Building Tomorrow's Networks

Session #1: New High-Speed and Long Reach Optical Interfaces

January 20, 2018

Introductions

- Panel Organizers
  - John D'Ambrosia (Futurewei), Acting Chair, IEEE 802.3 Beyond 10km Optical PHYs Study Group
  - Peter Stassar (Huawei), ITU-T Q6/15 Rapporteur
  - Pete Anslow (Ciena), ITU-T Q6/15 Associate Rapporteur

- Moderator: Pete Anslow
- Panelists
  - David Law – Chair, IEEE 802.3 Ethernet Working Group
  - Steve Trowbridge – Chairman, ITU-T Study Group 15
  - Jeffery Maki, Juniper Networks
  - Gary Nicholl, Cisco
  - Bernd Teichmann, Nokia

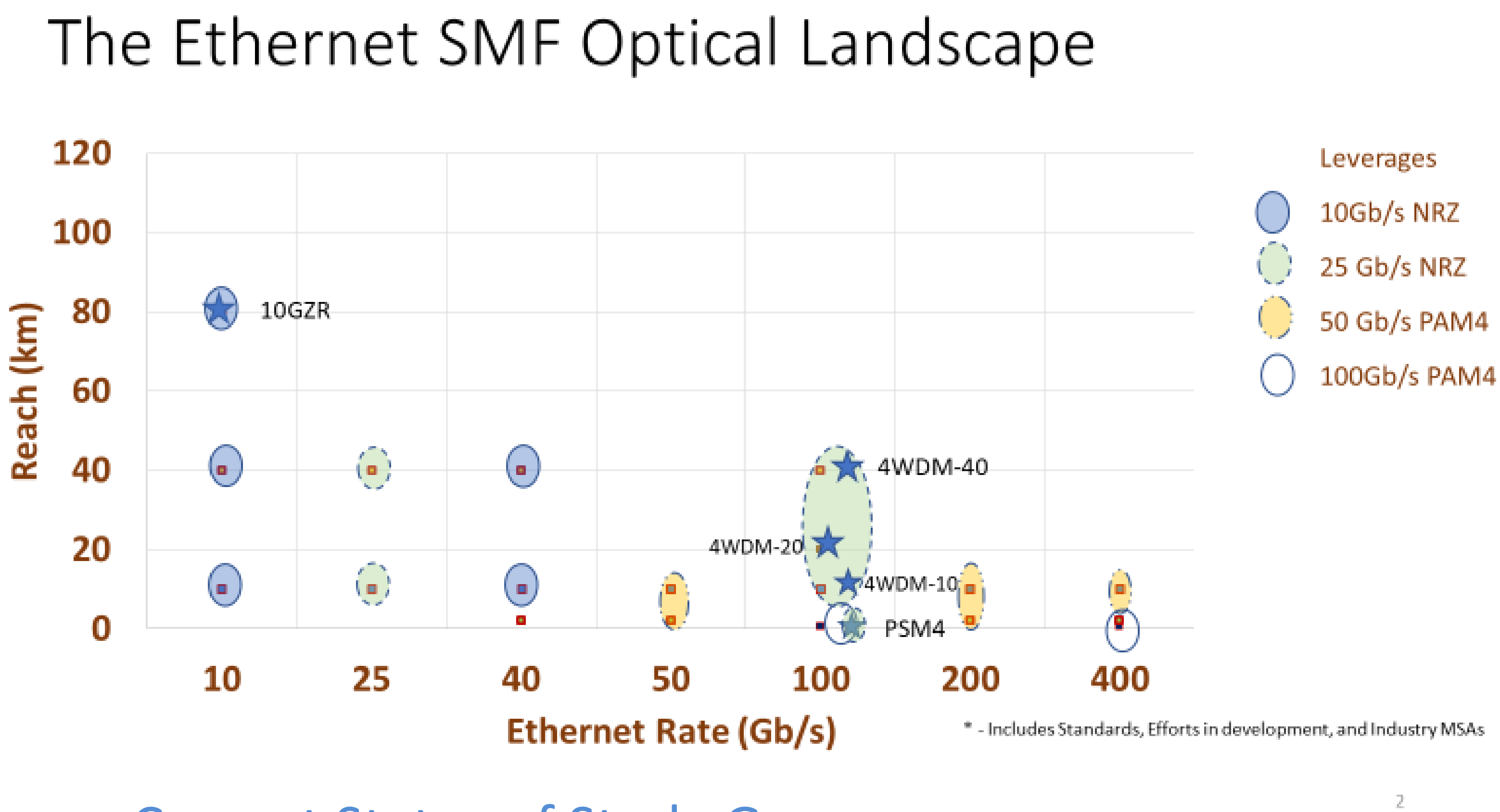
- Panel Goals
  - Clarify the characteristics of the network topologies that each respective group is seeking to define optical solutions to address.
  - Leverage knowledge between the two groups in understanding the technical challenges of the different network topologies.

