optics applications, and is highly recommended for DRx applications to save latency, power and cost.

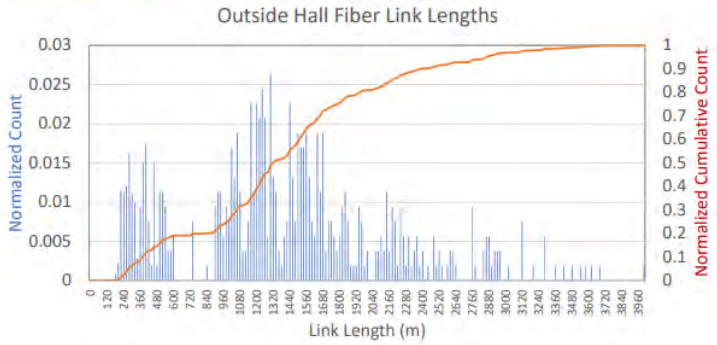
“Short” links take over 79% percentage interconnects in a datacenter

Facebook Data Center Properties

Physical Site Layout



SMF Interconnect Link Lengths

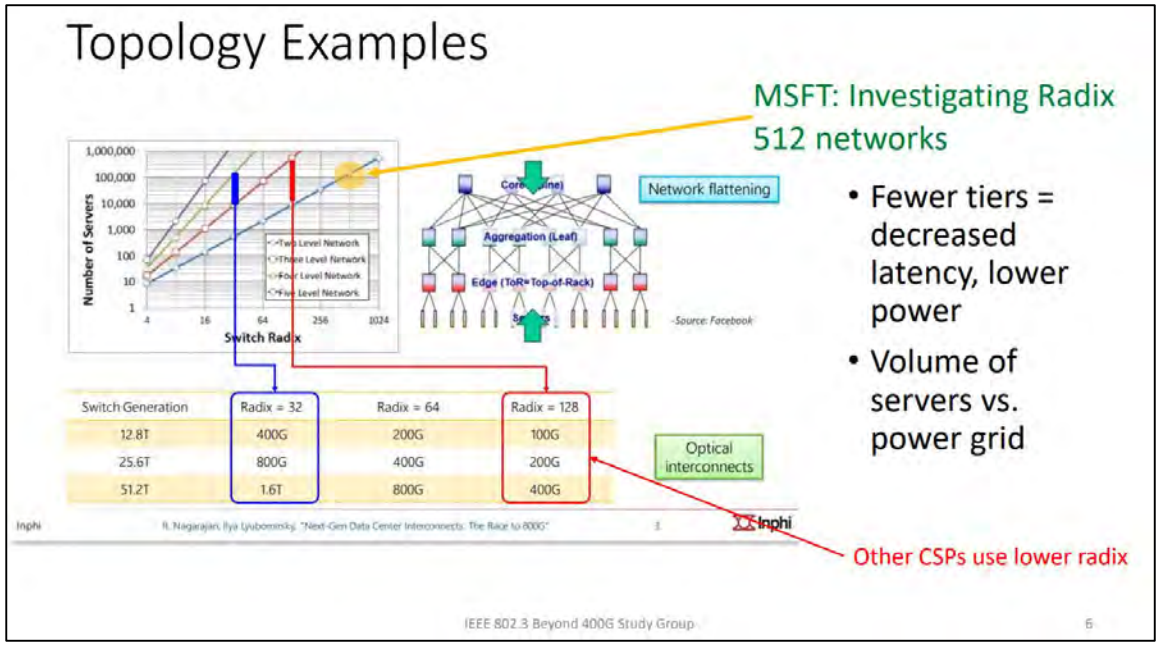


Summary: Inside + Outside Data Hall Links:

