Google

Coherent-Lite for beyond 400GbE

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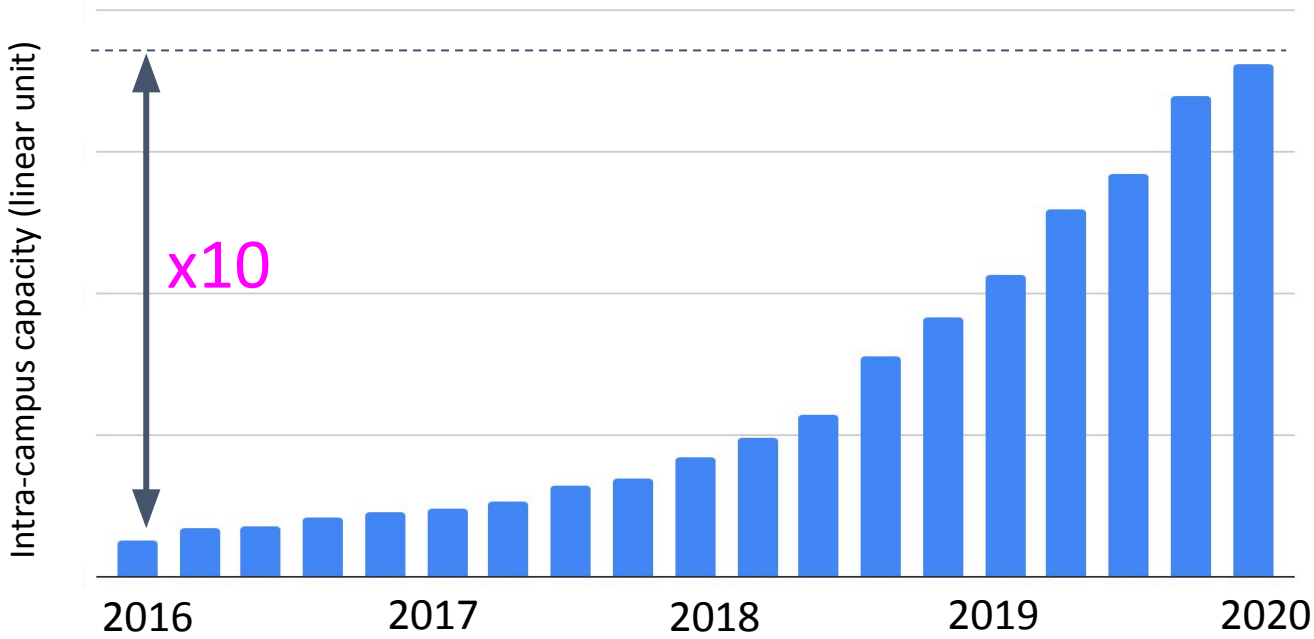
Outline

- Driver and use cases for Coherent-Lite inside datacenters
  - Recaps of the objectives passed in the B400GE SG
  - Campus network reach requirement and channel limitation
- Justification for coherent-lite
  - Coherent transmission benefits
  - Technical Feasibility
  - Economic Feasibility
- Coherent-Lite Implementation Challenges
  - Analog modulator and driver challenge
  - DSP challenge
  - Coherent-Lite as a complement to CWDM IM-DD

800GE Objectives Established in the April 2021 SG Meeting

- https://www.ieee802.org/3/B400G/public/21_04/motions_b400g_a_2104.pdf
- 200Gbps/Lane Objectives Passed
  - Define a physical layer specification that supports 800 Gb/s operation over 4 pairs of SMF with lengths up to at least 500 m
  - Define a physical layer specification that supports 800 Gb/s operation over 4 pairs of SMF with lengths up to at least 2 km
- 200Gbps/Lane with 4 wavelength objective passed
  - Define a physical layer specification that supports 800 Gb/s operation over 4 wavelengths over a single SMF in each direction with lengths up to at least 2 km
- 10km objective passed
  - Define a physical layer specification that supports 800 Gb/s operation over a single SMF in each direction with lengths up to at least 10 km
  - **There is no discussion about the implementation of the 10km objectives yet.**

