Towards an objective for 100 Gb/s for MSO applications

Mark Nowell - Cisco
Tom Williams – Acacia
Ilya Lyubomirsky – Inphi
Gary Nicholl – Cisco
Fernando Villarruel – Cisco
Matthew Schmitt - CableLabs

Supporters

- Jorg-Peter Elbers, Adva
- Christophe Metivier, Arista
- Rob Stone, Broadcom
- Alberto Campos, CableLabs
- Curtis Knittle, CableLabs
- Marek Hajduczenia, Charter
- Phillip Chang, Comcast
- Phil Miguelez, Comcast
- Jeff Finkelstein, Cox
- Ralf-Peter Braun, Deutsche Telekom
- Fabio Cavaliere, Ericsson
- Stephane Lessard, Ericsson
- Antonio Tartaglia, Ericsson
- Vipul Bhatt, Finisar
- Shawn Esser, Finisar
- Akinori Hayakawa, Fujitsu Labs
- Tomoo Takahara, Fujitsu Labs
- Hideki Isono, Fujitsu Optical Components
- Frank Chang, Inphi
- Martin Kuhlmann, Inphi
- Hai-Feng Liu, Intel
- Scott Schube, Intel
- Jeffery Maki, Juniper
- David Ofelt, Juniper
- Karen Liu, Kaiam
- Thananya Baldwin, Keysight
- Jerry Pepper, Keysight
- Justin Abbott, Lumentum
- David Lewis, Lumentum
- Matt Brown, Macom
- Ray Maroney, Macom
- Sridhar Ramesh, Maxlinear
- Bird (Huei-Chun) Yuan, Maxlinear
- Brad Booth, Microsoft
- Mizuki Shirao, Mitsubishi Electric Corporation
- Keisuke Kojima, Mitsubishi Electric Research Laboratories
- Tom Palkert, Molex
- Scott Sommers, Molex
- Ryan Yu, Molex
- Winston Way, Neophotonics
- Samuel Liu, Nokia
- David Malicoat, SENKO
- Ed Ulrichs, Source Photonics
- Kenneth Jackson, Sumitomo
- Nathan Tracy, TE
- Paul Brooks, Viavi
- Mark Gustlin, Xilinx
- James Chien, ZTE

Topics

- Background
- Terminology recap
- Coherent optical technology overview
- Proposed Objective

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.
  - http://www.ieee802.org/3/B10K/100GbE-Beyond10km_CFI_D-final2.pdf
  - http://www.ieee802.org/3/B10K/public/17_09/villarruel_b10k_01b_0917.pdf
  - http://www.ieee802.org/3/B10K/public/18_01/nicholl_b10k_01a_0118.pdf
  - http://www.ieee802.org/3/B10K/public/18_01/knittle_b10k_01_0118.pdf
- The intent of this presentation is to foster a better understanding of this application, technology options and associated terminology, with the ultimate goal of defining an objective for such a PHY.