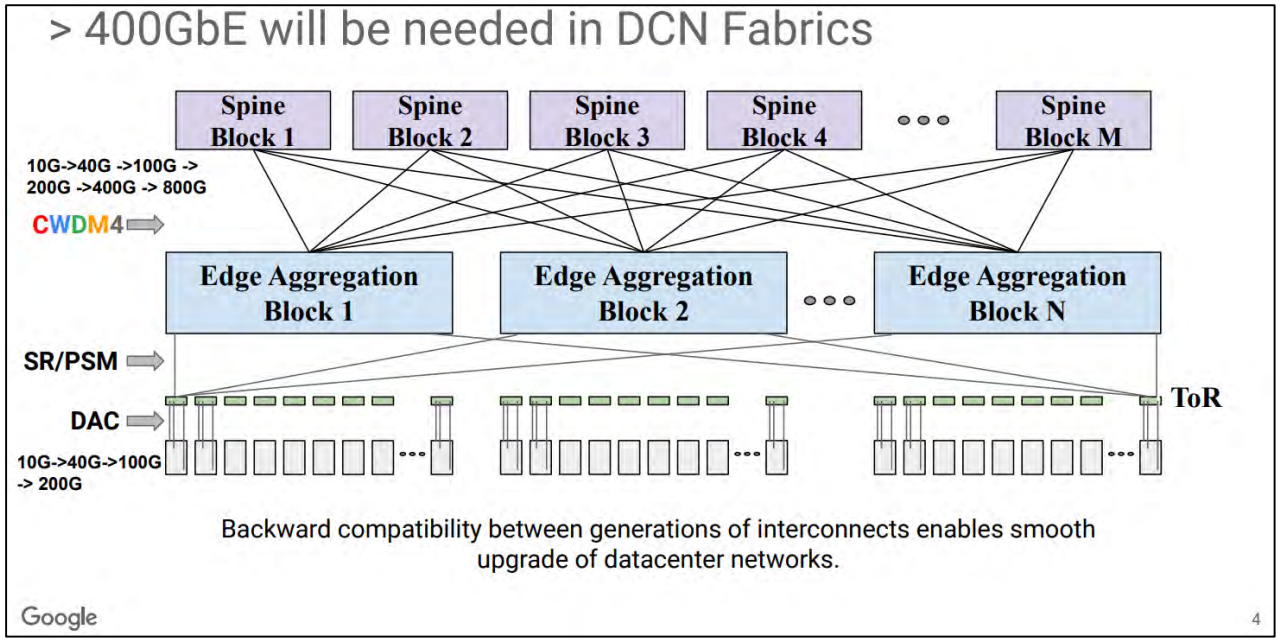
Length	Total Number of Links
Up to 500m	79%
Up to 1000m	81%
Up to 2000m	95%
Up to 3000m	99%

