Towards Consensus on a Coherent-based 800G 10/40km Specification

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Overview

- 802.3df includes the following 800Gb/s objectives that are suitable for a coherent optical solution
  - over a single SMF in each direction with lengths up to at least 10 km
  - over a single SMF in each direction with lengths up to at least 40 km

- Both coherent and 4 wavelength 200G/lane IMDD solutions have been proposed to meet the 10km SMF objective
  - Both approaches have more than one proposed implementation

- This contribution explores the technical feasibility and commercial considerations of coherent and IMDD approaches

Why Coherent Helps at Higher Data Rates

- Leveraging I/Q modulation and polarization multiplexing offers a 4:1 reduction in the number of lasers (e.g. WDM PAM4 vs DP-16QAM)
  - Same number of modulators and drivers
  - Nested MZ and hybrid receiver complexity results in small increase in PIC size
  - Coherent requires wavelength control, so relative cost is higher if IMDD is uncooled
- Coherent detection enables DSP to linearly compensate for nearly all impairments, such as chromatic dispersion, polarization mode dispersion, and Tx/Rx transfer functions independent of baud rate
  - Predictable and improved margin compared to IMDD
    - IMDD contends with complex stack up of multiple linear impairments due to square law detection, & is highly sensitive to increasing baud rate (CD, PMD,..)
  - Not susceptible to four wave mixing problems observed for IMDD at higher launch powers
  - Design can be optimized for fiber loss budget
- Coherent detection provides 12-13 dB sensitivity gain over IMDD
  - Local oscillator can be shared between transmitter and receiver
  - Net gain is reduced by splitting laser and higher modulation loss
  - Overall, some potential benefit from coherent, but not primary motivation

40 km Reach Objective

- Coherent implementation can use optical amplification to increase loss budget
- C-band operation reduces loss and increases amplification options
  - Chromatic dispersion addressed by the DSP
- Optical amplification, if needed, can be implemented within a pluggable module
  - Amplified coherent 400G in QSFP-DD form factor currently demonstrated
    - Both silicon photonics and indium phosphide technology
- Link budget and chromatic dispersion make the 40 km reach objective extremely challenging for IMDD approaches
- More details on 40km technical proposal in williams_3df_221011

10 km Reach Objective Decision Trade-offs

- Coherent
  - Advantages
    - Low technical risk
    - Good performance margin
    - Ability to monitor link impairments (CD, PMD, etc.)
    - Alignment with 40km PMD
    - Implementable as optimized-built or common design w/ 40km
      - Market driven implementation options
  - Disadvantages
    - Relative cost concerns

- 4λ IMDD
  - Advantages
    - Some alignment with 2km PMD
    - Potential re-use and alignment of some of 2km technology
  - Disadvantages
    - Potential impact on high-volume 2km DSP design requirements
      - Higher gain FEC
      - Additional filter taps
    - Yield risk
    - Complex Margin and link performance risk

10 km Reach Objective
Current status regarding technical feasibility

Coherent

- Proposals support 10km link budget with margin
- Design margin provides degrees of freedom to optimize for cost and power
- Multiple approaches have been proposed
  - maniloff_3df_01b_2207 showed a low-latency approach with link margin
  - williams_3df_01_2207 highlighted potential alignment between various reach objectives

4λ IMDD

- Four-wave mixing and polarization mode dispersion have been raised as technical risks
- Multiple approaches have been proposed
  - Change channel grid
    - rodes_3df_01a_220329
  - Polarization interleaving
    - rodes_3df_01c_2207
  - Polarization multiplexing
    - doerr_3df_01b_2207
  - 106Gbaud APD receivers
    - yu_3df_01a_220329
  - Higher gain FEC
    - liu_3df_01b_2207

10 km Reach Objective Commercial Feasibility

- Chicken & Egg: Cost depends strongly on volume. Coherent is moving from lower volume applications to higher volume applications but carries the burden of cost perception from lower volume applications.
- Based on an industry analyst forecast, a relative cost analysis of 400ZR (120km coherent) to 400LR4/8 (10km IMDD) that at comparable cumulative shipments (if achieved) a cost delta was projected to be only 2.2x (See williams_3df_01a_220329)
- 800G-LR1 offers simplifications (against 400ZR) that will reduce cost
    - At 10km reach, the DSP building blocks are similar between IMDD and Coherent, resulting in similar complexity designs