Agenda

- Introductions –
  - IEEE 802.3 Beyond 10km Optical PHYs Study Group
  - IEEE 802.3 – David Law
  - ITU-T – Steve Trowbridge
- Presentations
  - Bernd Teichmann – ITU-T G.698.2
  - Gary Nicholl - MSO Application
  - Jeffery Maki – Industry Perspective – Standards (including OIF 400ZR) / Industry MSAs
- Discussion

Introduction

IEEE 802.3 Beyond 10km Optical PHYs Study Group

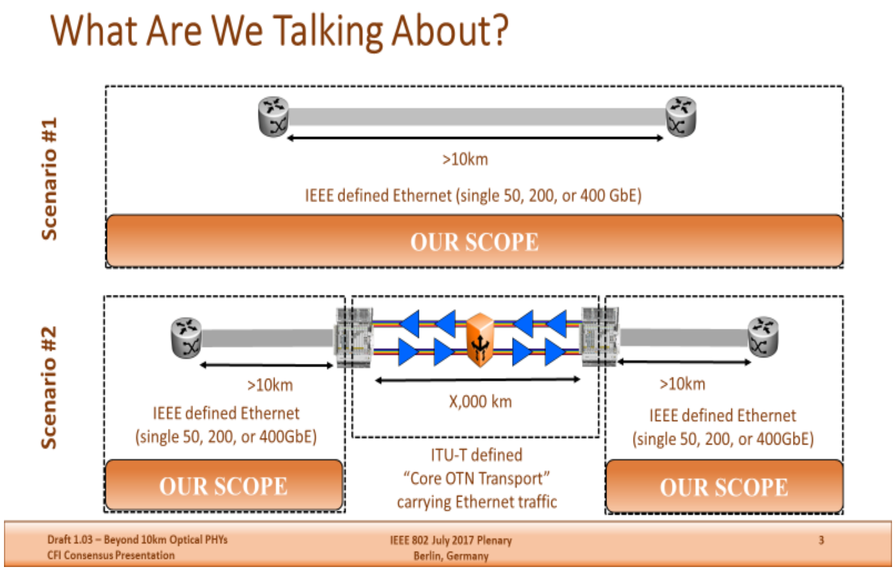


Current Status of Study Group

- Scope - Beyond 10km Optical PHYs for 50 Gb/s, 100 Gb/s, 200 Gb/s, and 400 Gb/s Ethernet
- 50 GbE for at least 40 km Adopted Reach Objective:

Introduction

IEEE 802.3 Beyond 10km Optical PHYs Study Group



Source – Beyond 10km July 2018 CFI - http://www.ieee802.org/3/cfi/0717_1/CFI_01_0717.pdf