https://www.ieee802.org/3/B400G/public/21_05/stone_b400g_01_210503.pdf

“Short” links take a large portion in data center networks

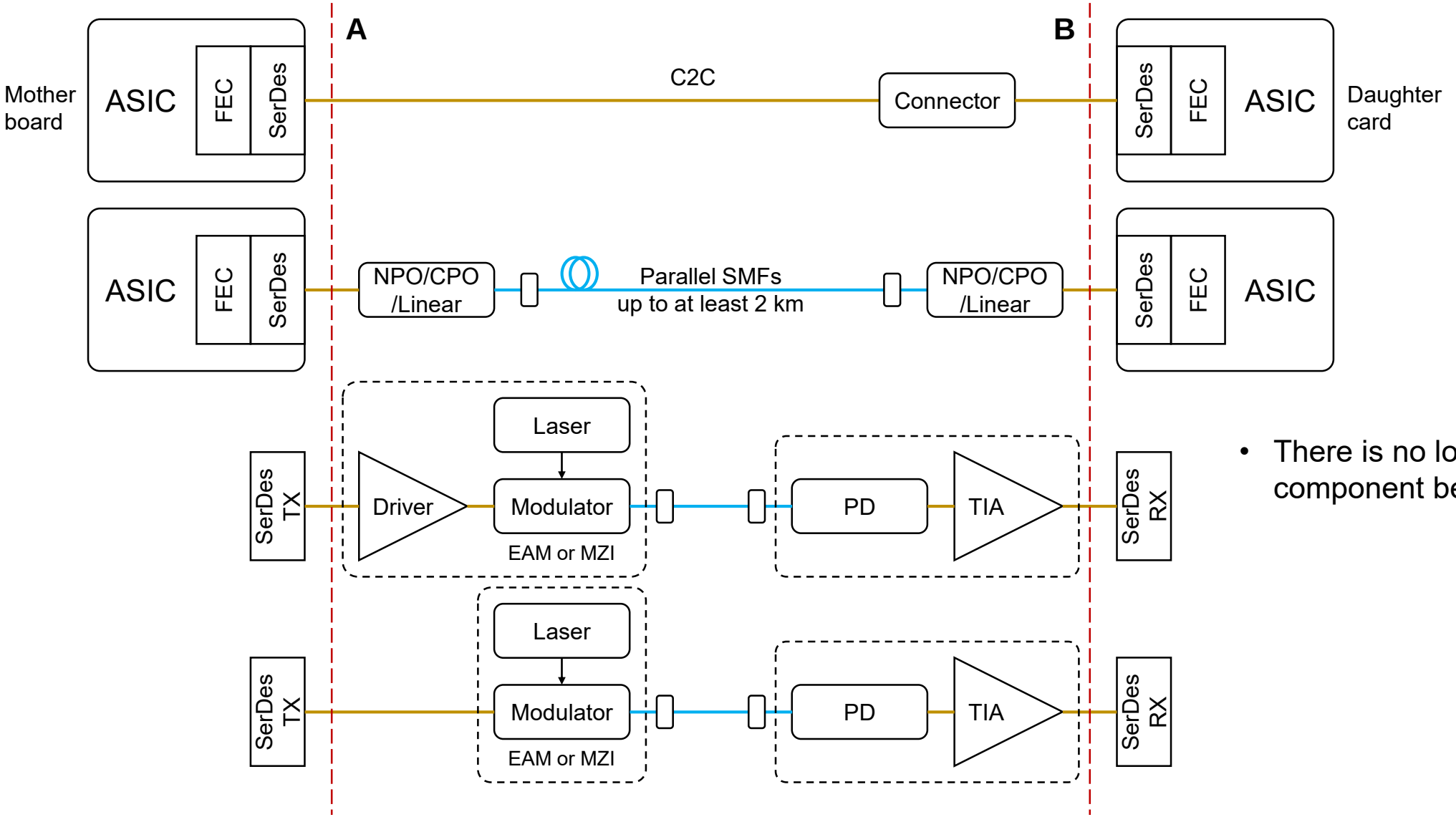


https://www.ieee802.org/3/B400G/public/21_05/booth_b400g_01b_210524.pdf



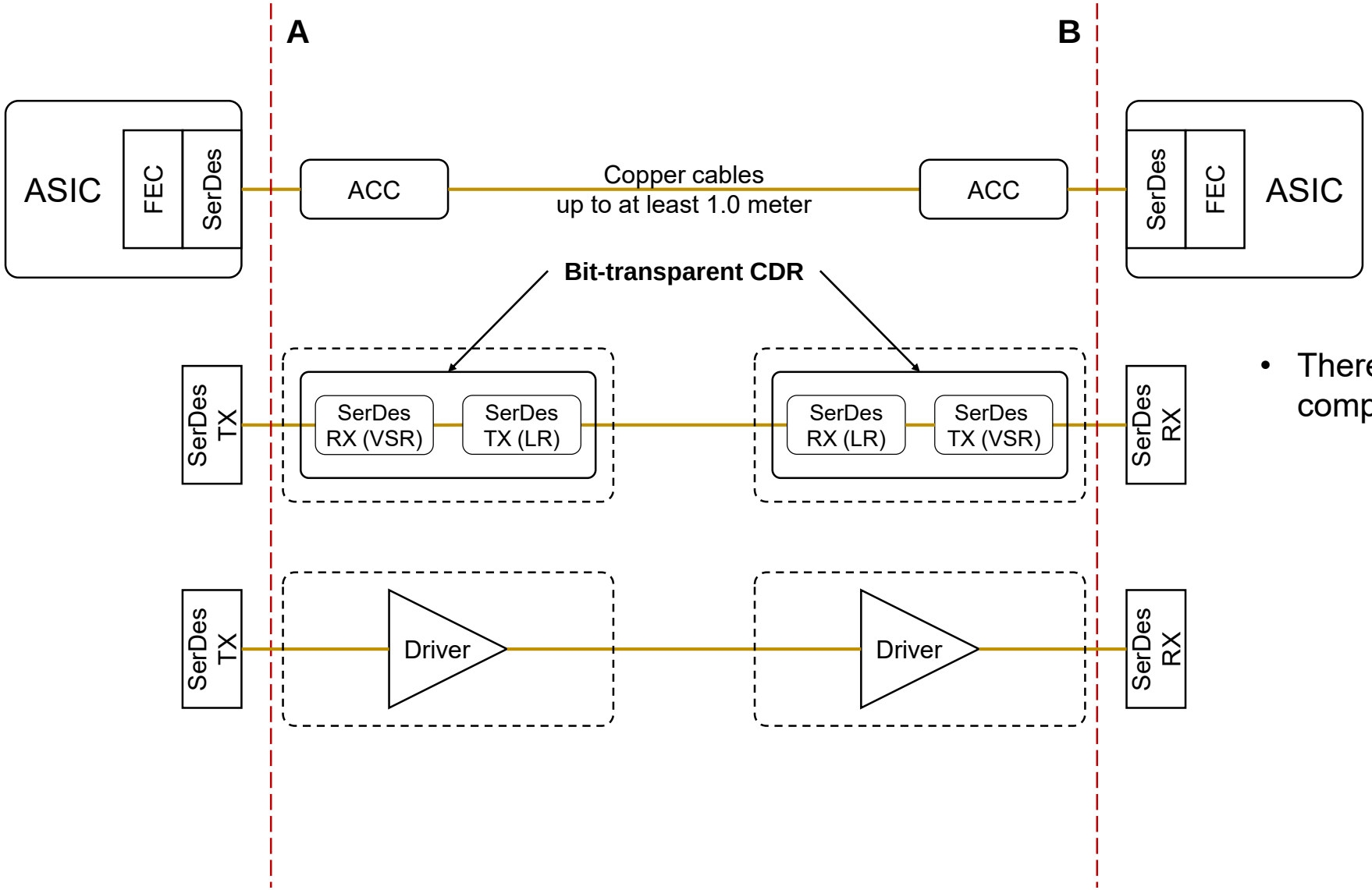
https://www.ieee802.org/3/B400G/public/21_03/lam_b400g_01a_210329.pdf

