# Towards an objective for 400 Gb/s for DCI applications

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# Topics

- Background
- Market Need
- Technical Feasibility and Leverage
  - 400G Extender Sublayer
  - Framing (PCS)
  - FEC
  - 400G Coherent Optics
- Economic Feasibility
- Summary
- Proposed Objective
- Backup

# Background

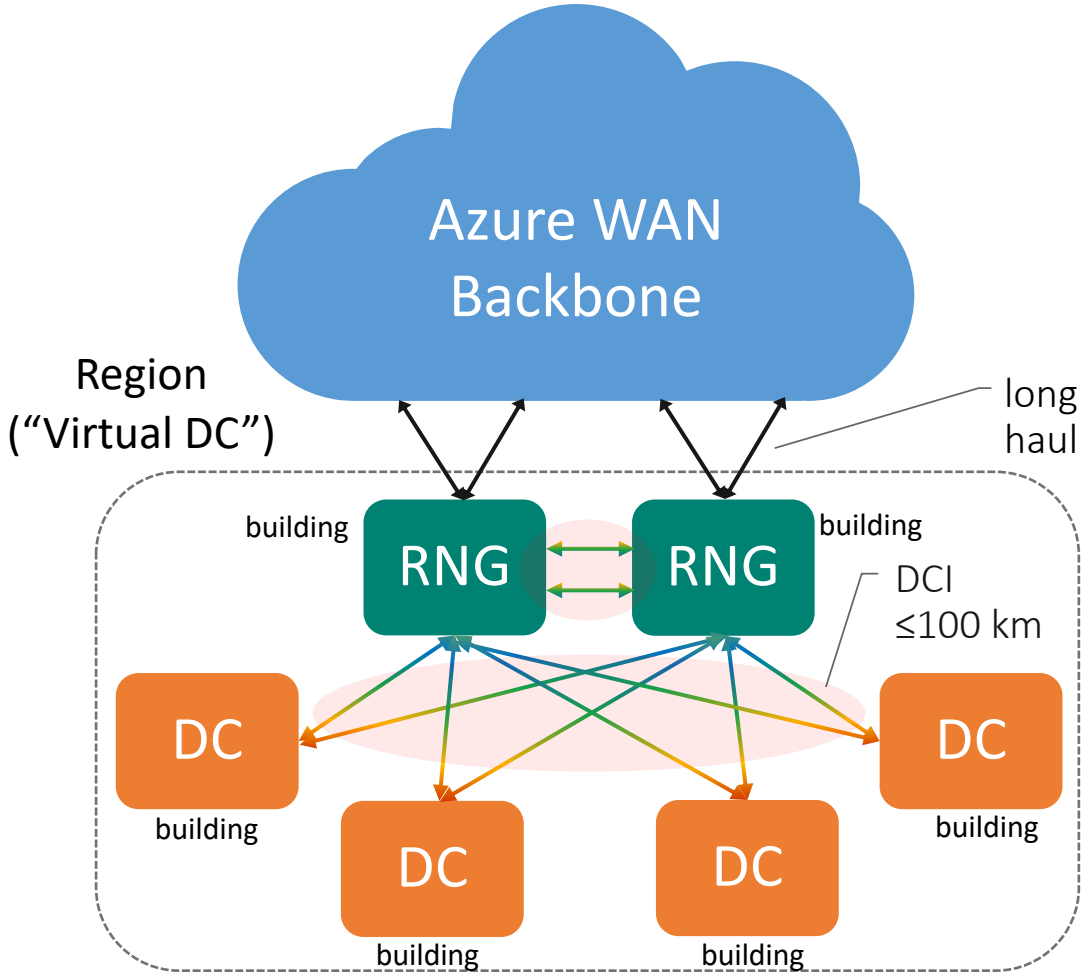
- There is interest within the industry in defining new Ethernet DWDM PHYs with the ability to run over a single-channel (wavelength) port on a DWDM multichannel optical system.
- At the Chicago meeting (March, 2018) an objective was adopted to support 100 Gb/s operation on a single wavelength capable of at least 80km over a DWDM system, and initially targeting the Cable/MSO market.
  - nowell_b10k_01b_0318
- This presentation proposes the study group adopt a similar objective to support 400 Gb/s operation on a single wavelength capable of at least 80km over a DWDM system, and initially targeting the DCI market.

# Market Need

# What is DCI ?

- DCI = Data Center Interconnect
- Continued growth in data center traffic is fueling a trend towards new distributed data center architectures (see baca_b10k_01_0518)
- In these new architectures,  a multi-tier (leaf/spine) data center is not all physically located within a single building, but instead distributed over multiple buildings within a regional area.
- A large portion of the data center east/west traffic that traditionally remained within a single building, now has to transit between several buildings
- This inter-building (east/west) traffic is driving a demand for high capacity (100G and 400G) DWDM links capable of running over distances of up to 80km
- This is the DCI application that is the focus of this presentation and proposed objective