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**

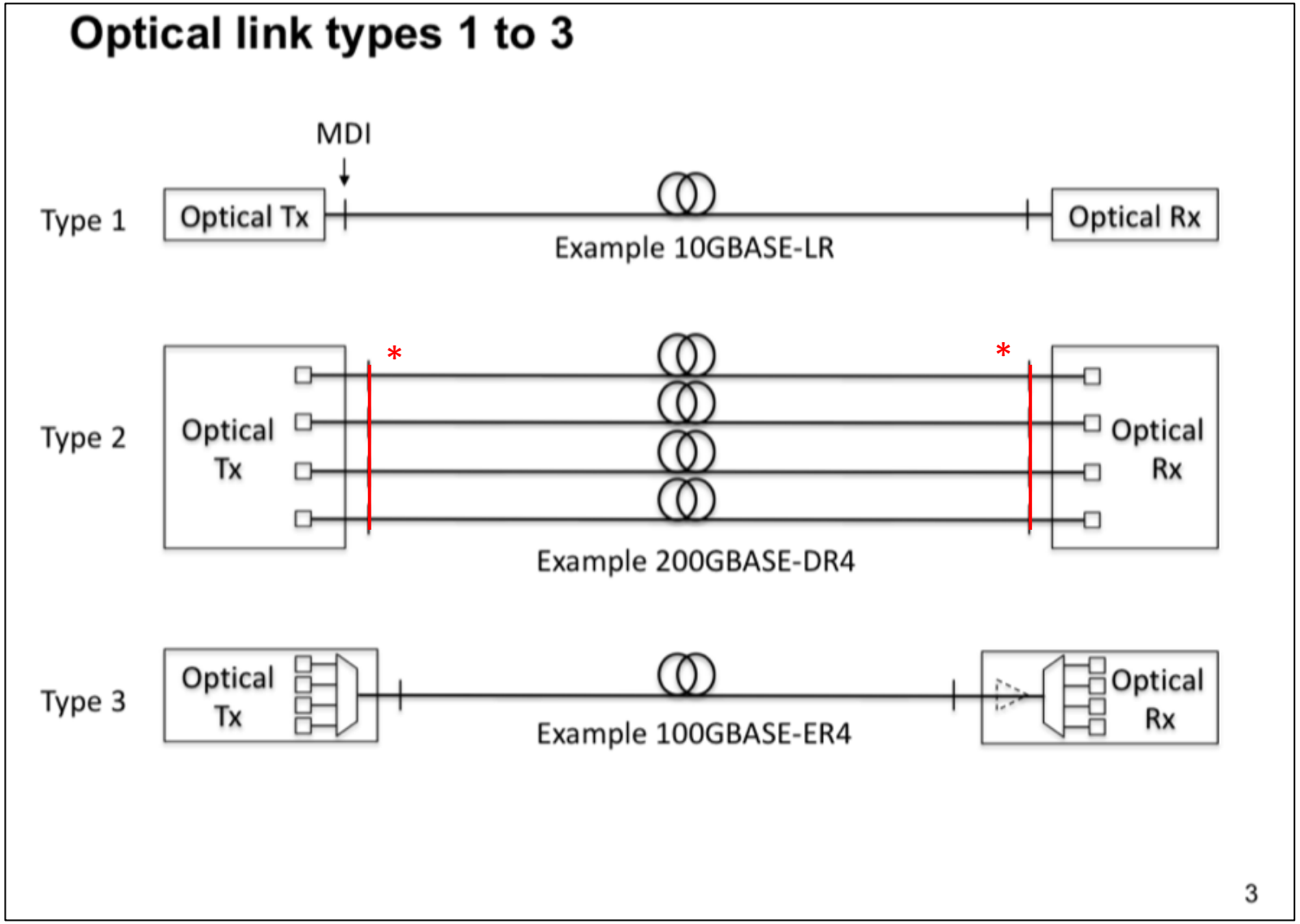
Link Types

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.



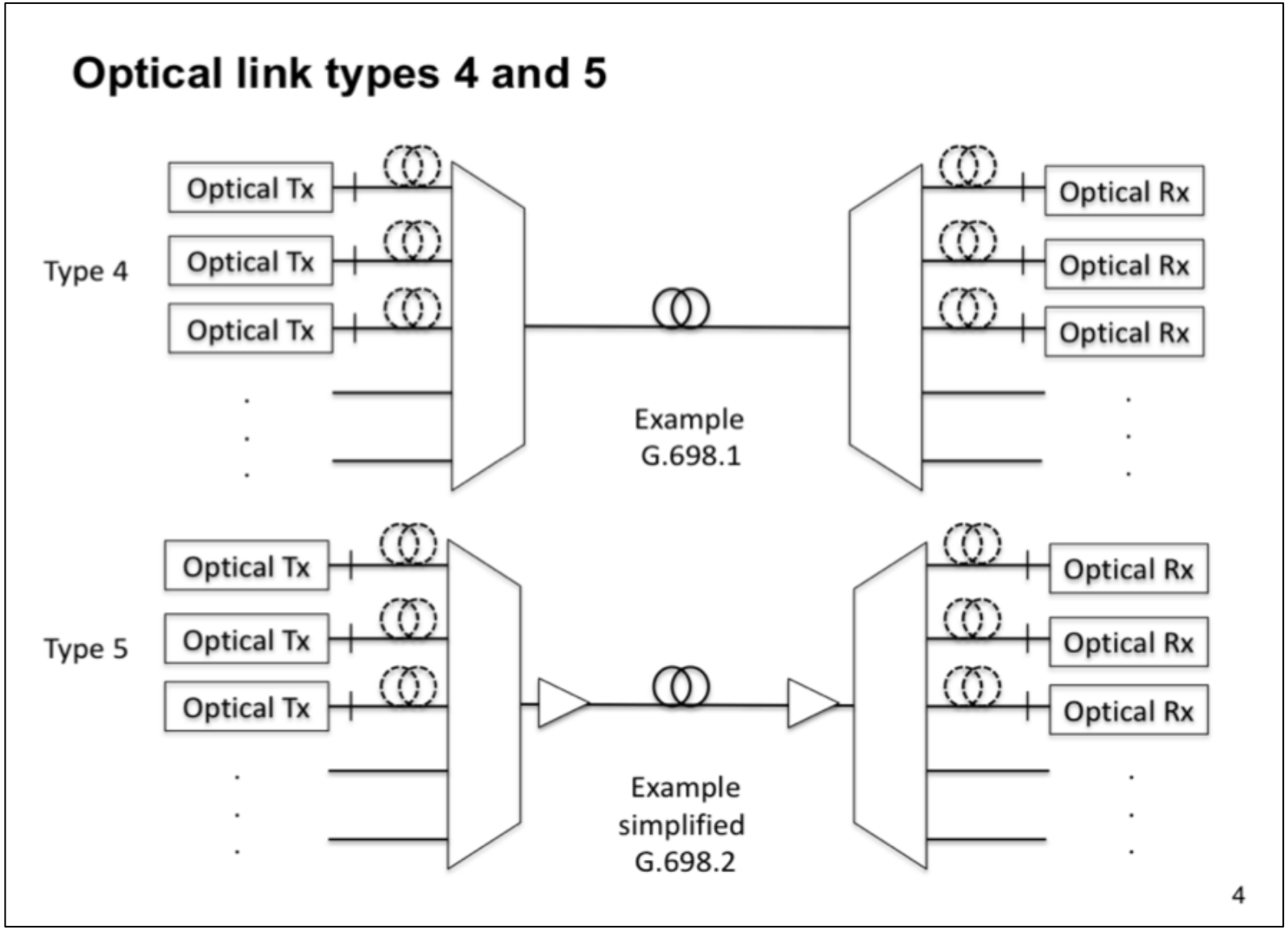
http://www.ieee802.org/3/B10K/public/18_01/anslow_b10k_01_0118.pdf