Google Intra-Campus Traffic Trend

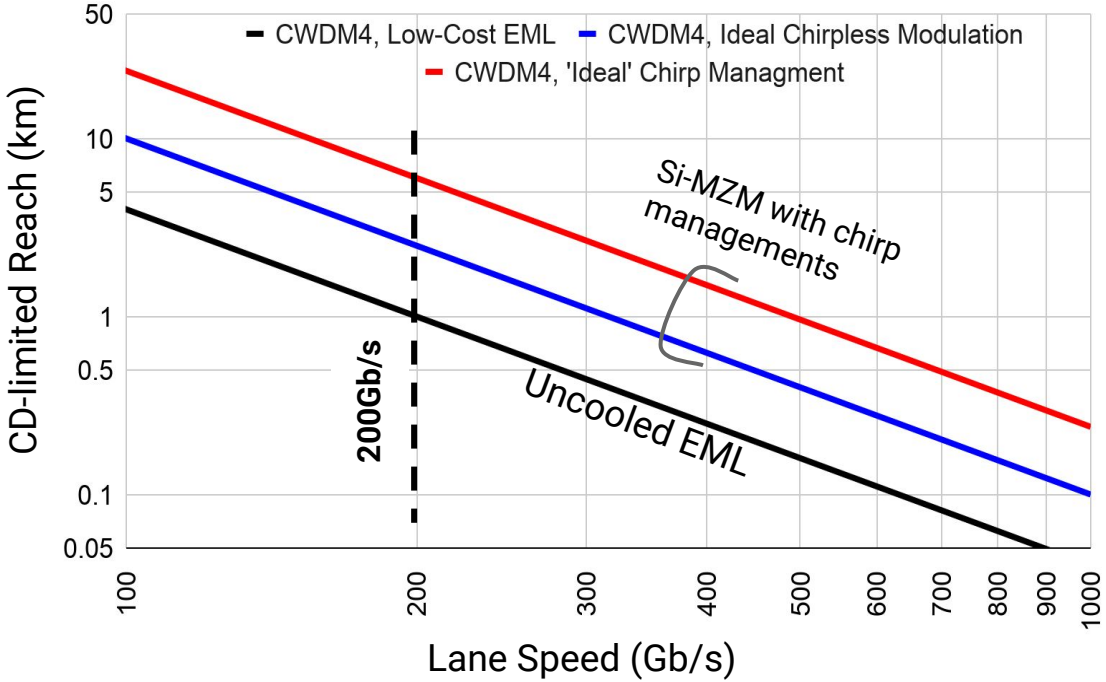


- Intra-campus capacity increased by more an a decade over 4 years (2016 to 2020)

Campus Network Reach Requirements

- Campus networks are growing beyond 2km to 10km.
  - We have seen 5km and even 10km requirements
  - In https://www.ieee802.org/3/B400G/public/21_05/stone_b400g_01_210503.pdf, Rob Stone proposed to extend the objective of 800Gb/s over 4 wavelengths up to 3km on SMF.
- Nov 2020, OIF started 800G-LR as part of the OIF 800G coherent project
  - From OIF 2020.359.07
    800G-LR: unamplified 2-10km fixed wavelength link (e.g. campus applications)

Chromatic Dispersion Limit of CWDM4 IMDD



- **CD-limited reach (with CWDM4-EML)**
  - 100Gb/s PAM4: ~4km
  - 200Gb/s PAM4: ~1km
  - 400Gb/s PAM4: ~0.25km