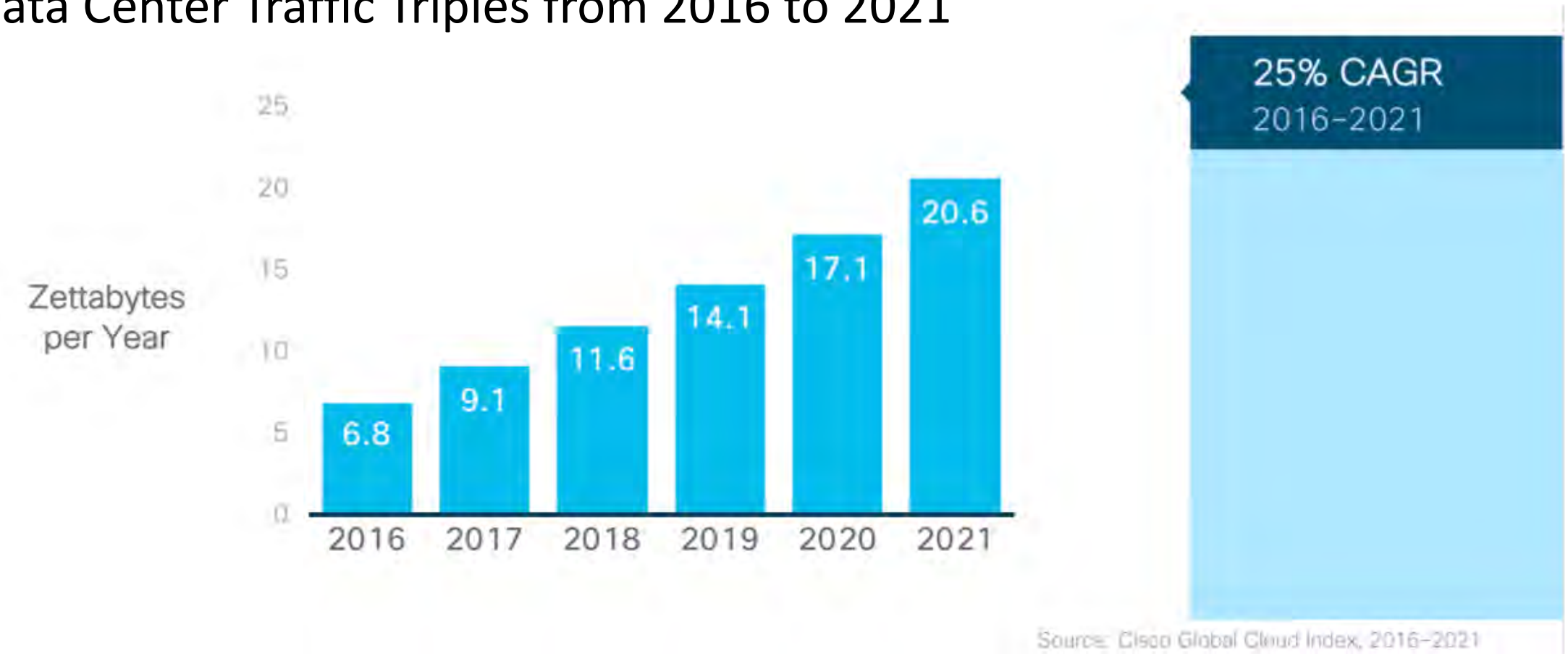
# Use Case Example – 400Gb/s DCI



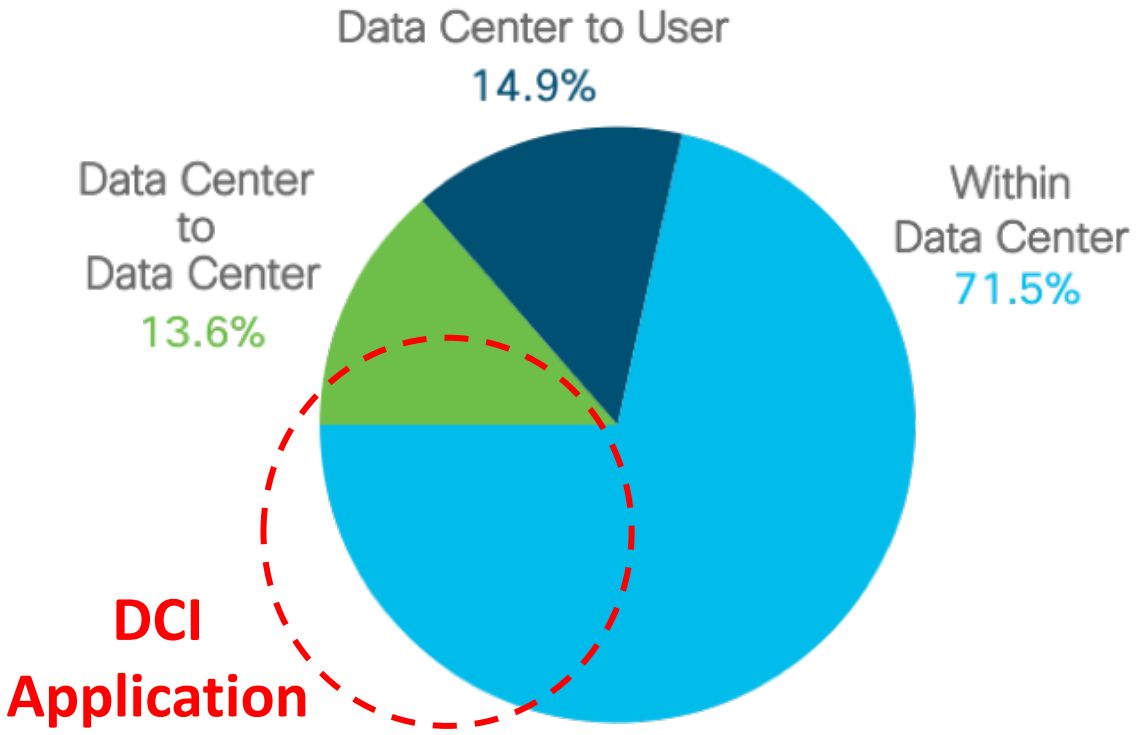

- Distributed data center model
- Leaf/Spine architecture is split across multiple buildings located within a regional area
- Latency SLAs constrain maximum fiber distances between buildings
- Ethernet based fabric
- DWDM based inter-building interconnect (carrying east/west traffic)

# Global Data Center Traffic Growth

## Data Center Traffic Triples from 2016 to 2021



# Global Data Center Traffic by Destination, 2021




Total East-West Traffic forecasted to grow to
~ 85% beyond 2021

## Within Data Center (71.5%)

Storage, production and development data, authentication

## Data Center to Data Center (13.6%)

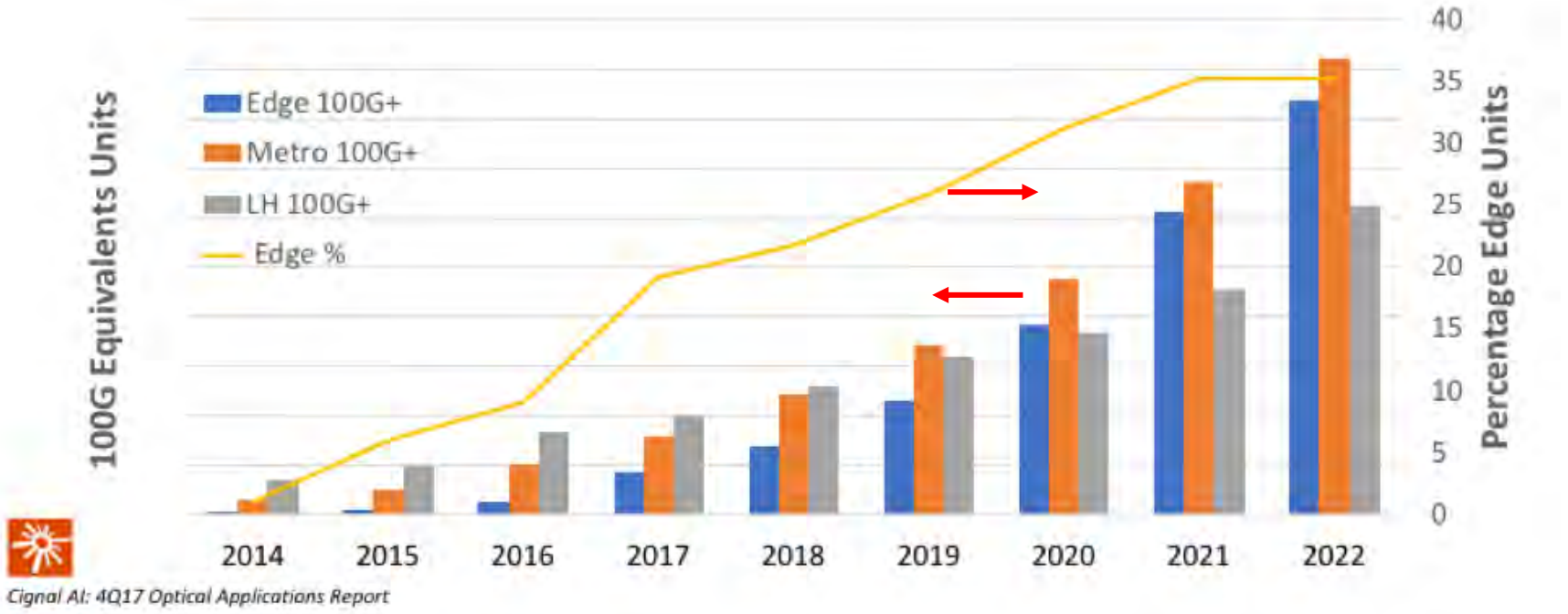
Replication, CDN, intercloud links

## Data Center to User (14.9%)

Web, email, internal VoD, WebEx...

Source: Cisco Global Cloud Index, 2016-2021

# Coherent market forecast by reach




100G and above, in 100G equivalents
Edge: < 120km
Metro: < 600km
LH: >600km

DCI drove edge growth in 2017

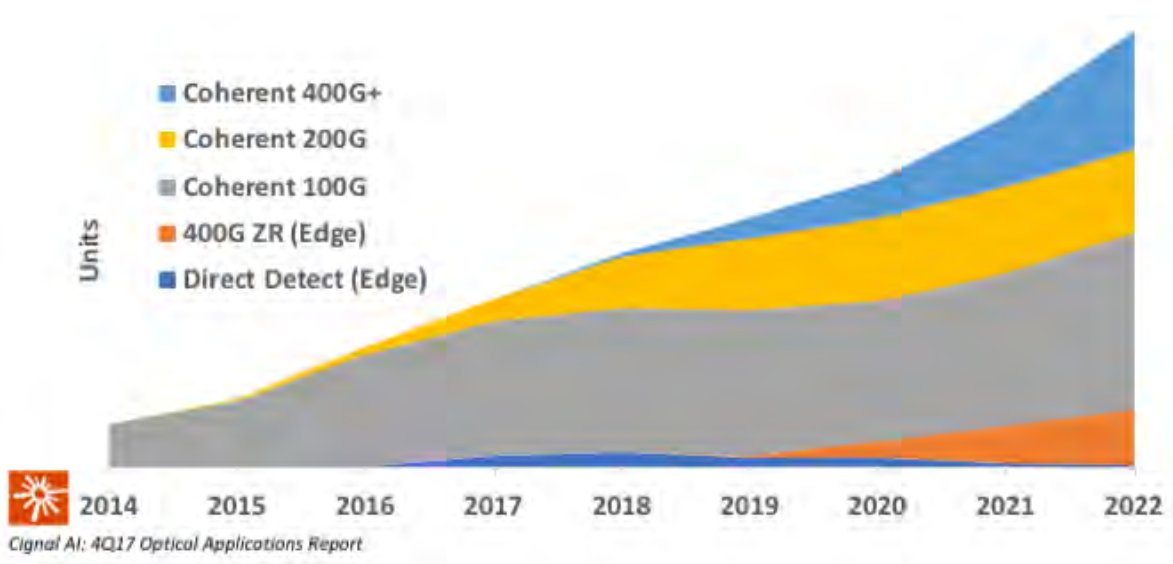
- Next wave coming in 2020
- 100G/400G "ZR" pluggable market