Defining scope of IEEE 802.3 efforts in relation to ITU-T has been key

- "Beyond 10km" Study Group objectives proposal targeting MSOs included "appropriate support for DWDM systems"
- What does this mean to Beyond 10km Study Group , IEEE 802.3, and ITU-T?
- Simple diagram and common industry terminology causing confusion

IEEE 802.3 Ethernet

David Law
Chair, IEEE 802.3 Ethernet Working Group

IEEE 802.3 Ethernet WG Activities

- **Recently Ratified Standards**
  - IEEE 802.3bp 1000BASE-T1 — 2016
  - IEEE 802.3bq 25G/40G BASE-T — 2016
  - IEEE 802.3bu PoDL — 2016
  - IEEE 802.3bv GbE POF — 2017
  - IEEE 802.3by 25GbE — 2016
  - IEEE 802.3bz 2.5G/5GBASE-T — 2016
  - IEEE 802.3bs 200 GbE & 400 GbE — 2017
  - IEEE 802.3cc 25 GbE SMF — 2017
- **Task Forces in Process**
  - IEEE P802.3bt DTE Power via MDI over 4-Pair (PoE) — Sept 2018
  - IEEE P802.3ca 25GbE/50GbE/100GbE PON — Apr 2020
  - IEEE P802.3cb 2.5 Gb/s and 5 Gb/s Backplane — June 2018
  - IEEE P802.3cd 50GbE/100GbE/200GbE — Sept 2018
  - IEEE P802.3.2 (IEEE 802.3cf) YANG Data Model Definitions — June 2018
  - IEEE P802.3cg 10 Mb/s Single Twisted Pair Ethernet
  - IEEE P802.3ch Multi-Gig Automotive Ethernet PHY
- **Study Groups in Process**
  - Beyond 10km Optical PHYs (50Gb/s, 100Gb/s, 200Gb/s, and 400Gb/s Ethernet)
  - 100 Gb/s Electrical Interfaces and Electrical PHYs
  - 10 Mb/s Backplane Ethernet
  - Next-gen 200G & 400G PHYs for MMF

IEEE 802.3 / ITU-T Cooperation

- IEEE P802.3ae 10 Gb/s
  - LAN PHY
  - WAN PHY
- IEEE P802.3ba onward
  - "Provide appropriate support for OTN"