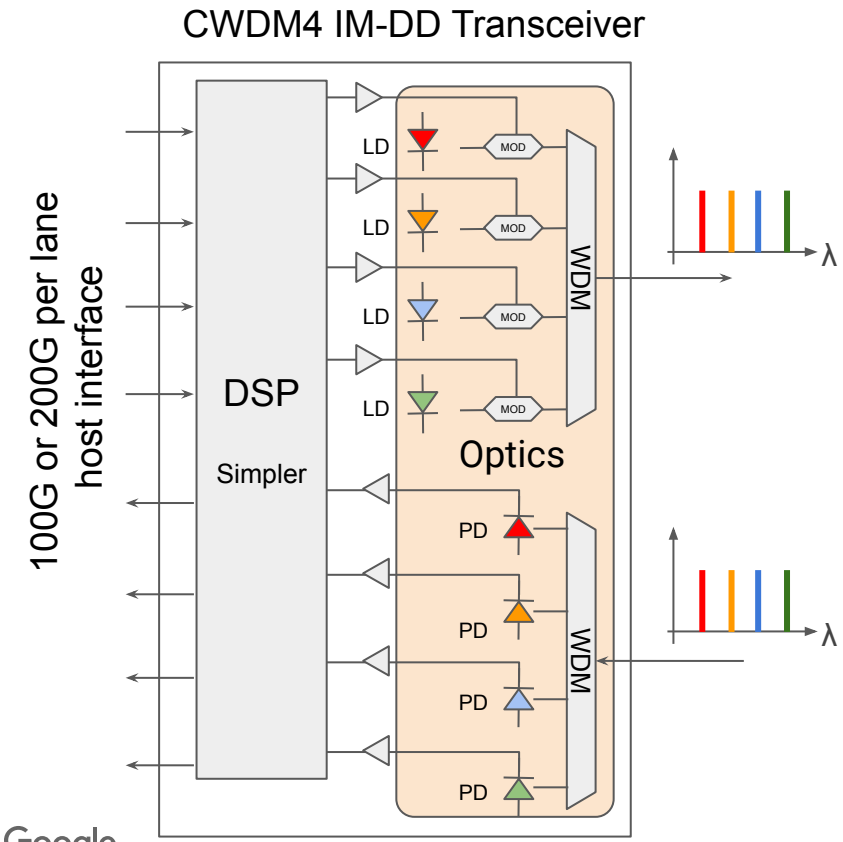
- Sophisticated chirp management techniques could make incremental improvement in dispersion-limited reach , but face loss-budget challenge.

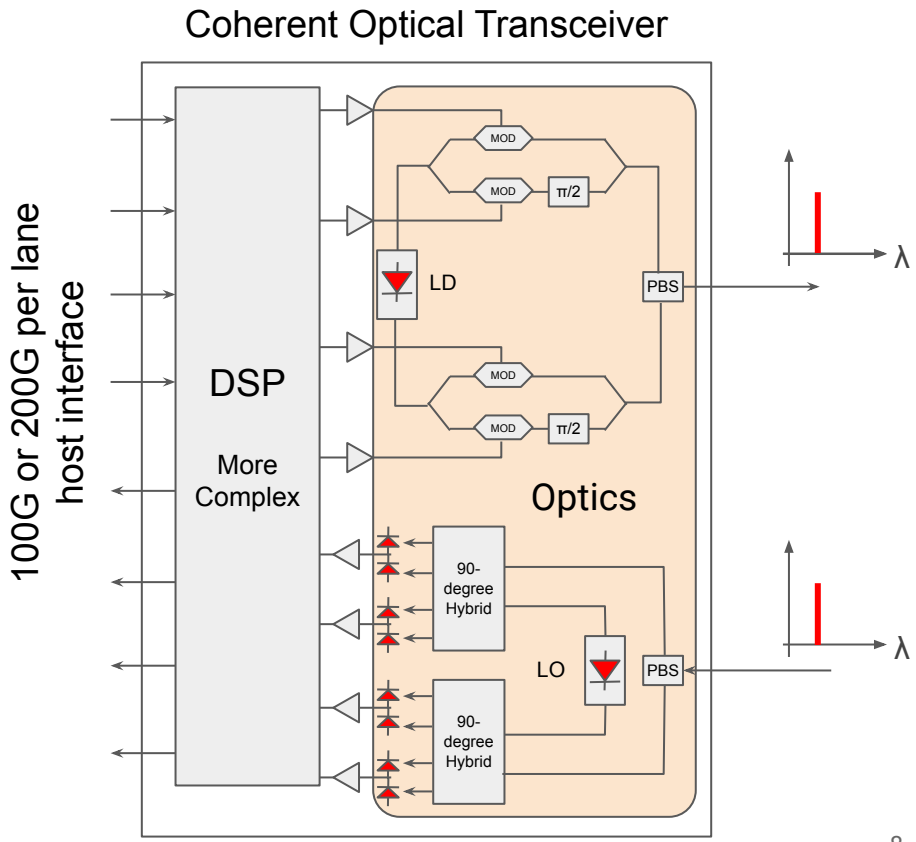
Why Coherent-Lite?