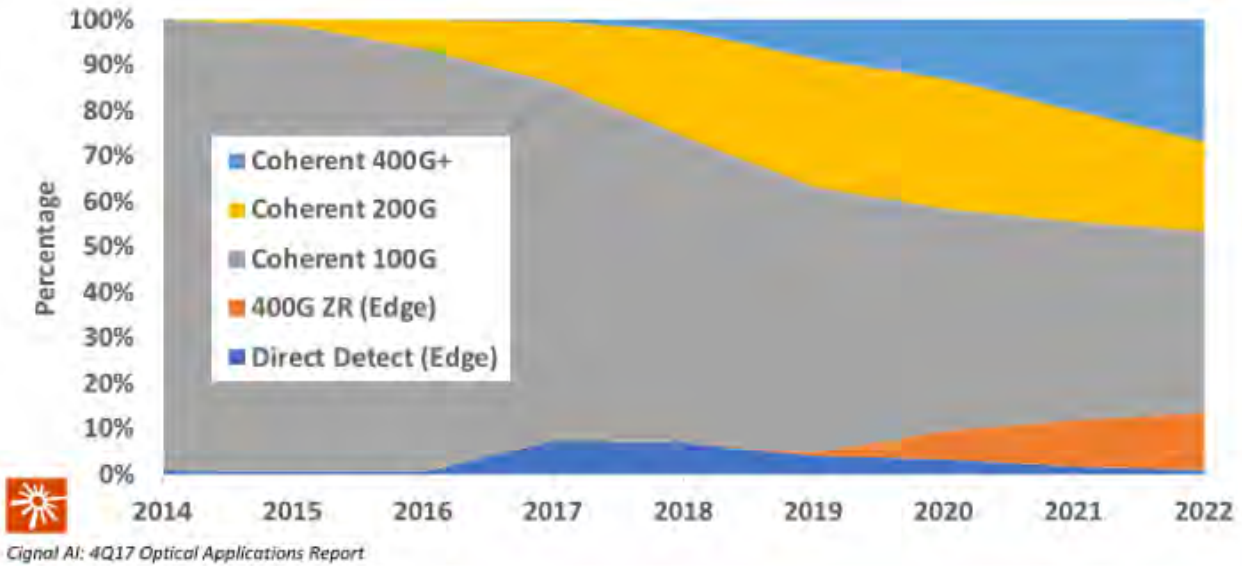
10G Migration

- 10G Long Haul migration to Coherent complete
- 45% of all 10G links are <80km
- This will migrate to 100G coherent at the right price

Courtesy of Andrew Schmitt, Cignal AI

# Coherent market forecast by data rate



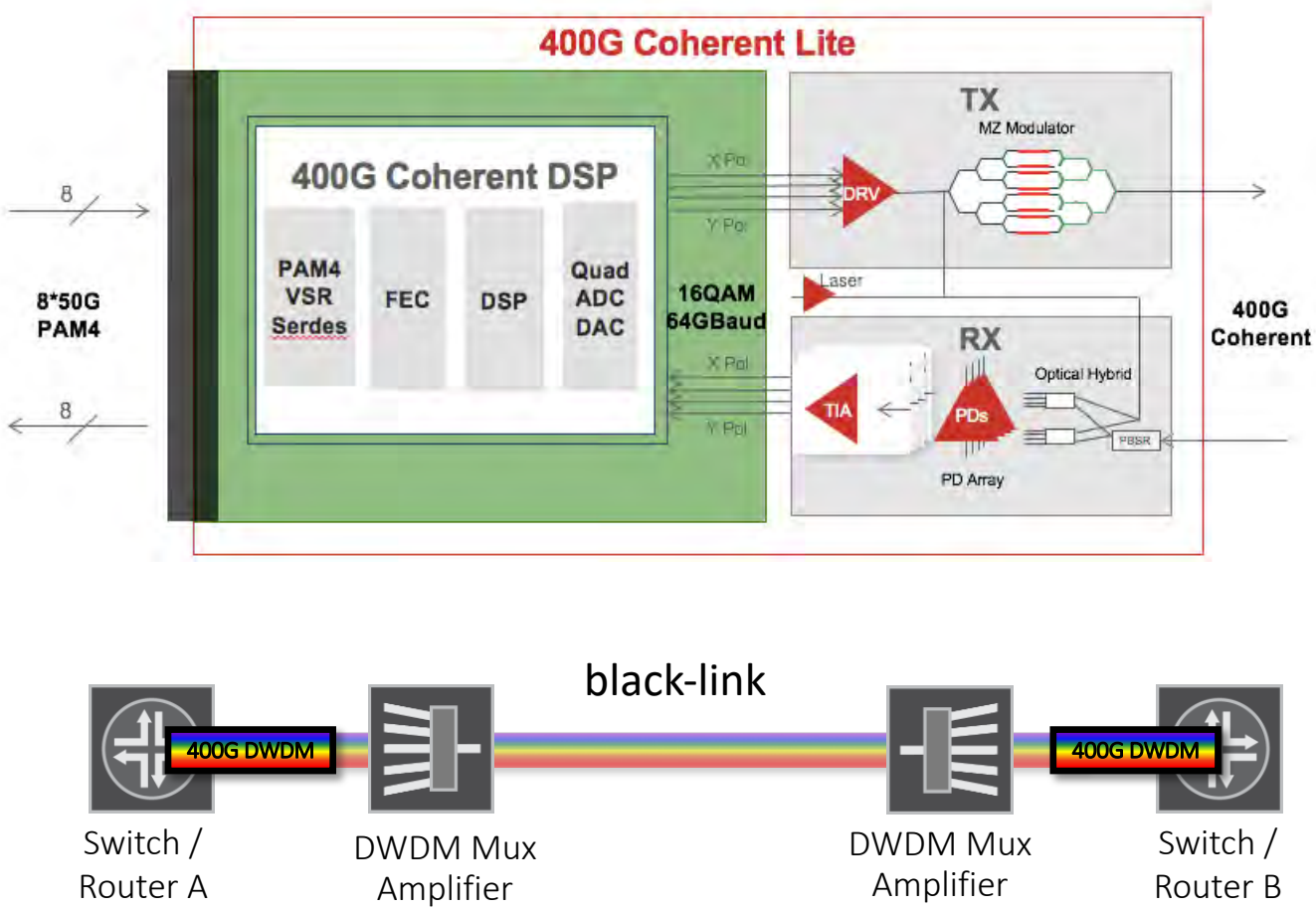

- 400 Gb/s market starts in 2019
- Coherent edge (100G and 400G) represents ~ 35% of total coherent market in 2022
  - Edge applications expected to be dominated by Ethernet