ITU-T Study Group 15

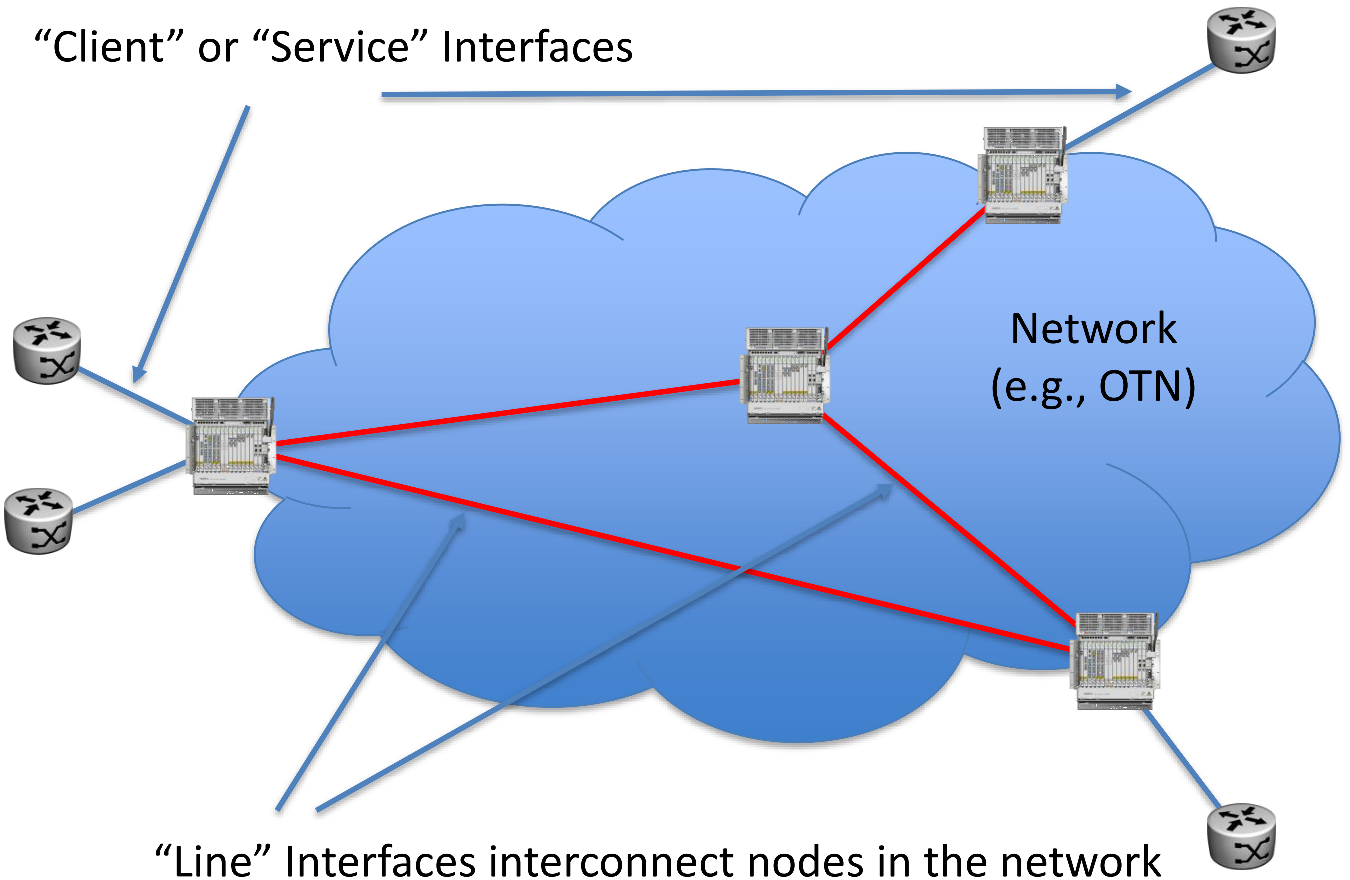
Optical Interface Specifications and relationship to IEEE 802.3

Steve Trowbridge
Chairman, ITU-T Study Group 15

Historical Distinction: "Client" vs. "Line" Interfaces

- "Client" Interfaces are interfaces like Ethernet or Fibre Channel to an end system or router – Many are specified outside of ITU-T
  - Typically a point-to-point link carrying a single service over a dedicated cable or medium
  - Relatively modest reach (e.g., 2, 10, 40km)
  - Simple OAM (link up, link down, as with LF/RF)
  - Ethernet, Fibre-Channel are examples that could be client interfaces for an OTN network
  - OTN also has its own client interfaces, often running over an Ethernet optical specification with an OTN frame format where the management domain continues to the edge
- "Line" Interfaces were between nodes in a network – Historically, most "line" interfaces have been specified in ITU-T (PDH, SDH, OTN)
  - May use similar technologies as Client interfaces: When similar technologies are used, the Client/Line distinction can be made according to the role that the interface plays in the network rather than the technology that is used
- Line interfaces may also support:
  - Greater reach than client interfaces (e.g., 100s or 1000s of km)
  - Multiplexing of multiple client signals over the interface (WDM, Packet, TDM)
  - More complex OAM for connectivity verification (Is the correct signal connected to the correct place in the network) and for fault localization
  - May support protection switching to improve availability

Client and Line Interfaces



To the end device, the network just appears to extend the client interface between end devices that may be geographically distant from each other, and the infrastructure for that network may be shared

What does SG15 Standardize?