- Transmission-penalty-free electronic dispersion compensation
  - Remove the CD transmission limit of IM-DD
  - Possibility to use higher-dispersion wavelengths (e.g. C-band)
    - Optical amplification and DWDM enable new architectures
- 10dB better receiver sensitivity
  - Possibility for lower overhead FEC for latency-sensitive applications
- Lower baud-rate optical component enables better future scalability
  - How to scale to 3.2Tb/s modules (16x200G IM-DD or 4x800G Coh-Lite)?
- Robustness against link reflection and multi-path optical interference

Ref: X. Zhou, et al, "Beyond 1 Tb/s Intra-Data Center Interconnect Technology: IM-DD OR Coherent?," JLT, 38, 475-484 (2020)

Transceiver Architectures (CWDM4 vs. Coherent)





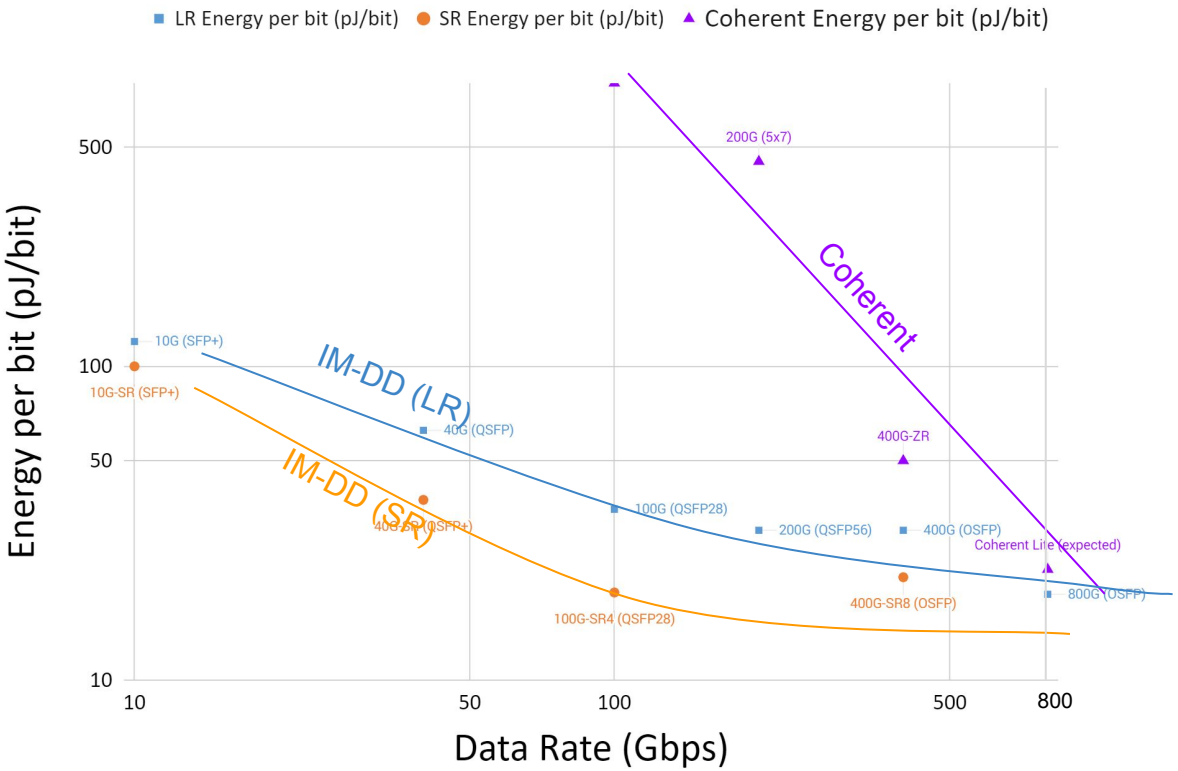
CWDM4 vs. Coherent Comparison

- **CWDM4 PAM-4 and PM-16QAM coherent share similar 200Gbps per lane component requirements**
  - 4 optical modulators of similar baud rates
  - 4 ADC and DAC pairs of similar baud-rate
  - High performance FEC, equalizers etc.
  - Same host interface and framer
- But CWDM4 requires 4 wavelengths (4 lasers) whereas PM-16QAM requires only 1 laser and more complex DSP
- Coherent takes natural advantage of polarization multiplexing which leads to simpler PIC implementations.