Courtesy of Andrew Schmitt, Cignal AI

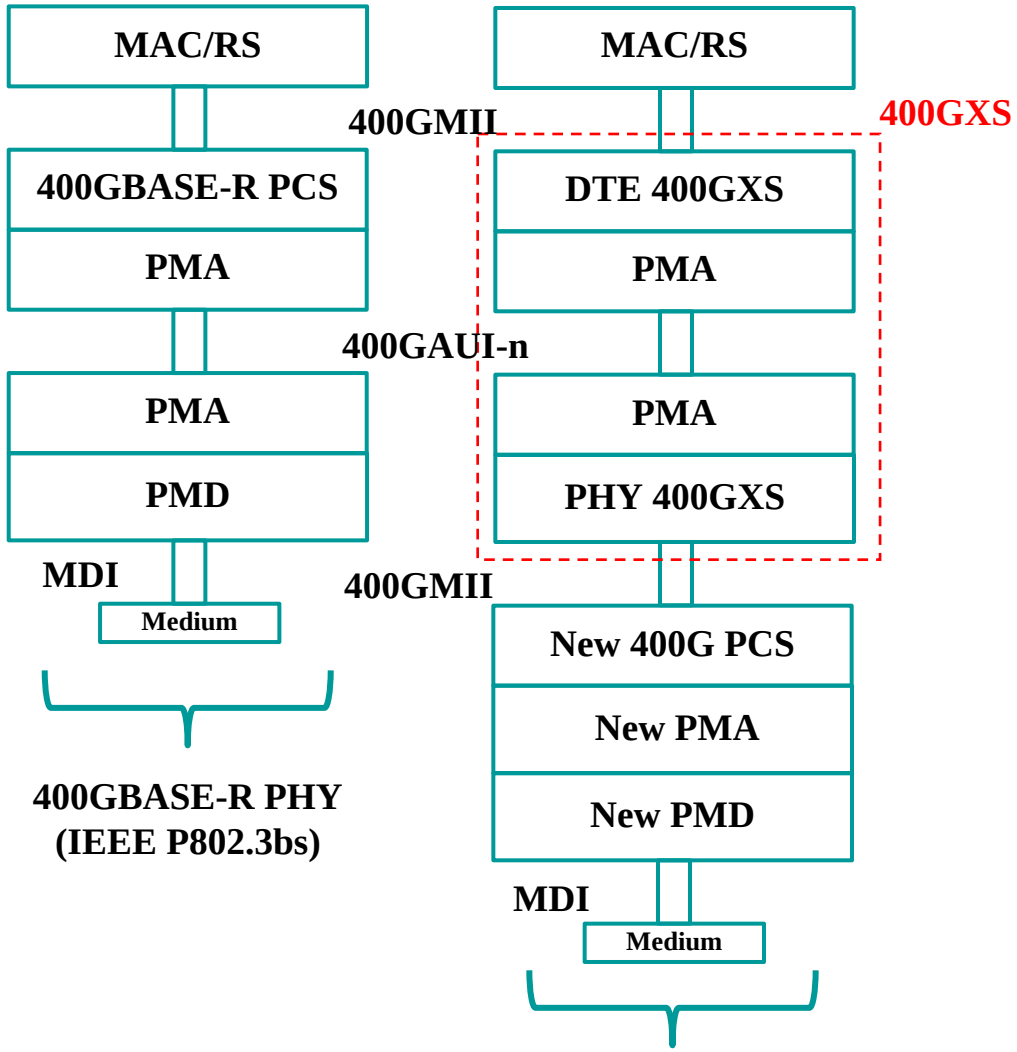
# Technical Feasibility

# 400Gb/s DCI Application Overview

- 400Gb/s Ethernet
- A solution compatible with 400G Ethernet switch/router ports
  - QSFP-DD/OSFP form factor
  - 400GAUI electrical interface
- Single wavelength
- Reach of at least 80km over a DWDM system
  - Black link is assumed approach (to enable end user deployment flexibility)
- ≥16 Tb/s per fiber
- Multi-vendor interop



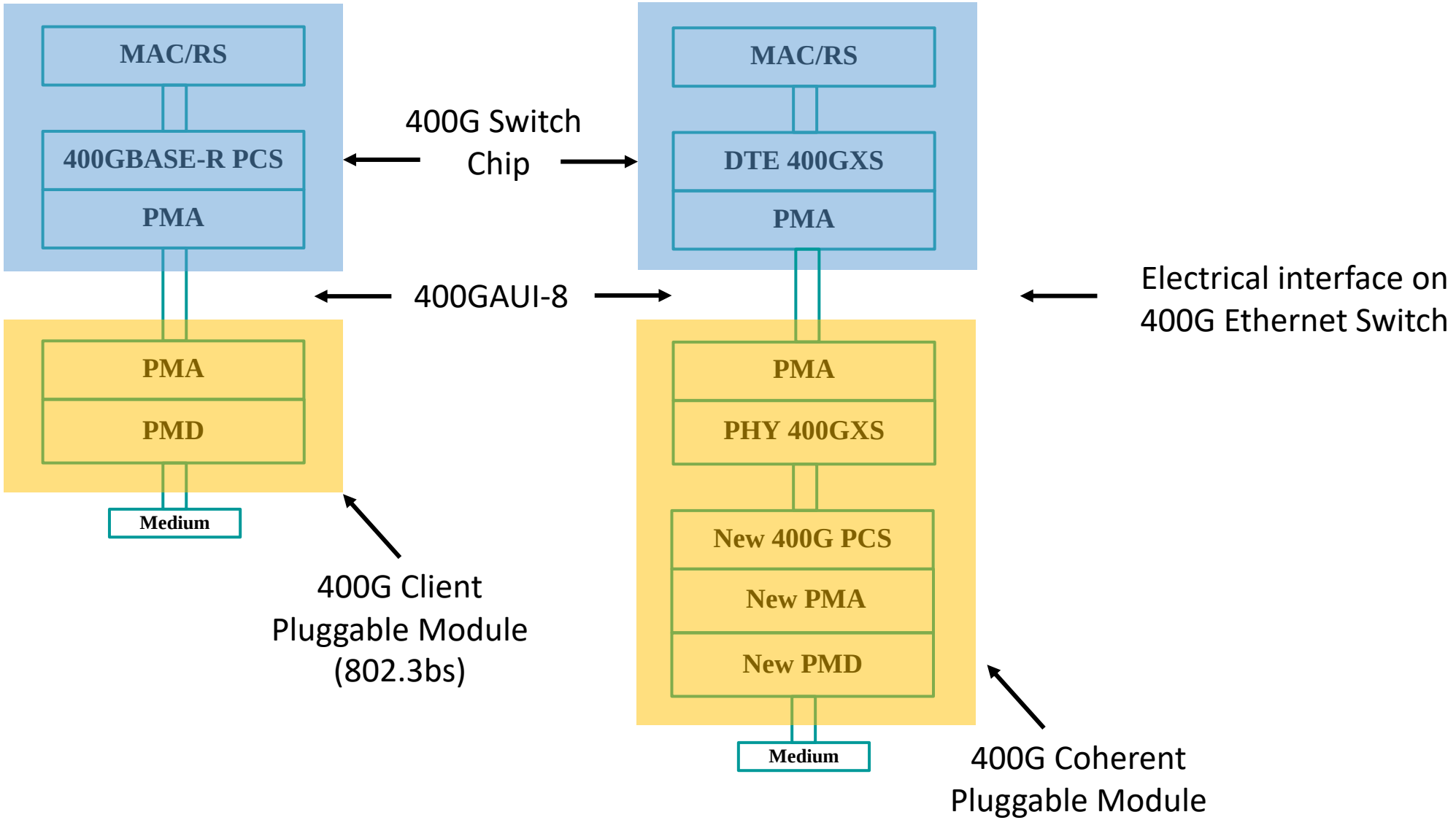
# 400GbE Extender Sublayer Recap



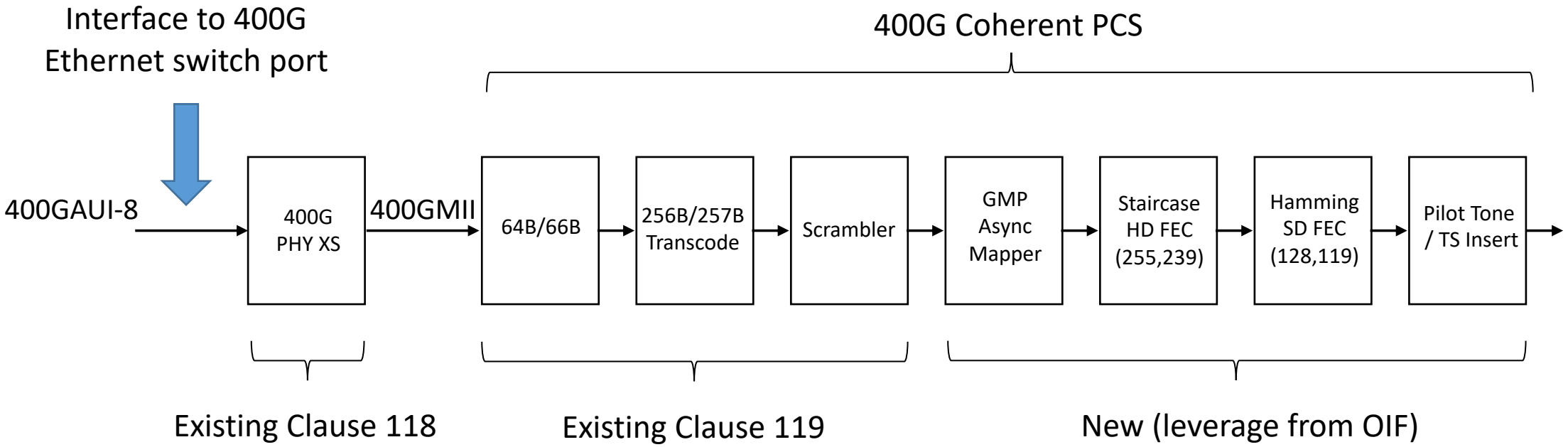

- 400GXS (Extender Sublayer) extends the 400GMII over a physically instantiated 400GAUI-n
- 400GXS is defined in IEEE P802.3bs Clause 118
- The 400GXS allows a new 400G PHY (with different line coding/FEC) to interface to an existing 400G switch port/ASIC over the 400GAUI
- 400G Coherent DWDM PHY is an example of a new 400G PHY that requires different coding/FEC

Extender sublayer enables a new 400G DWDM PHY to be plugged into a 400G Ethernet switch/router port