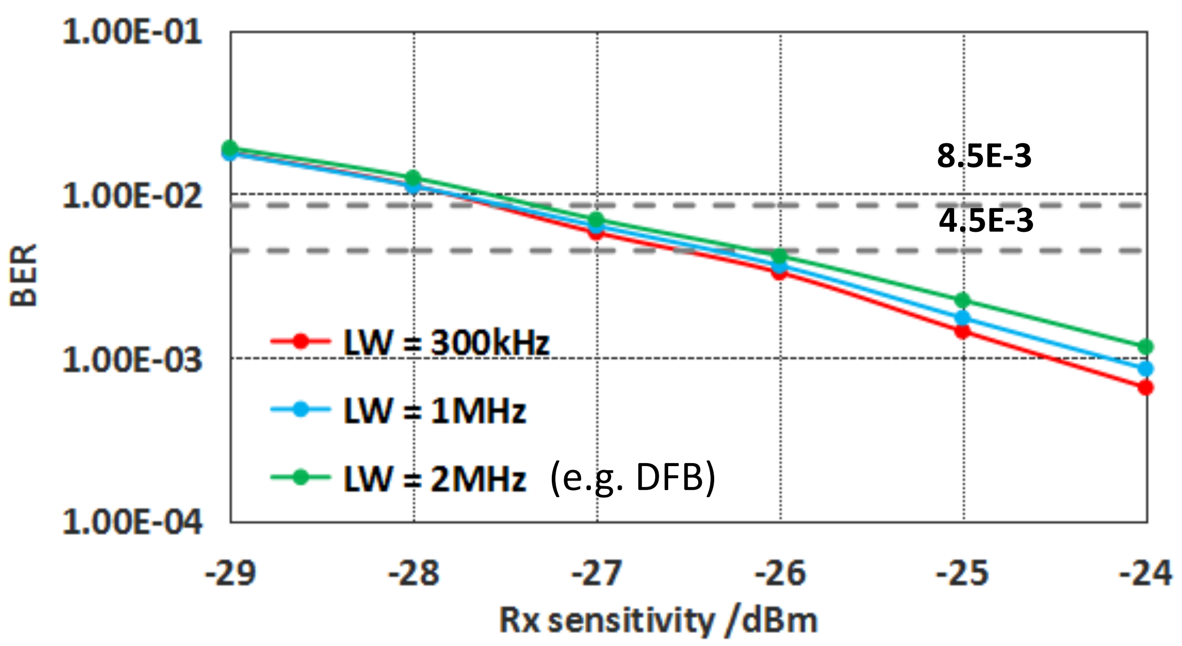
10 km Reach Objective Commercial Feasibility

- 400ZR to 800G-LR1
  - Single fixed DFB laser vs tunable
  - Higher yield
  - Less test time on lower cost test equipment
    - No OSNR test requirements

- 400G-LR4 to 800G-LR4
  - No longer a screened version of FR4
  - Requires investment in custom optical design
    - Grid not aligned with CWDM
    - Polarization and wavelength (temperature) control may be necessary for all 4 lasers
    - Chirp tuned to offset dispersion
  - Chromatic dispersion more challenging even with modified wavelength grid
  - Common DSP with FR4 depends on FEC scheme

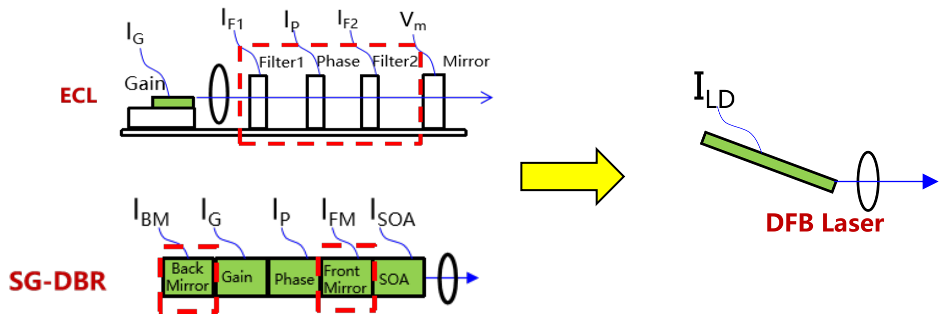
Cost reduction example: Relaxing Laser linewidth