* Proposed modification to slides

Link Types

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

The range of Cable/MSO deployments are consistent with both Type 4 & 5 link types



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

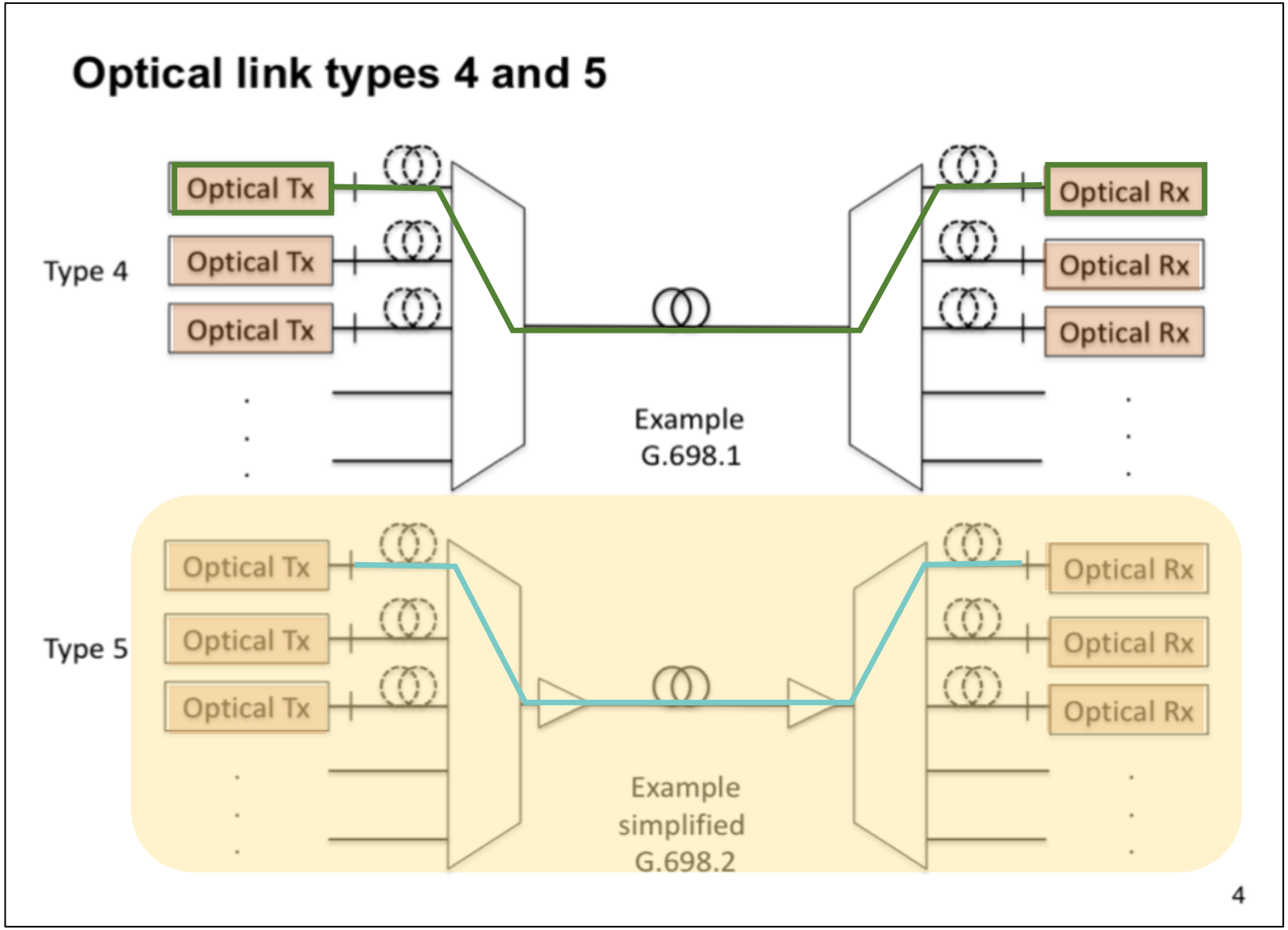
DWDM Link Types and Terminology

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

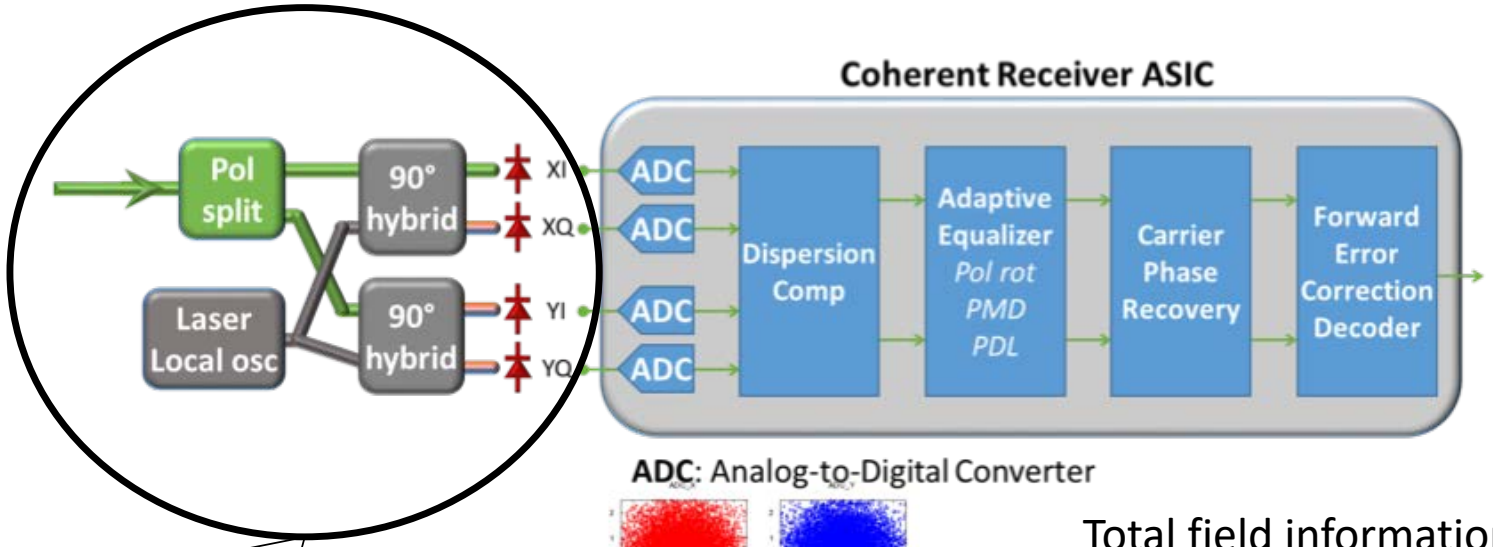