# 400GbE Extender Sublayer Implementation



# 400G Coherent PCS Overview



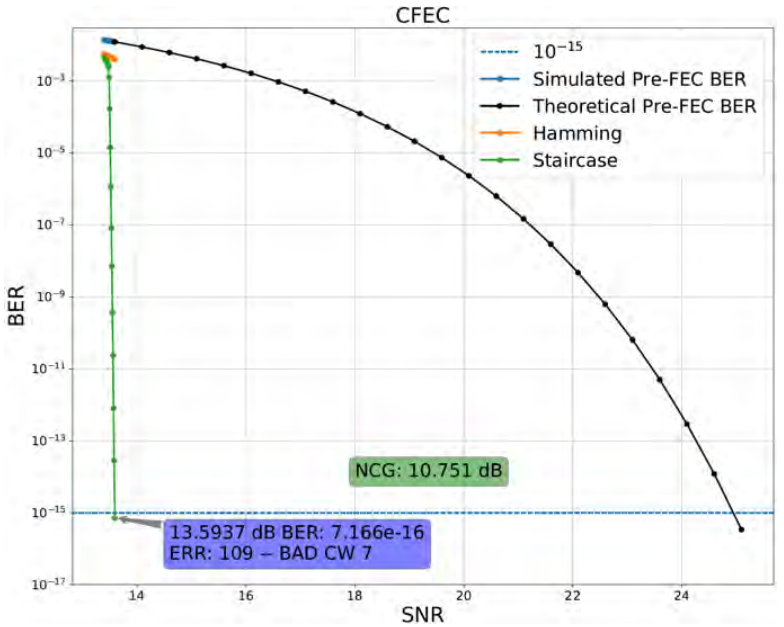

- 400G PHY XS provides the interface between new 400G Coherent PCS and an existing 400G Ethernet Switch port (i.e. 400GAUI-8 electrical interface)
- Reuse significant amount of 802.3bs PCS (Clause 119)
- Leverage FEC from OIF 400ZR project

# 400G Coherent FEC

Strong industry consensus already exists for a multi-vendor FEC for 400G coherent applications, and it is currently under development in the OIF as part of the 400ZR project.

400G Concatenated FEC:

- Soft decision inner – Hamming (128,119) Code
- Hard decision outer – Staircase Code (255,239)
- NCG = 10.8dB for 16QAM
- FEC overhead = 14.8 %
- Ultra Low Power = 420 mW (7nm, 400G)
- Burst Tolerance = 1024 bits, including random errors from background noise (more than 2048 bits without background noise)
- Latency = 4us




Source Inphi

# 400G Coherent Technical Feasibility

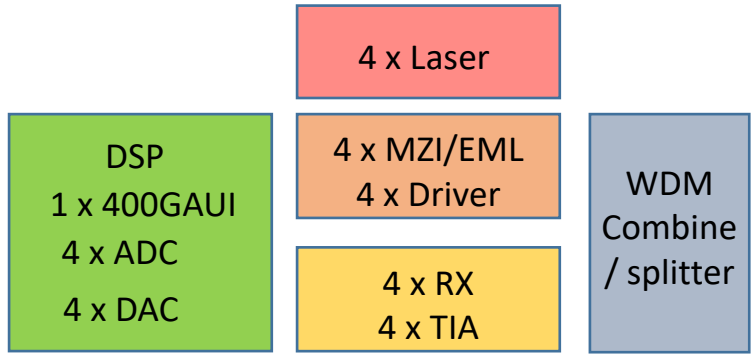
- **Product Availability**
  - 400G coherent shipping today
  - Multiple 400G+ coherent product announcements at OFC 2018
    - Components
    - Modules
    - Systems
- **Standards Activity**
  - 400G industry standardization activities
    - OIF
      - 400ZR
      - CFP2-DCO supporting 400G

# Economic Feasibility

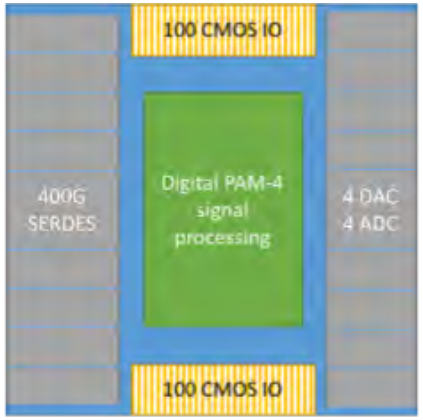
- Traditionally long haul transmission technology has been higher power, higher cost and physically larger, than corresponding client interface technology
- With the combination of reduced reach targets (80km) and advanced CMOS technology nodes (7nm), both coherent and client technologies can be implemented in the same form factors
- Economically this significantly lowers network cost and increases flexibility

# Comparing 400G Coherent with 400G Client

**400G FR4:** PAM4 on 4 wavelengths

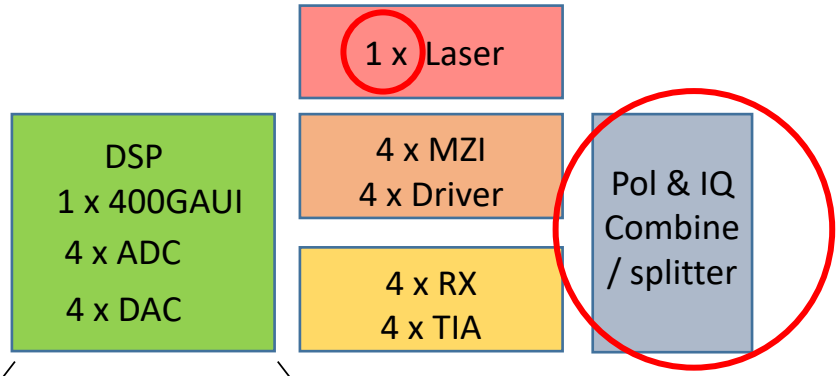



Client DSP

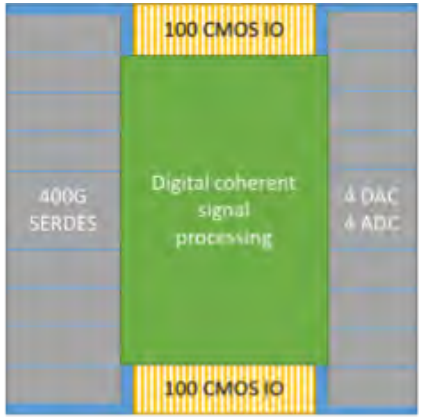



- Similar size die (pad limited)
- > 50% of power consumption is in ADC/DAC and SERDES

**400G Coherent:** "PAM4" on XI, XQ, YI, YQ




Coherent DSP

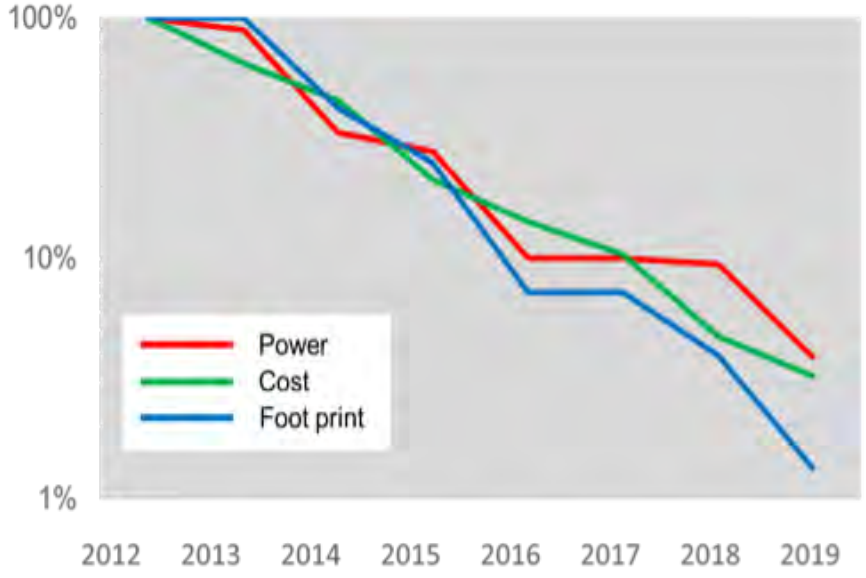


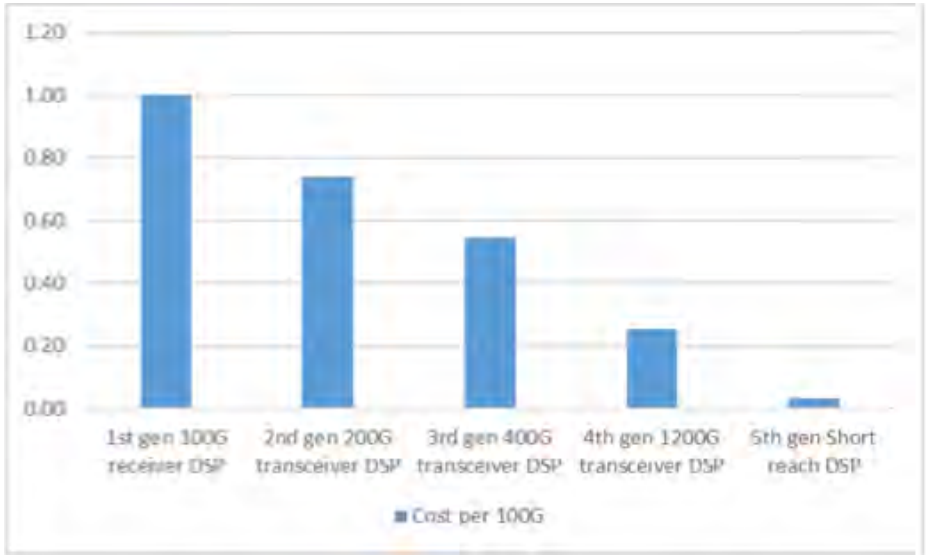

Source Acacia

Both coherent and client interfaces feasible in same form factor

# Impact of advanced integration

- Advances in CMOS and optical integration have driven reductions in size, cost and power for coherent solutions