End-to-end FEC can be used for C2C, NPO/CPO, Linear



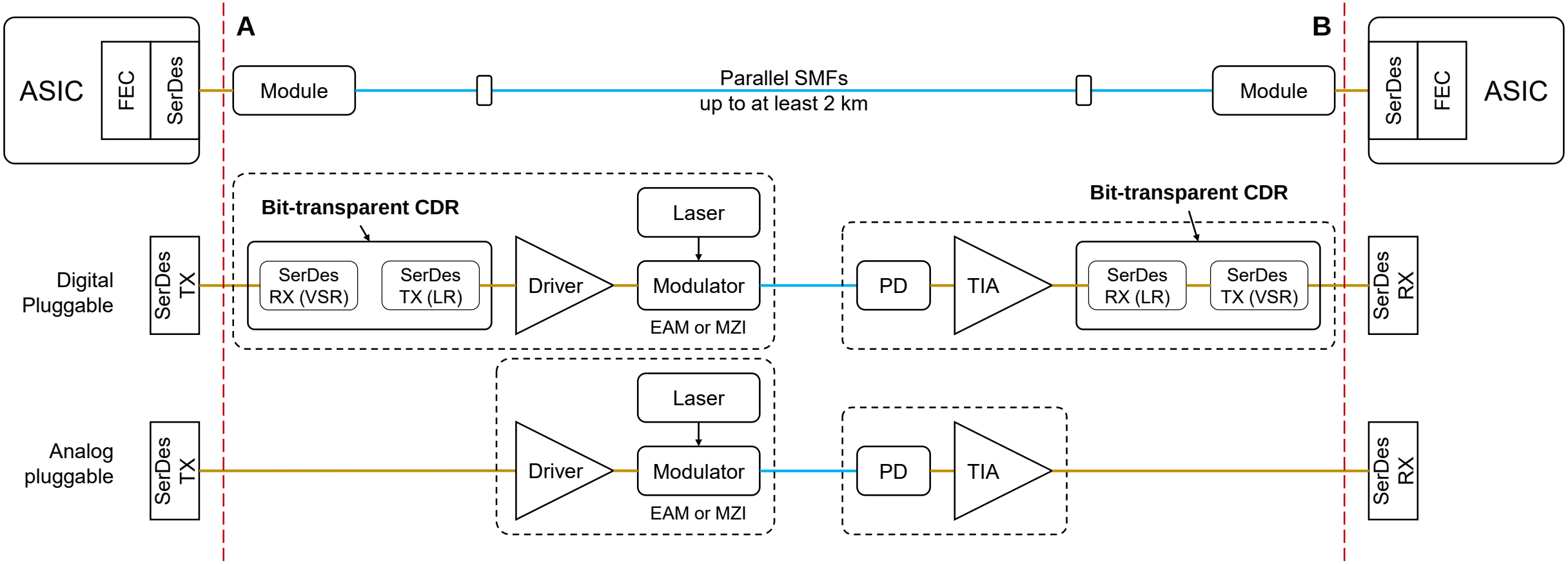
- There is no logical processing component between point A and B.