- Coherent optical technology was significantly studied and researched from the mid-80's due to it's potential to overcome optical fiber transmission challenges that exist with the direct-detection approaches.
- Invention of Erbium optical amplifier, stalled progress for a while
- Above 10 Gb/s, direct 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

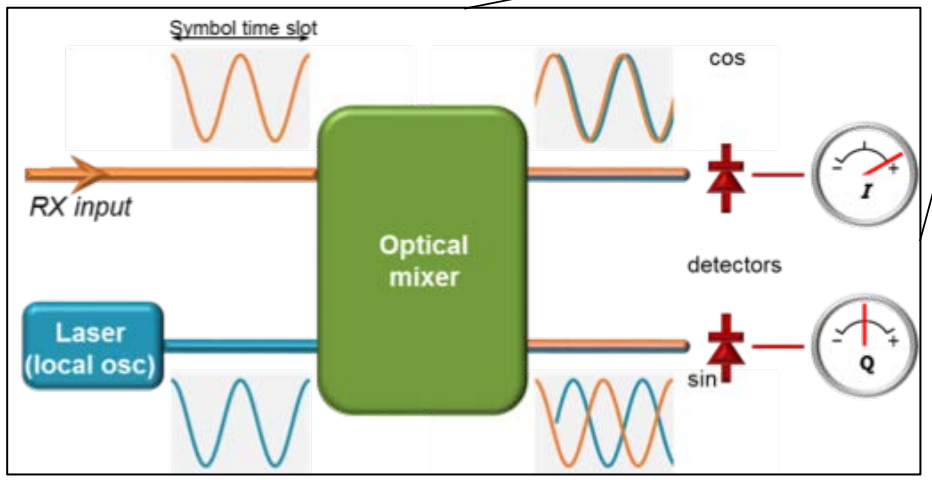
Key points: Coherent vs. direct detection