Source Acacia

# Summary

- Market need for 400 Gb/s Ethernet DWDM solutions up to 80km has been identified
- Coherent technology for 400 Gb/s long-haul and metro applications exists and is being deployed, suggesting IEEE 802.3 specifications for 80km links are feasible
- Current industry activities and consensus will enable interoperable specifications be developed
- Clear use case identified for proposed SG objective

# Proposed Objective

Propose the SG adopts an objective:

- Provide physical layer specifications supporting 400 Gb/s operation on a single wavelength capable of at least 80km over a DWDM system.

# Companion objectives

Associated with the proposed PHY objective, the SG would also need the related objectives to be adopted:

- Support  a MAC data rate of 400 Gb/s
- Support a BER of better than or equal to 10^-13 at the MAC/PLS service interface (or the frame loss ratio equivalent) for 400 Gb/s

Assumption is these would be all included together in same motion

# Backup

# DWDM terminology recap

# Updated terminology (from 2/27/18 ad hoc)

- **WDM** – optical technology that couples more than one wavelength in the same fiber, thus effectively increasing the aggregate bandwidth per fiber to the sum of the bit rates of each wavelength.
- **DWDM** – A WDM technology where the frequency spacing is less than or equal to 1000 GHz.
- **DWDM PHY**: An Ethernet PHY that operates at a single wavelength on a defined frequency grid and is capable of running over a DWDM system.
- **DWDM Channel**: The transmission path between a DWDM PHY transmitting to another DWDM PHY.
- **DWDM Link**: One DWDM PHY transmitting to one other DWDM PHY through the transmission path between them.
- **DWDM System**: An aggregate of DWDM links over either a single optical fiber or a single optical fiber per direction.
- **DWDM Network** - same as DWDM System so term not to be used
- **In-line amplification:** Optical amplification that resides within a DWDM Channel

**Modified/New from ad hoc** **Proposed Delete**

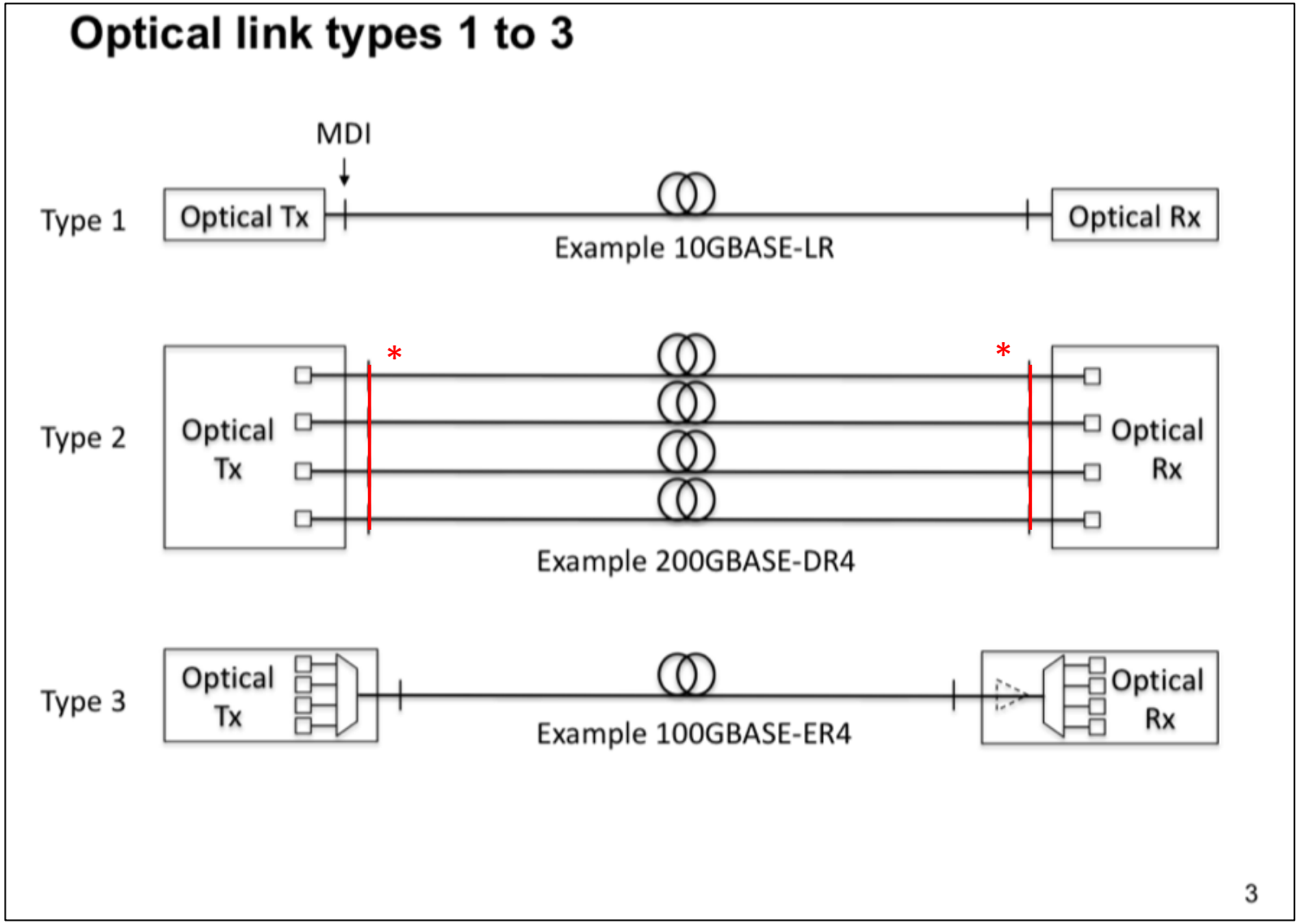
# Link Types

Presented by Pete Anslow.

Excellent summary of link type configurations.

Type 1, 2, 3 all represent what would be typical of past IEEE 802.3 PMDs

Common usage would call these “Optical PHYs” as opposed to “Electrical PHYs” and different to the “DWDM PHY” which could be the outcome of the proposed objective in this presentation.



