The increasing implementation cost due to chromatic dispersion in duplex optical PHYs

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Motivation

- With each Ethernet speed generation, CD penalty is becoming a more significant part of the power budget at ever shorter reaches.
- Through the 100G/L generation, more costly mitigation strategies were only needed for low volume long reach duplex PHYs, but at 200G/L, additional mitigation is needed for high volume 2km FR4.
- The use of overly conservative worst-case fiber specs in Ethernet channel models burdens the industry with the cost of unnecessarily complex, costly and power-hungry modules: cole_3df_01_2211
- The development of new channel models utilizing statistical techniques can reduce the growing impact of CD at higher rates

Mitigation strategies for CD penalty

- Adaptive launch power: OMA – TDECQ introduced in 50GbE generation
  - Higher launch OMA requires higher laser power consumption
- Modulation format: IM-DD → Coherent
  - Coherent is more costly and higher power consumption than IM-DD
- Wavelength plan: Uncooled CWDM → Cooled LAN-WDM
  - Uncooled CWDM has been the low-cost workhorse for duplex PHYs
  - Cooled lasers on tighter spacing increase cost and power consumption
- Inner FEC: Host end-to-end RS FEC → RS + Inner FEC in module
  - Inner FEC increases baud rate and adds DSP cost, power consumption and latency
- Updated channel models: Reduced CD requirements
  - Worst case fiber specs → Specs based on statistical distributions of deployed or recently manufactured fibers
    - cole_3dj_optx_01_230427, rodes_3dj_01a_2401, johnson_3dj_01a_2307
  - Uniform fiber → Statistical averaging over multi-segment links (“CDq”)
    - SG15-LS86_Redacted.pdf, Liu_3dj_01_2401, ferretti_3dj_optx_01b_230615, stassar_3df_01_2401

Evolution of modulation format

Rate	500 m	2 km	6-10 km	30-40 km
4x25G				
4x50G				
4x100G				
4x200G				
4x400G*				

* This is one illustrative scenario of 4x400G. The actual implementation is TBD based on consideration of multiple technology choices.

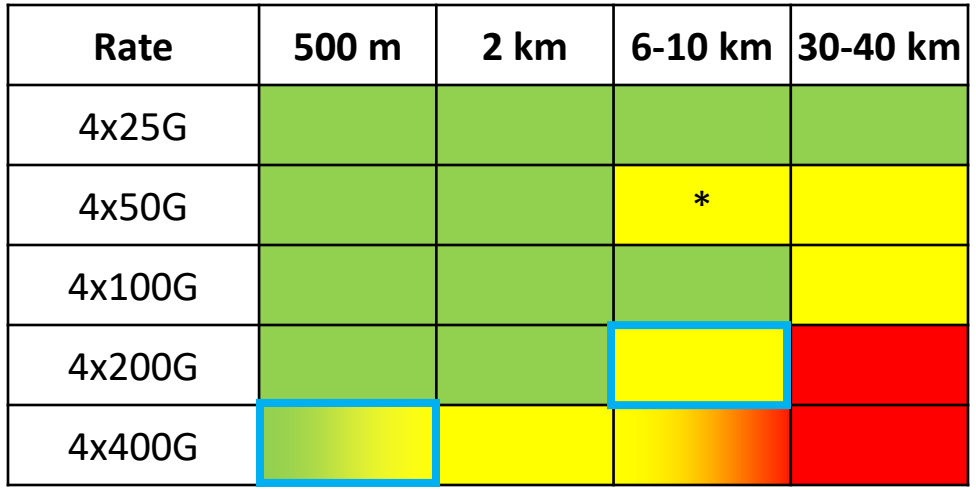
	NRZ	lowest RX sensitivity, higher BW/baud components
	PAM	higher RX sensitivity, DSP-enabled
	Coherent	higher cost optics, high sample rate DSP, higher Pdis

Statistical averaging over multiple cable segments enables 800GBASE-LR4 to serve datacenter applications up to 10km

- IM-DD has been used for all Ethernet generations through 100G/L
- Starting with 200G/L, coherent objectives have been adopted down to 10km
- Coherent is likely to be required for > 2km at 4x400G, depending on implementation choices

Evolution of wavelength plan

Rate	500 m	2 km	6-10 km	30-40 km
4x25G				
4x50G			*	
4x100G				
4x200G				
4x400G				



* 802.3cn chose LAN-WDM, but CWDM is possible

	Uncooled CWDM	lower cost lasers, no TEC, lowest Pdis
	Cooled LAN-WDM	higher laser and TEC cost, Pdis ~ +1W for 4 channels
	Coherent Single WL	highest per-laser cost (± 10GHz), TEC cost and Pdis

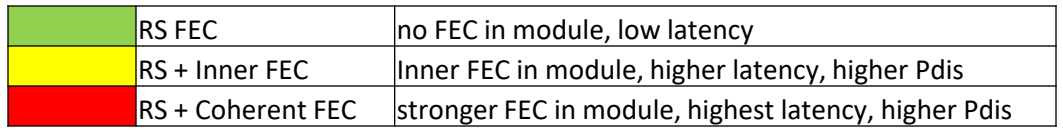
New channel models could enable CWDM?

- 800GBASE-LR4-x with reach up to ~6 km
- 1.6TBASE-FR4-500, depends on mod. format

- Uncooled CWDM has been used for extensively for low-cost 4λ PHYs
  - Relaxed laser WL and mux specs
  - No added TEC power consumption
- Maintaining CWDM at higher rates allows multi-rate interoperability
- The CD-limited WL range has been shrinking, forcing use of cooled LAN-WDM WL's for long reach PHYs
  - Rodes_3df_01b_221012
  - Johnson_3df_1a_221011
- CWDM might not be possible at all for 4x400G IM-DD: maybe only for 500m with new channel model

Evolution of FEC

Rate	500 m	2 km	6-10 km	30-40 km
4x25G				
4x50G				
4x100G				
4x200G				
4x400G				



	RS FEC	no FEC in module, low latency
	RS + Inner FEC	Inner FEC in module, higher latency, higher Pdis
	RS + Coherent FEC	stronger FEC in module, highest latency, higher Pdis

New channel models could enable RS FEC only?

- 800GBASE-FR4
- 1.6TBASE-FR4-500, depends on mod. format

- RS FEC alone has been used through the 100G/L generation
  - No added module power consumption
  - Low latency
- 200G/L brought in Hamming inner FEC for ≥ 2km reach
  - Added DSP IC cost and power
  - Added latency
- It's unclear if any 4x400G PHY will be able to use RS FEC alone: possibly only for 500m with new channel model

Discussion

- Chromatic dispersion is forcing ever more costly mitigation strategies to be implemented for popular 4λ duplex PHYs
- Previously, this was a long-reach issue; now it affects 2km reaches at 4x200G, and will be a serious impediment to IM-DD adoption at 4x400G
- The use of overly conservative worst-case fiber specs in Ethernet channel models (G.652) burdens the industry with the extra cost of unnecessarily complex, costly and power-hungry modules
- The development of new channel models utilizing statistical techniques can help reduce the growing impact of CD at higher rates
- It's not a panacea, but it could allow some high-volume PHYs on the margin to be able to avoid the use of LAN-WDM, inner FEC or other mitigations

Thank you