- Fully Standardized Interfaces and Aspects
  - Mappings of Client Interfaces into Line Interface Frame formats
  - Fully Standardized OTN Client Interfaces – Optical Budgets recently based on IEEE 802.3 with an OTN frame Format
  - Line interfaces where technology is sufficiently mature for multi-vendor interoperability (typically 200-450km over amplified metro ROADM networks (80km under consideration), initially 2.5G and 10G NRZ, under development 100G DP-QPSK)
- Functionally Standardized Interfaces
  - Long/Ultra-Long Haul (1000s of km terrestrial or subsea)
  - The Information flow across an interface, the OAM and how it is processed are standardized so that different vendor systems are managed in the same way, but the precise modulation, FEC, Frame Format is left to individual vendor designs
  - Examples: Flexible Coherent with probabilistic constellation shaping and exotic proprietary FEC
  - Single-vendor subnetworks composed of functionally standardized interfaces are interconnected using shorter reach fully-standardized interfaces

OTN Client Interfaces based on Ethernet Optics (Link Types 1 & 3)

<table>
<tr><th>Ethernet Spec (optical and logic)</th><th>ITU-T Optical</th><th>ITU-T Frame Format</th></tr>
<tr><td>100GBASE-LR4</td><td>G.959.1 4I1-9D1F</td><td rowspan="4">G.709 OTL4.4 or
G.709.1 FOIC1.4</td></tr>
<tr><td>100GBASE-ER4</td><td>G.959.1 4L1-9C1F</td></tr>
<tr><td>CWDM4 MSA</td><td>G.695 C4S1-9D1F</td></tr>
<tr><td>4WDM 40km “ER4-lite”</td><td>G.959.1 4L1-9D1F</td></tr>
<tr><td>200GBASE-FR4</td><td>G.695 C4S1-4D1F</td><td rowspan="2">G.709.1 FOIC2.4</td></tr>
<tr><td>200GBASE-LR4</td><td>G.959.1 4I1-4D1F</td></tr>
<tr><td>400GBASE-FR4</td><td>G.959.1 8R1-4D1F</td><td rowspan="2">G.709.1 FOIC4.8</td></tr>
<tr><td>400GBASE-LR4</td><td>G.959.1 8I1-4D1F</td></tr>
</table>

ITU-T has used the completed optical specification from IEEE 802.3 as a basis for how to use the same pluggable modules for OTN client interfaces rather than developing competing or differing optical specifications for similar link types.

Ethernet “Line” Interfaces

- Proposals to define Ethernet over link types 4-6 appear to be proposals to define an Ethernet “Line” interface as opposed to the traditional Ethernet “Client” interface
- All existing standards for optical link types 4-6 have been developed by Q6/15 (ITU-T G.698.1 (unamplified); G.698.2 (amplified)
- IEEE 802.3 and ITU-T SG15 should avoid developing (competing) optical specifications for these link types for similar signaling rates and channel characteristics that have differences that preclude using the same components for both IEEE 802.3 and ITU-T applications