Technology Feasibility of Low-Cost Coherent Lite

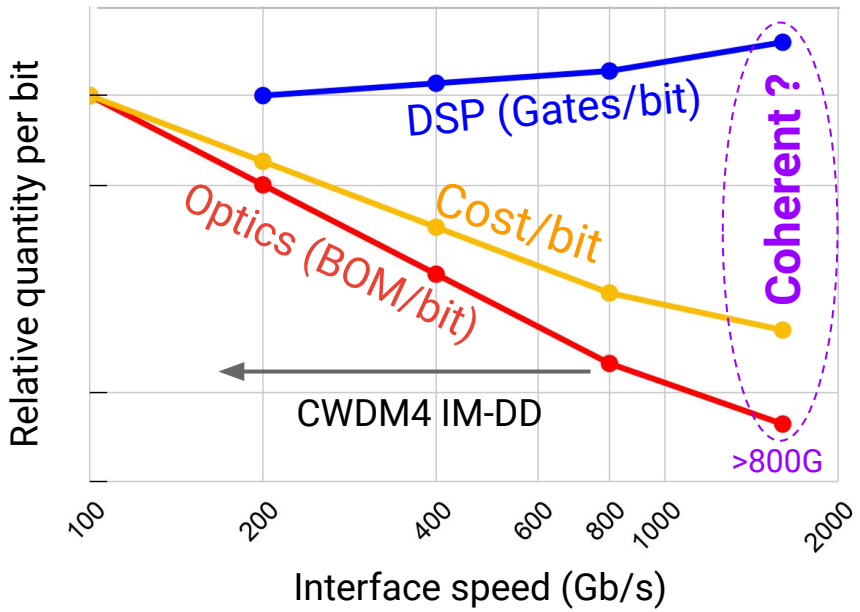
- Feasibility of the 200Gbps per lane optical and electronic components established in the March 2021 B400G SG meeting (https://www.ieee802.org/3/B400G/public/21_03/index.html) are applicable to PM-16QAM coherent implementation for 800GE
- Low-cost coherent laser feasibility presentation on May 11, 2021
  - Maxim Kuschnerov, et al, OIF2021.218.00, *Considerations on a cheap coherent laser for 800G-LR*
- 400G-ZR pluggable module volume deployments started in 2021

Coherent Benefits More from CMOS Advances



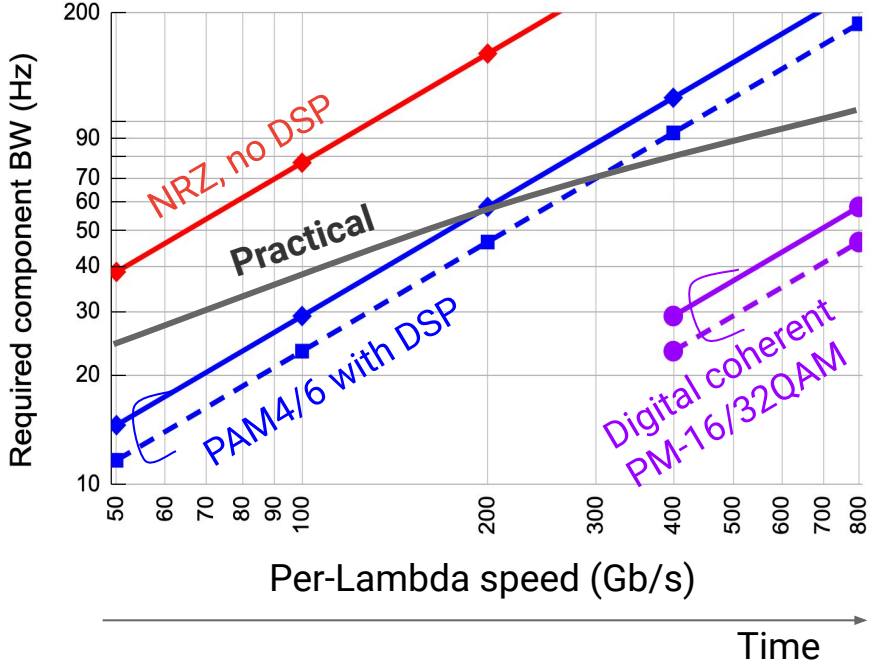
- Optics scales with much more modest progress than electronics.
  - No Moore's law in optics
- Simple optics & smart electronics
- We need low-power and low cost DSP designs optimized for intra-datacenter applications

Better Future Scalability of Coherent Interconnects



- Parallel optics cost scales linearly with BW
- DSP cost scales with CMOS: Sublinear !