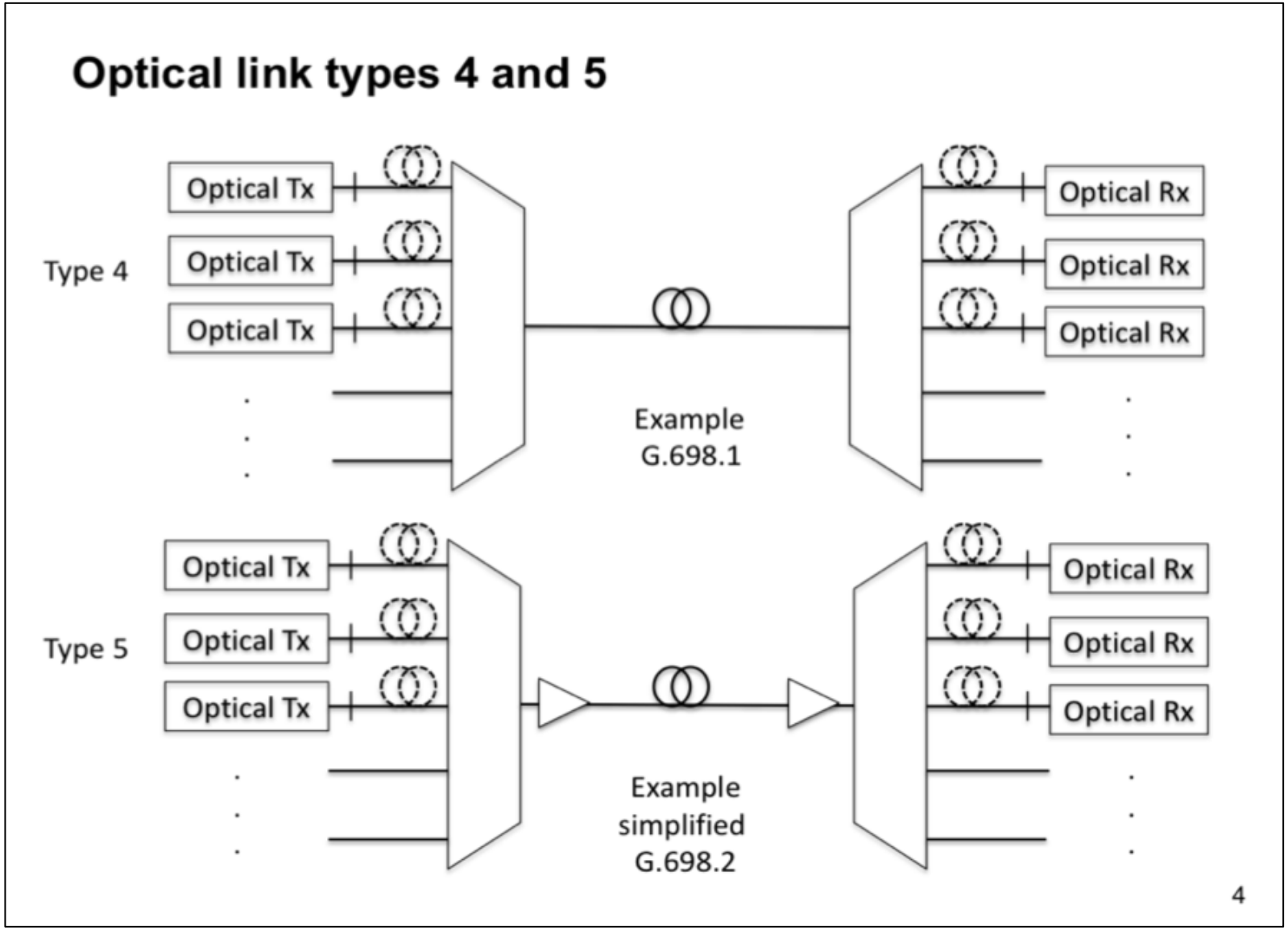

http://www.ieee802.org/3/B10K/public/18_01/anslow_b10k_01_0118.pdf

* Proposed modification to slides

# Link Types

Link Types 4 & 5 are representative of network topologies consistent with DWDM Systems and technologies.

The range of DCI deployments are consistent with both Type 4 & 5 link types

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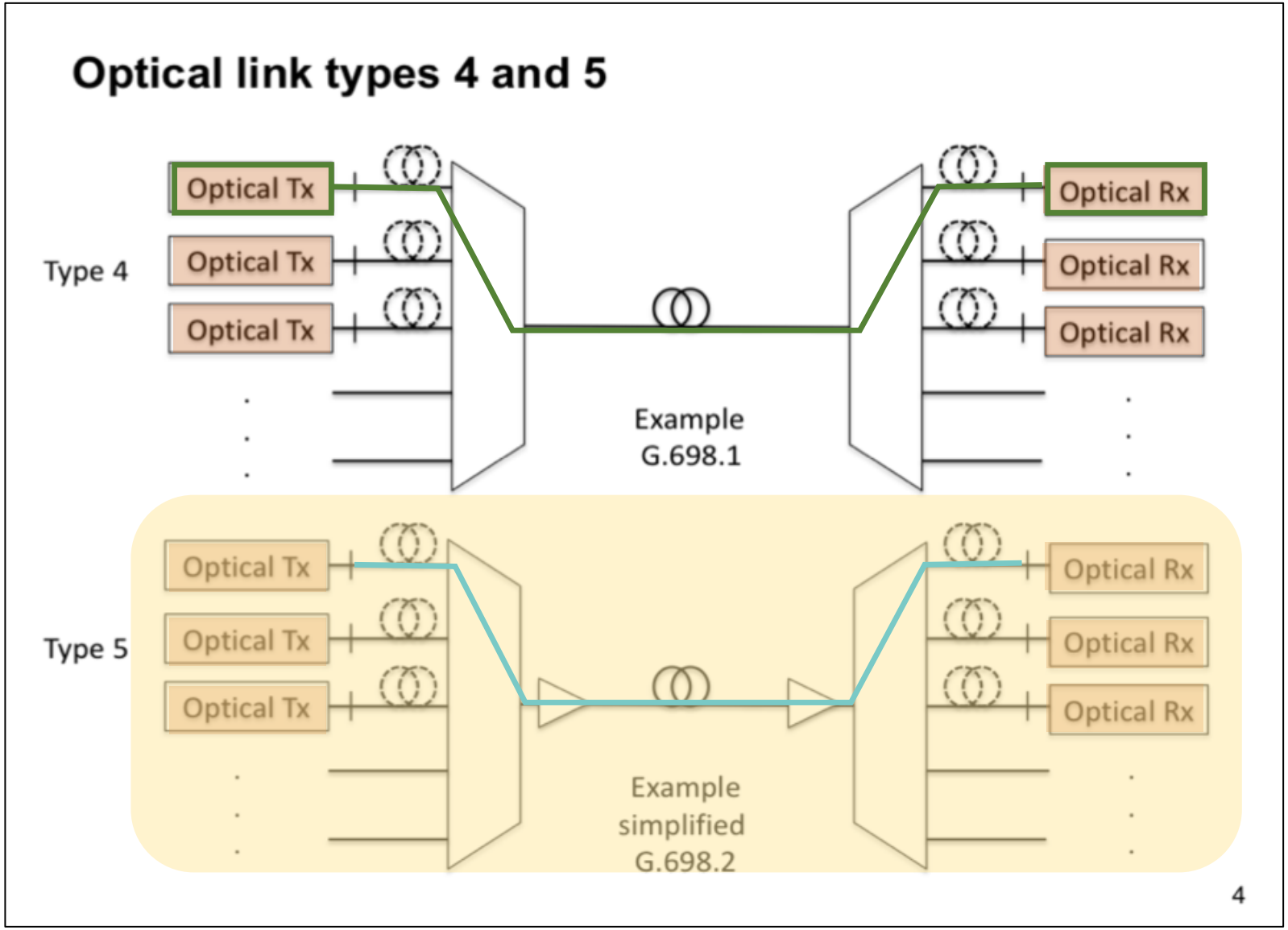
# DWDM Link Types and Terminology

DWDM PHY:

DWDM Channel:

DWDM Link:

DWDM System:




http://www.ieee802.org/3/B10K/public/18_01/anslow_b10k_01_0118.pdf

# Coherent optical DWDM technology overview

# Coherent DWDM Overview

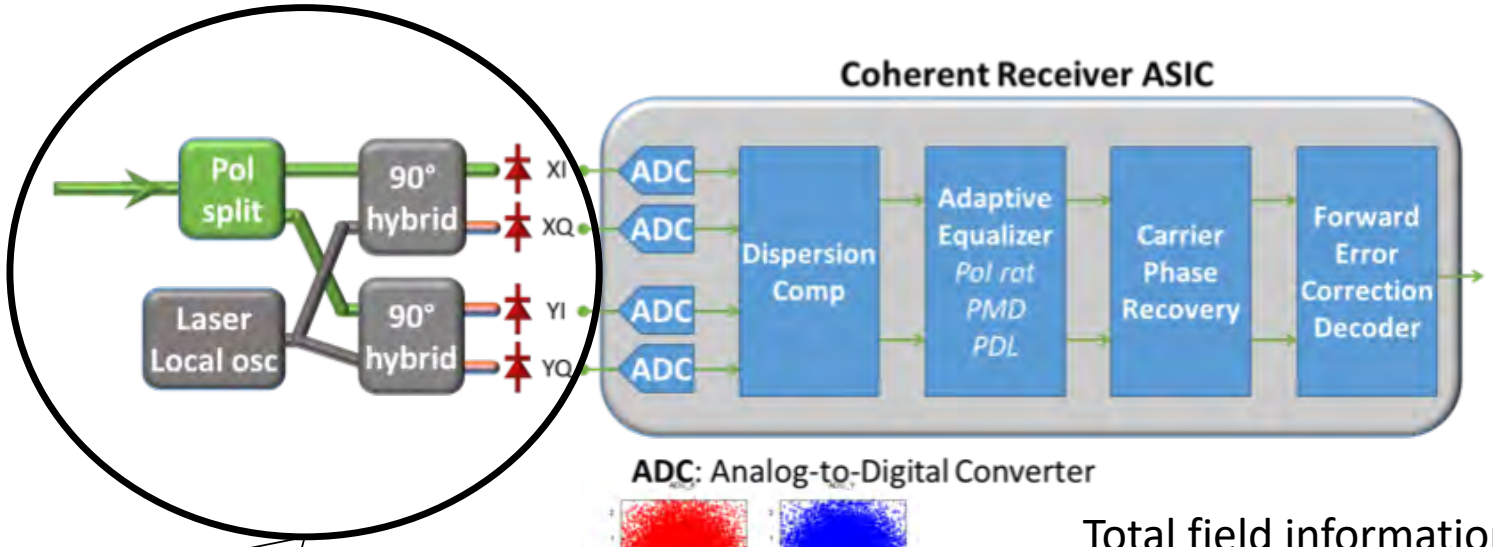
- Coherent optical technology was significantly studied and researched from the mid-80's due to it's potential to overcome optical fiber transmission challenges that exist with the direct-detection approaches.
- Invention of Erbium optical amplifier, stalled progress for a while
- Above 10 Gb/s, direct detection transmission was becoming a challenging solution to achieve
- Mid-2000's, intersection of CMOS and optical technology capabilities opened possibility that a coherent-detection solution was feasible for 40 Gb/s
- March 2008, Nortel (Ciena) announce first commercial transmission system @ 40 Gb/s
- Today, coherent-based transport is now the de-facto standard technology choice for transmission solutions @ 40 Gb/s, 100 Gb/s, 250 Gb/s, 400 Gb/s and beyond
  - Widespread & mature technology
  - Originally targeted for Long-haul and Ultra-long haul solutions, recent market focus includes metro and lower reach optimizations