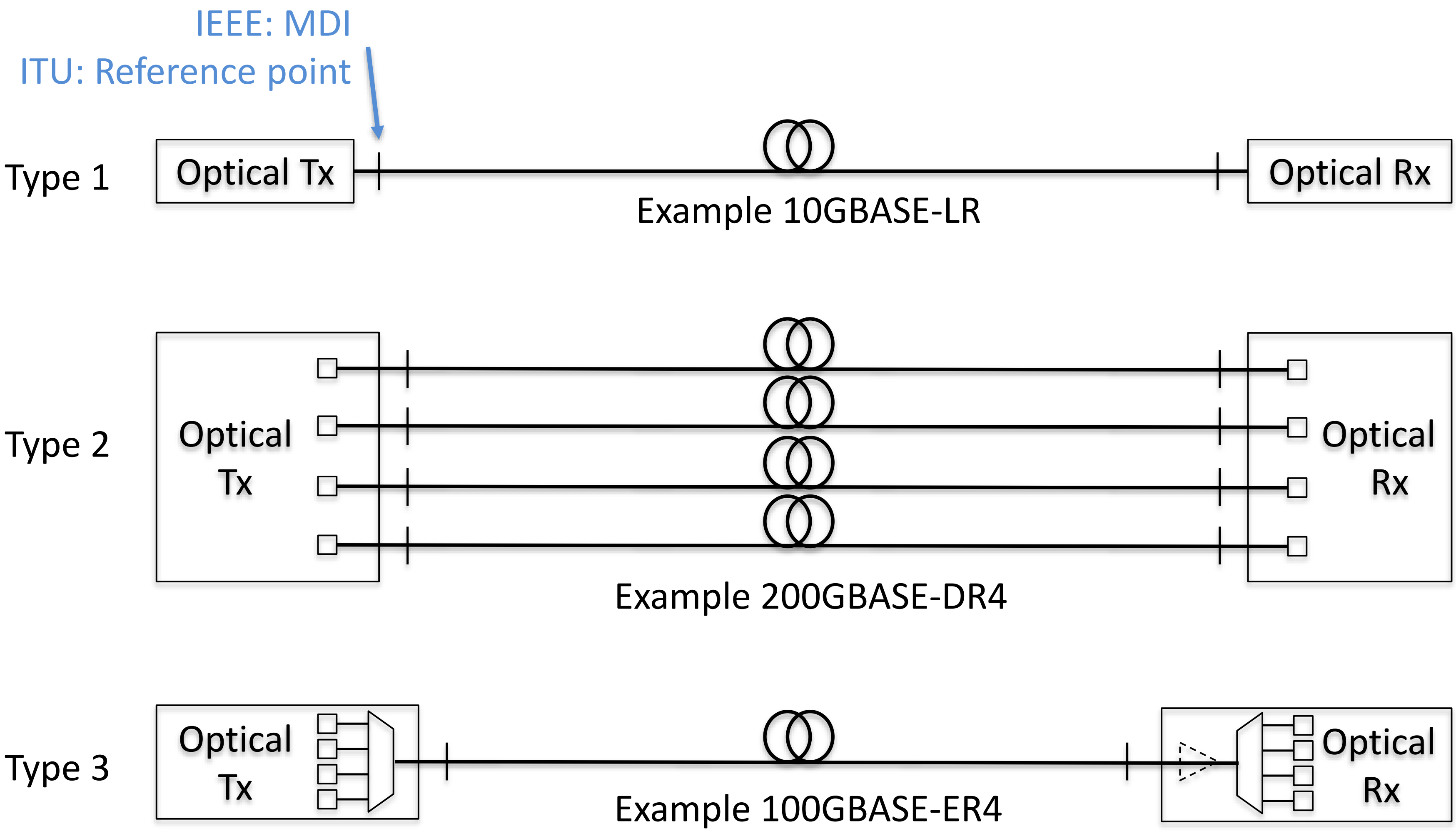
Optical link types

To attempt to avoid differences in terminology between organizations (and individuals) getting in the way of clear communication, six optical link types that have been the subject of standardization by the two groups are illustrated and given a "type number" in the following slides