Constrained Component Bandwidth



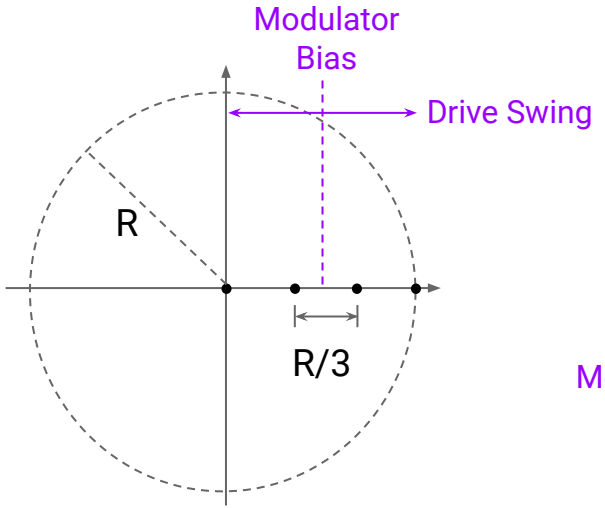
- DSP increases lane speed and reduces optics BOM per bit

Challenges for Coherent Datacenter Interconnects

- Modulator efficiency (loss and Vpi)
- Modulator Drive
- DSP optimized for <10km datacenter applications

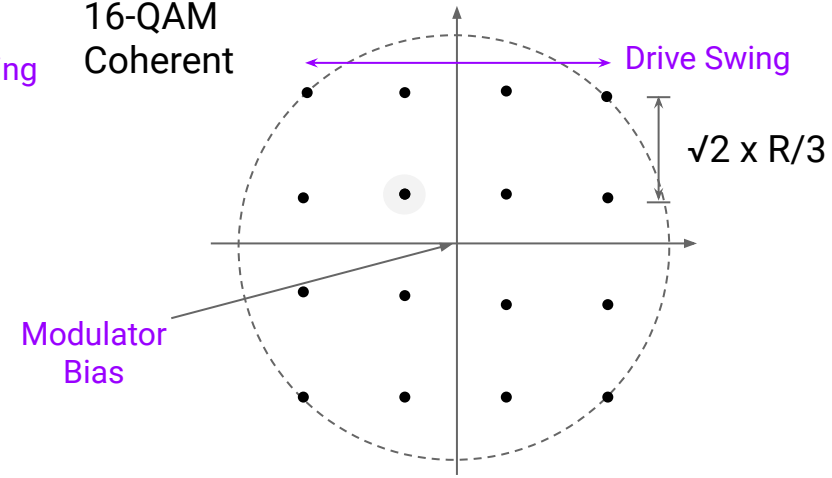
Coherent Transmitter Requires Higher Modulator Drives

PAM-4
(IM-DD)



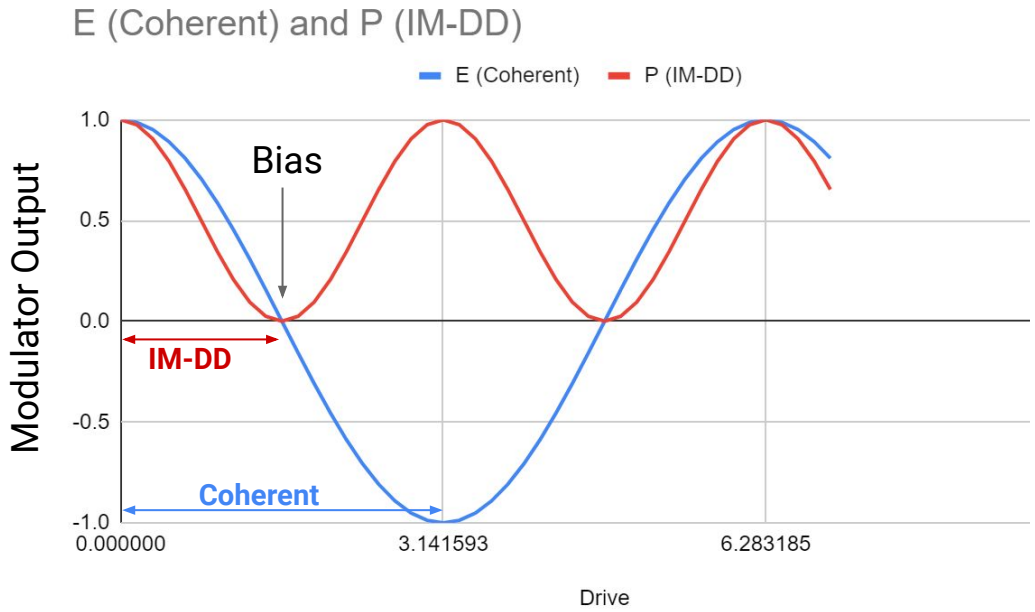
- Intensity encoding, signal symbols very crowded
- Poor SNR tolerance