- 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

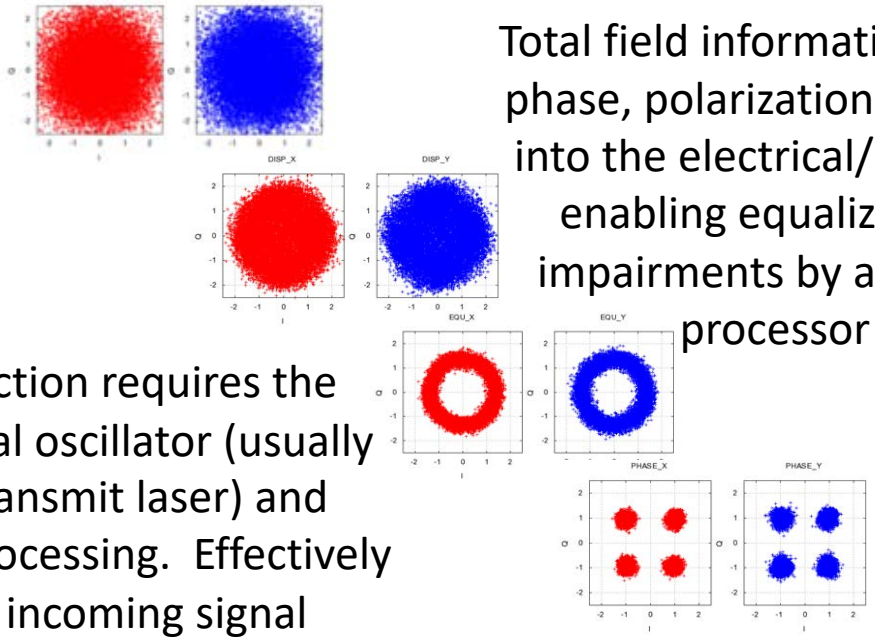
What is Coherent Detection?

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





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



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

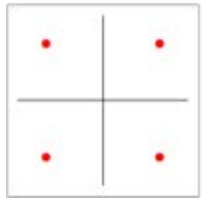
How Does Coherent Increase Capacity?

Modulation in Phase and Amplitude

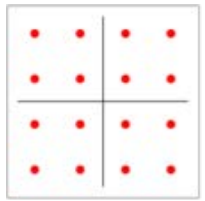
Capacity

Performance

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



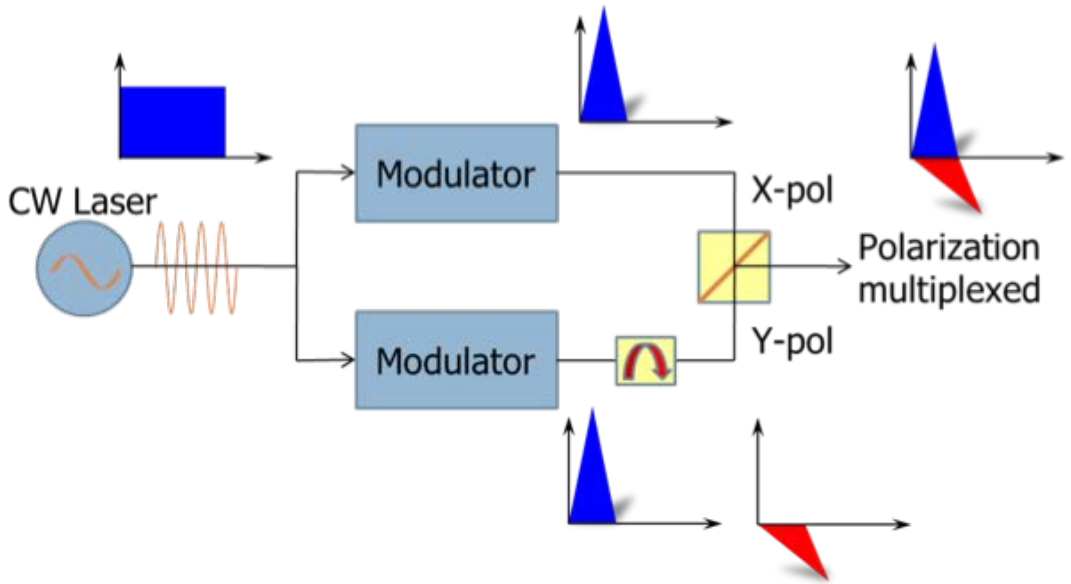
QPSK
4 (=2^2) states: 2 bit pr symbol ("time slot")
Modulating Signal – 2 NRZ (I/Q)