End-to-end FEC can be used for active copper cable (ACC)



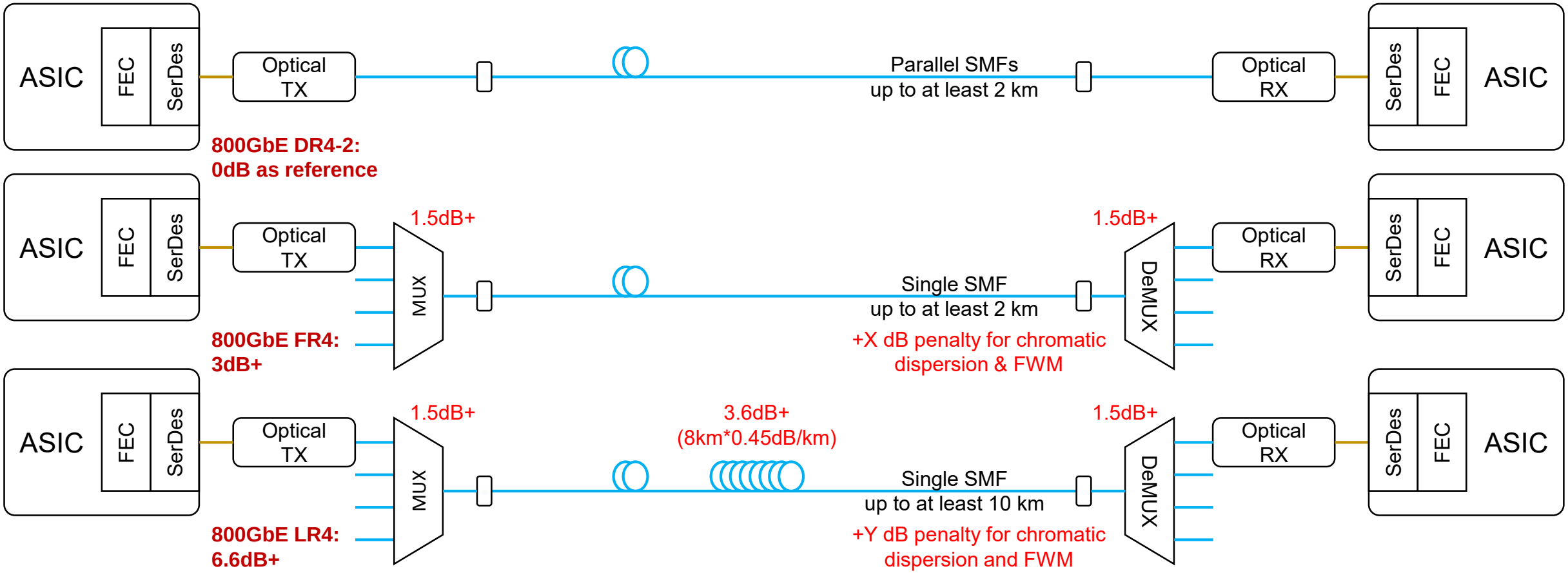
- There is no logical processing component between point A and B.

End-to-end FEC is optimal for DR pluggable module



- There is no logical processing component between point A and B. End-to-end FEC is used (bit-transparent CDR).
- FEC processing inside the CDR might not be acceptable for applications, because the constrains of latency, power consumption, and cost cannot be satisfied.

Link budget differences for DR, FR and LR applications



- The link budget difference between DR links and FR links is at least **3dB** (MUX & DeMUX).
- The link budget difference between DR links and LR links is at least **6.6dB** (MUX & DeMUX + 8km SMF fiber).
- For DR links end-to-end FEC should be sufficient compared with the FR and LR links.

Discussion about end-to-end FEC for DR applications

- The contributions about using end-to-end RS(544, 514) FEC for DR applications. simms_3df_01_221005 , welch_3df_01a_221011 , ingham_3df_01_221011.

- The contributions of FR4/LR4 kuschnerov_3df_02a_221012, liu_3df_01a_221012 indicate that if 4.5e-3 is used as reference BER for LR4 with link budget difference considered, the reference BER for DR links can be much smaller than 1e-5.

- lu_3df_01b_220215, lu_3df_logic_220425 illustrates why end-to-end FEC architecture is always the best choice that we should pursue.

Summary

- End-to-end FEC is sufficient and preferred for 200G per lane DR links (<=2km).
  - DR links have 3dB+ and 6.6dB+ more optical power margin compared with FR and LR links, respectively. They are far beyond the margin that stronger FEC can provide (margin difference between 1e-5 @ 106.25GBd to 4.5e-3 @ 112.5GBd).
  - If DR links need stronger FEC, it means FR and LR links are not feasible with FEC options under discussion (probably beyond the capability of FEC).
  - If FR and LR links are feasible, it means the end-to-end FEC is sufficient for DR links.
- End-to-end FEC is recommended for 200G per lane DR links. Including:
  - 200GBASE-DR1, 200GBASE-FR1,
  - 400GBASE-DR2,
  - 800GBASE-DR4, 800GBASE-DR4-2,
  - 1.6TBASE-DR8, 1.6TBASE-DR8-2.
- The end-to-end FEC can be regenerated inside the module to support “segmented FEC” architecture.

Q & A