16-QAM
Coherent



- Electric field encoding, signal symbols well spread out
- Better SNR tolerance & higher capacity
- Easier to scale baud rate with higher-constellation sizes

Low-Loss High Efficiency Modulator Needed



- Coherent modulation requires twice drive swing to achieve the same ideal peak power as IM-DD
- Drivers today are designed for IM-DD modulations
- Modulator V-pi is still a challenge (especially for SiPh).
  - Need to develop efficient drivers and efficient modulators.

Modulator Loss Offsets Sensitivity Gain in Coherent Links

IM-DD Vs Coherent: 1.6Tb/s Link Budget

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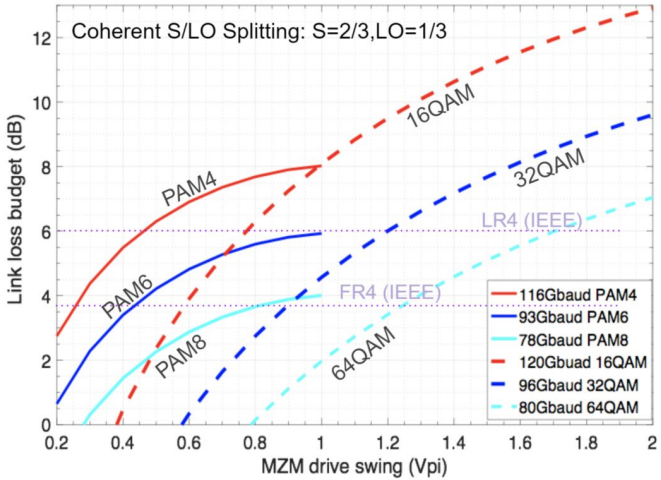
Assume FEC threshold=1e-2
(both PAM and PM-QAM)



An example

Item \ Technique	2x800Gb/s PM-QAM	8x200Gb/s (IM-DD) PAM
Laser number	2	8
Per laser power (dBm)	16	16
MZM IL (dB)	4	4
Tx path loss(dB)	7.8[a]	4
Rx path loss (dB)	4	2
Mux+DeMux (dB)	1	4
Implement. penalty (dB)	5/5.5/6	4/4.5/5

[a]: include 1.8dB signal/LO splitting loss, additional 3dB I/Q modulation loss not included here

- At identical per laser power, coherent needs to drive the MZM harder to achieve a similar link budget
- At full drive swing, coherent can achieve about 5dB higher link budget

Ref: X. Zhou, OFC 2019, *Beyond 1Tb/s Datacenter Interconnect Technology, Challenge and Solutions*

Other Challenges & Improvements for Datacenter Uses

- Think about coherent-lite modules as direct replacement for traditional IM-DD modules
- Volume for intra-datacenter optics is orders of magnitude higher than metro and long-haul optics for traditional telecom applications, so
- We need to optimize DSP for intra-datacenter applications
  - Power consumption
  - Latency
  - Cost
- There is no need for expensive full C-band tunable lasers
  - Low-cost fixed wavelength lasers or
  - Few-channel WDM tunable lasers would be good

Conclusions

- Coherent transmission scales better with bit-rate and reach.
- Coherent-Lite would be a cost-effective solution for 10km campus networking at > 800Gbps
- 800G coherent-Lite shares similar optoelectronics component requirements with 200G/lane IM-DD solutions
- The industry should optimize coherent solutions (DSP, laser, PIC, etc.) for intra-datacenter connectivity.