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

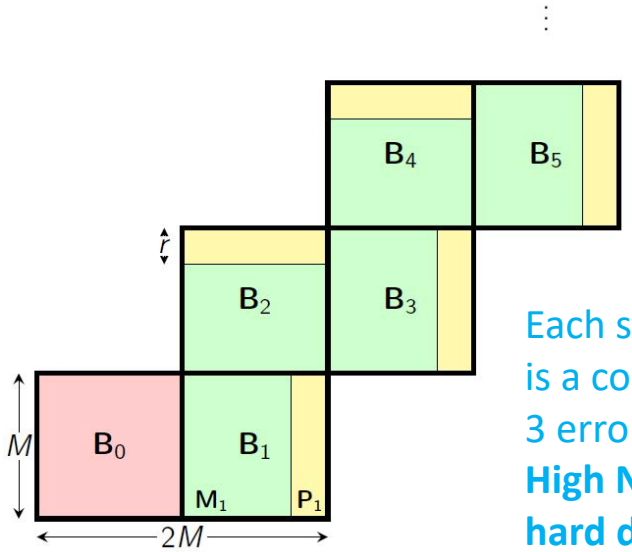
2x capacity of intensity modulation

Polarization Multiplexing

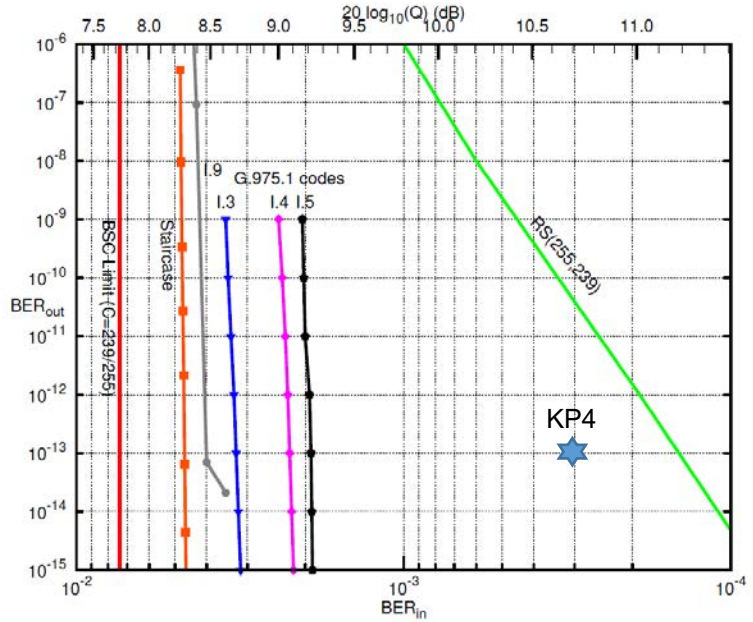


2x capacity of single polarization

Staircase FEC – Strong Industry consensus for 100 Gb/s



Each staircase row/column is a codeword of a simple 3 error correcting BCH code.
High NCG with low power hard decision decoding.



Staircase FEC:

- widely used and deployed for 100G coherent metro
- multi-vendor interop has already been demonstrated
- adopted by ITU as base of the 100G coherent optical specs being finalized in G.698.2 revision

ITU 512×510 Staircase code specs for 100G QPSK:

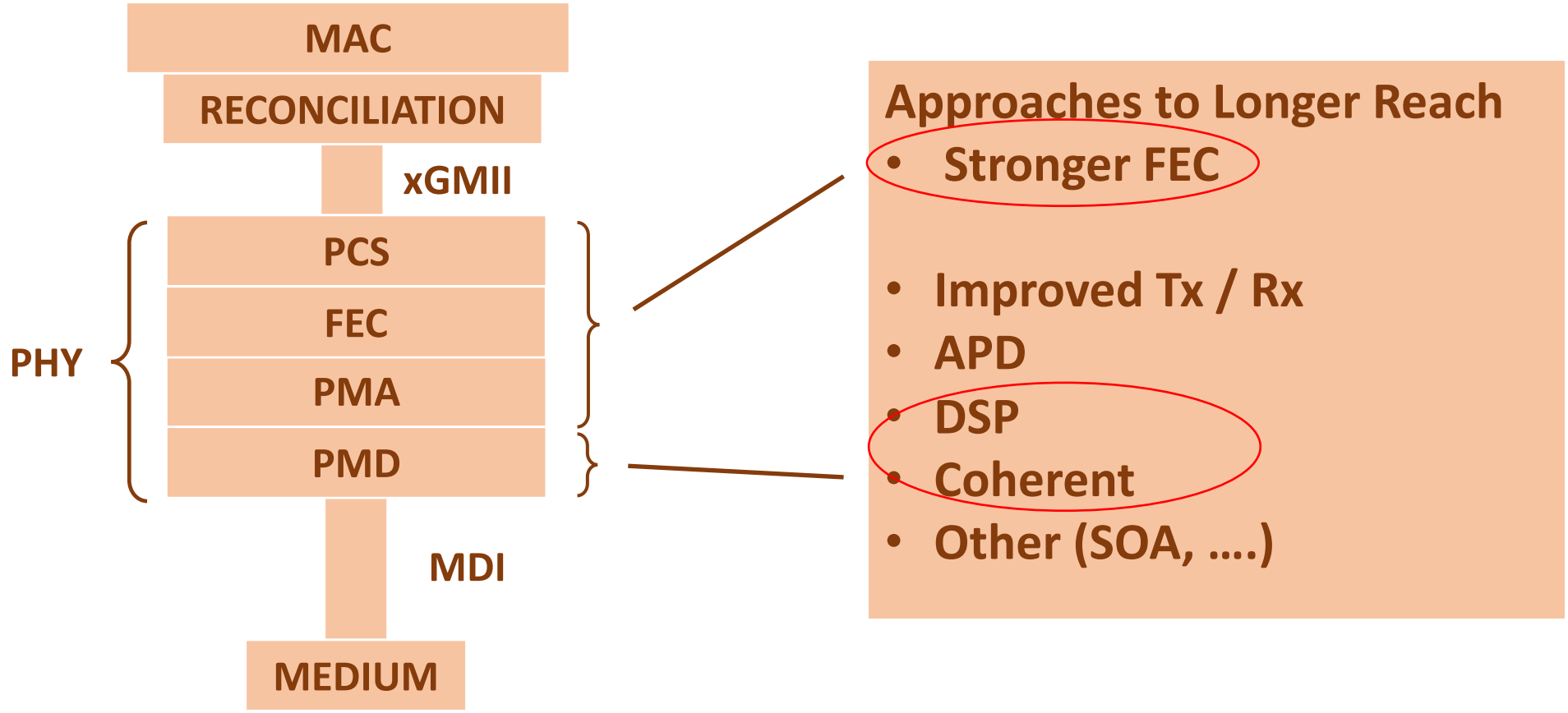
- Net Coding Gain (NCG) = 9.38 dB at output BER=1.e-15
- Input BER threshold = 4.5e-3
- Overhead = 6.7%
- Latency ~ 7 × 512×510 = 1,827,840 bits
- Burst error tolerance = 1538 bits if there are no additional random or correlated errors (400 bits with random errors at BER = 4e-3 and correlated errors from diff. decoding)
- Power ~ 2.5 * KP4 FEC Power