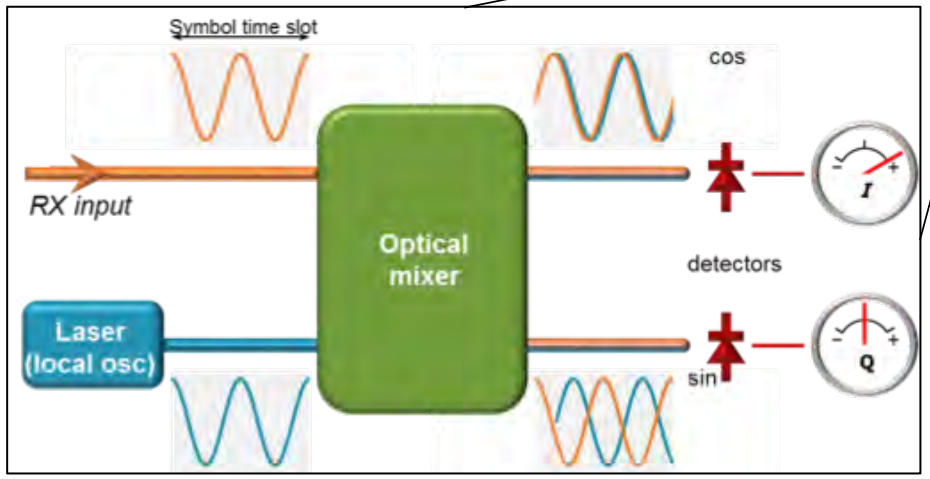
# Key points:  Coherent vs. direct detection

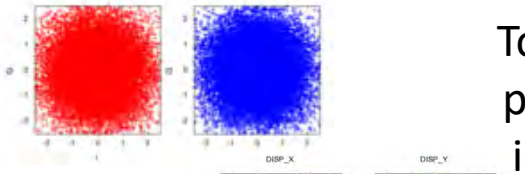
- Coherent transceivers use linear E/O & O/E conversion
  - Use of local oscillator at receiver ensures full optical field (amplitude and phase) survives after the photodetector
  - Enables more complex modulation schemes to be employed to increase capacity
- Linear optical distortions remain linear.
- Digital Signal Processing may then be used to compensate the channel / transceiver
- Complexity / constraints of DSP depends upon application
  - Wide range of optical impairments can be compensated in the DSP
  - Simplifies operational issues
  - Complexity shared between optical and digital technologies

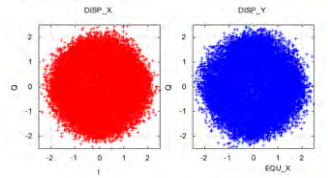
# What is Coherent Detection?

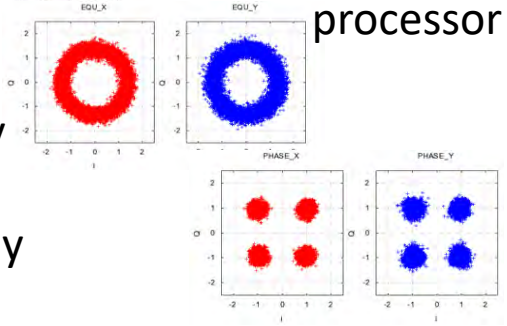
By mixing with a local oscillator, the received optical signal is down-converted to baseband and sampled with a high speed ADC







Total field information (amplitude, phase, polarization) is maintained into the electrical/digital domain enabling equalization of link impairments by a digital signal processor (DSP)

Coherent detection requires the addition of a local oscillator (usually shared with transmit laser) and additional DSP processing. Effectively amplifies the incoming signal

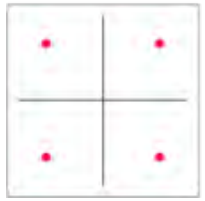
# How Does Coherent Increase Capacity?

Modulation in Phase and Amplitude

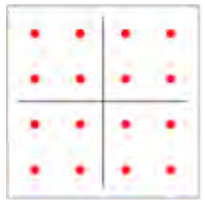
Capacity

Performance

BPSK
2 (=$2^1$) states: 1 bit pr symbol ("time slot")
Modulating Signal – 1 NRZ



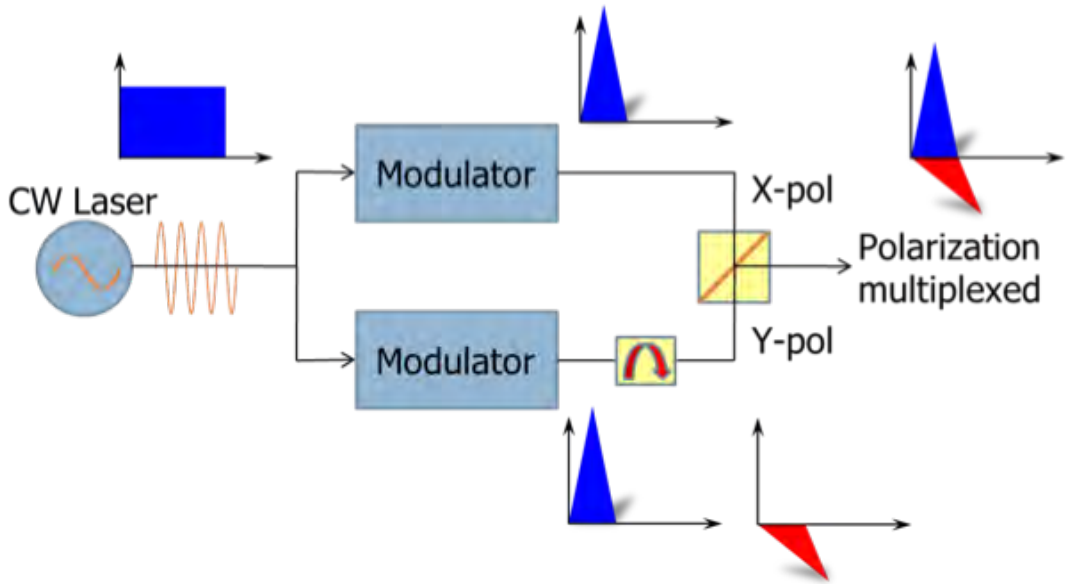
QPSK
4 (=$2^2$) states: 2 bit pr symbol ("time slot")
Modulating Signal – 2 NRZ (I/Q)



16QAM
16 (=$2^4$) states: 4 bit pr symbol ("time slot")
Modulating Signal – 2 PAM4 (I/Q)

**2x capacity of intensity modulation**

Polarization Multiplexing




**2x capacity of single polarization**

# Coherent DWDM Applications

Proven Applications

| Aspect | Cable/MSO/ Data Center | Metro | Regional | Long-Haul | Submarine |
|---|---|---|---|---|---|
| Reach (km) | 80 | 300 | 600 | 4000 | 10000 |
| Chromatic Dispersion (ps/nm) | 1280 | 5000 | 15000 | 80000 | 240000 |
| DGD max (ps) | 16 | 30 | 43 | 111 | 35 |
| Latency (Critical?) | Yes | Sometimes | Less so | Not so | Not really |
| OSNR/FEC | Low Perf. | Hi-perf | Hi-perf | Hi-perf | Hi-perf |
| Cost | Low | Low | Mid | Mid | High |
| Power | Ultra low | Low | Mid | Mid | Mid |