- When the laser linewidth is relaxed from 300kHz to 2MHz the additional link penalty is about 0.4dB (BER 4.5e-3)
- Lasers with lower cost and power consumption, such as fixed DFB lasers, are feasible for 10km coherent design



Rx Sens @ BER	300 kHz	1 MHz	2 MHz
8.5e-3	-27.6 dBm	-27.5 dBm	-27.3 dBm
4.5e-3	-26.5 dBm	-26.3 dBm	-26.1 dBm

- **Fixed-wavelength Laser:**
- **Lower cost:** simplified wavelength tuning unit, smaller chip size, manufacturing and testing cost, more vendors
- **Lower power consumption:** without active control units, power efficient with higher coupling efficiency



Tunable Lasers (discrete or integrated designs)

Fixed-wavelength Laser

P802.3cu debated this before:

Review of 400G LR4 Reasoning

Cost is King

- CWDM grid has technical cost advantages:
  - No TEC, and associated simpler assembly techniques
  - Simpler WDM filters
- However, main cost drivers are:
  - Volume
  - Manufacturing margin
- 400G FR4 in 3+ years is expected to be a high volume interface in the cloud datacenter
- Using TF contributions, worst case 10km SMF link CWDM4 spec does not have good, if any, manufacturing margin
- Ideal spec leverages the FR4 volume and has good manufacturing margin (multiple yield sigmas)

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cole_3cu_01b_0919.pdf

Applied to 800-LR4

Not utilizing CWDM grid

Custom optics design with higher complexity than FR4

Questionable manufacturing margin

Polarization Mode Dispersion Specification

- In 802.3bs, a DGD Max specification of 8 ps was applied to 10km links
- Due to excessive penalty for 100Gb/s signaling, PMD was revisited in 802.3cu
  - https://www.ieee802.org/3/cu/public/cu_adhoc/cu_archive/anslow_3cu_adhoc_051519.pdf
  - The PMD coefficient derived for concatenated segments in longer reach applications isn’t applicable shorter reaches with fiber from a single spool.
  - A 5ps allocation was recommended for 10 km links, the DGD spec was reduced to 4ps for 6km links in 802.3cu
- PMD will result in a significant penalty for 200G PAM4 direct detect
  - DGD has been estimated to produce a 3.4 dB penalty, see: https://www.ieee802.org/3/df/public/22_07/zhang_3df_01b_2207.pdf

Baseline Specifications

- Regardless of operating band (fiber loss coefficient), the LR specifications should be based on a 6.3dB loss
  - In many applications this loss is used to accommodate losses from optical components rather than fiber
- For the ER application, the loss budget can be based on an 0.35dB/km fiber loss specification for G.652.B fiber

Optical power budgets

	800GBASE-LR1	800GBASE-ER1	
Signalling Rate			
Modulation Format	DP-16QAM	DP-16QAM	
Wavelength Range	1550	1550	nm
Average Launch Power (max)	-6	2	dBm
Average Launch Power (min)	-10	-2	dBm
Rx Sensitivity	-17.3	-17	dBm
Operating Distance	10	40	km
Link Loss	6.3	14	dB
DGD	5	10	ps
Chromatic Dispersion	200	800	ps/nm
Allocation for Penalties	0.5	1	dB

- These budgets are consistent with G.652.B and G.652.D fiber

Summary

- Coherent can support the 40 km reach objective based on 1550 nm operation with internal amplification
- Coherent can support the 10 km reach objective without internal amplification
  - Multiple options for a baseline proposal – all with good margin
  - Either C-band or O-band can be supported with a 6.3dB loss budget
  - Adds no burden to 500m/2km IMDD designs
- IMDD proposals for 10 km reach objective require custom optical design
- Relative cost of higher yielding coherent implementation can be comparable to IMDD
- Optical budgets are presented which are intended as a starting point for baseline development