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

An Ethernet Perspective of the solution



http://www.ieee802.org/3/B10K/100GbE-Beyond10km_CFI_D-final2.pdf

Towards the proposed objective

802.3 adoption of DWDM objectives

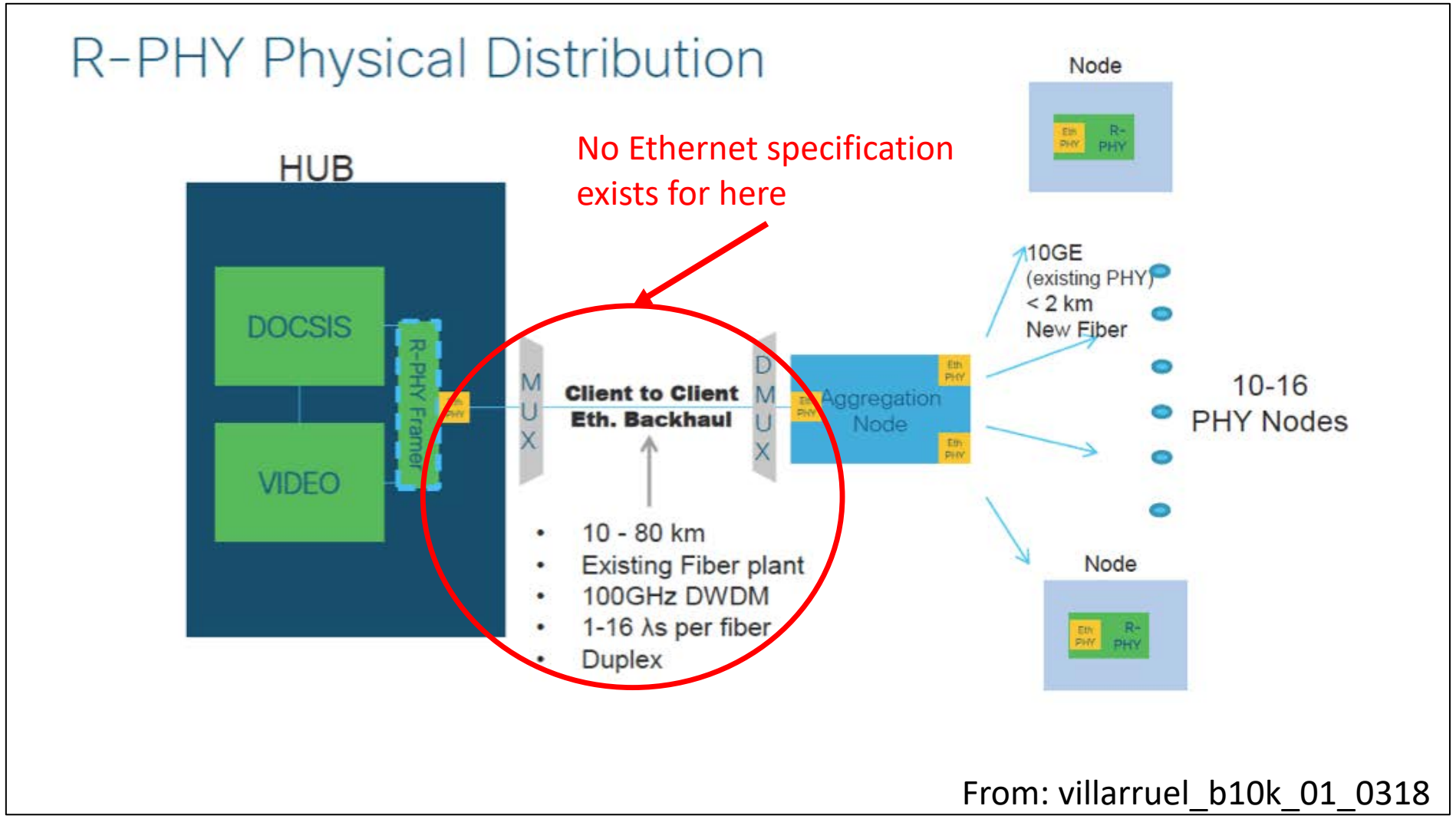
Market need

- Cable/MSO industry is architecting their next gen Distributed Access Architecture to run over Ethernet PHYs
  - Require DWDM PHY up to 80km over existing installed DWDM infrastructure
    - http://www.ieee802.org/3/B10K/public/adhoc/18_0220/villarruel_b10k_01a_180220.pdf
- More than just Cable/MSO
  - Mobile backhaul (non-China) identified as target market for 5G deployments.
  - LightCounting market analysis indicates > 40km market is growing faster than 40km market
    - http://www.ieee802.org/3/B10K/100GbE-Beyond10km_CFI_D-final2.pdf

Technology leverage

- ITU-T G698.2 revision underway that specifies compliance methodologies that can be leveraged which are necessary to define interoperable specifications
  - http://www.ieee802.org/3/B10K/public/17_11/stassar_b10k_01a_1117.pdf
- Existing industry consensus on preferred 100 Gb/s FEC solution

Proposed DWDM Objective



Summary

- Market need for 100 Gb/s Ethernet DWDM solutions up to 80km has been identified
- Widely adopted and mature technology for 100 Gb/s long-haul and metro applications exists, suggesting IEEE 802.3 specifications for 80km links are feasible
- Current industry activities and consensus will enable interoperable specifications be developed
- (Hopefully) clear use case identified for proposed SG objective

Proposed Objective

With the assumptions covered in this presentation:

Propose the SG adopts an objective:

- Provide physical layer specifications supporting 100 Gb/s operation on a single wavelength capable of at least 80km over a DWDM system.

Once adopted, Task Force will need to identify some representative DWDM Channels in order to define DWDM PHY specifications

- Same 802.3 methodology applied to other Optical and Electrical PHYs

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 100 Gb/s
- Support a BER of better than or equal to 10^-12 at the MAC/PLS service interface (or the frame loss ratio equivalent) for 100 Gb/s

Assumption is these would be all included together in same motion