Pete Anslow

IEEE 802.3 Secretary *SG15 Q6 Associate Rapporteur*

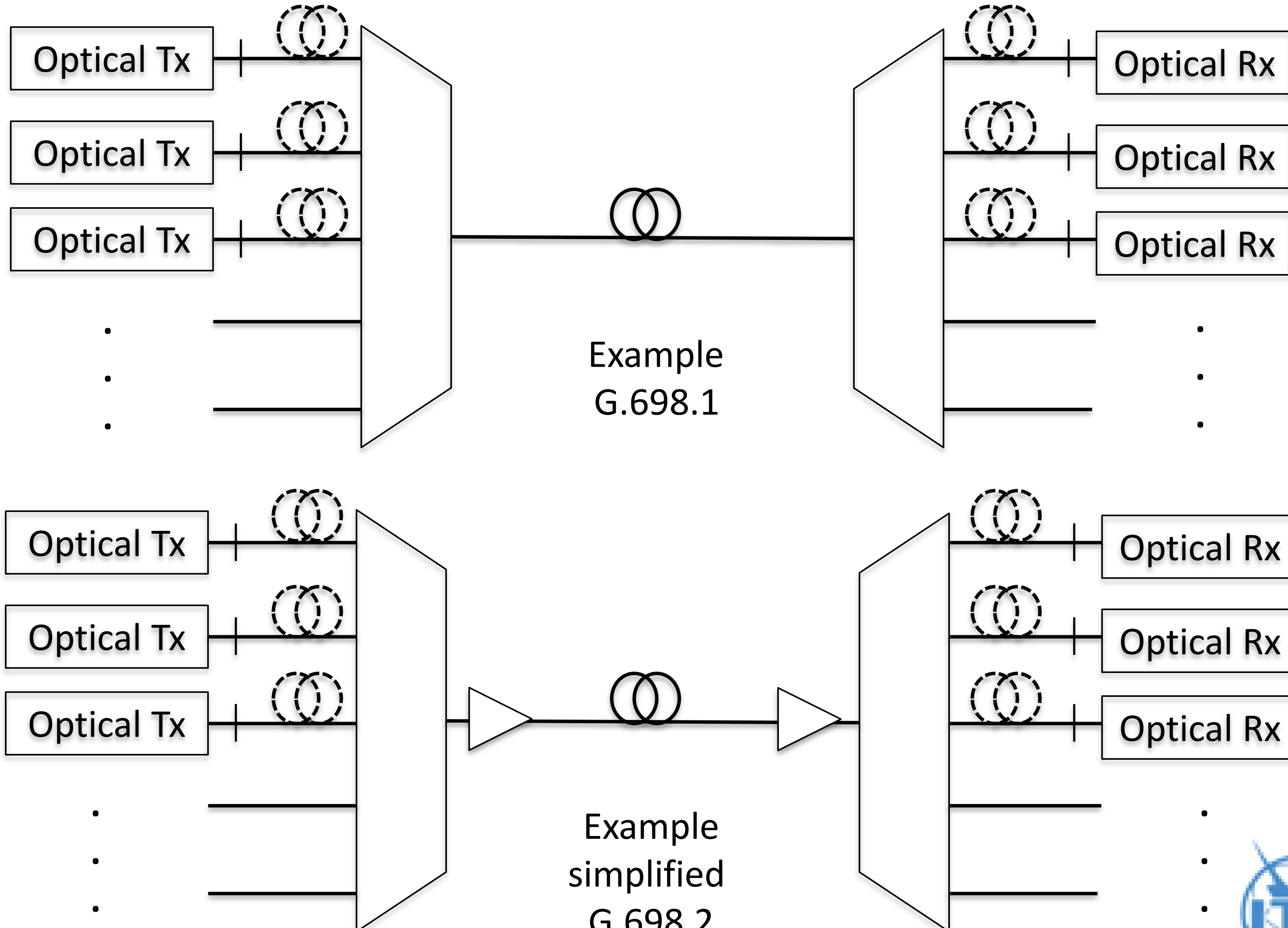
Optical link types 1 to 3



Optical link types 4 and 5

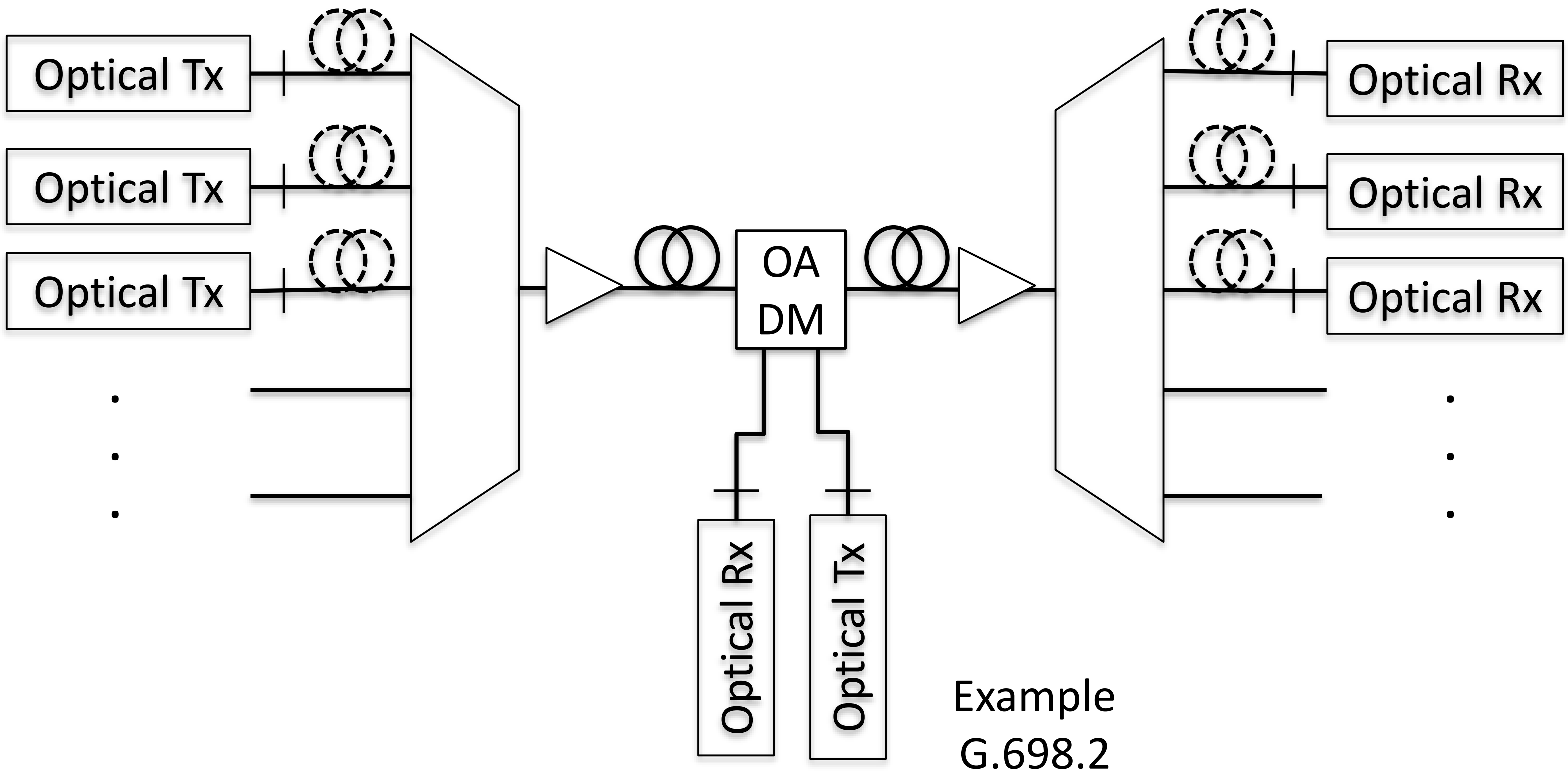
Type 4

Type 5



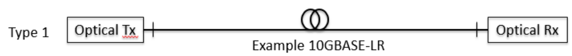
Optical link type 6

Type 6



Example
G.698.2

Optical link types vs organization

<table>
<tr><th>Type</th><th></th><th>IEEE 802.3</th><th>ITU-T SG15</th></tr>
<tr><td>1</td><td>
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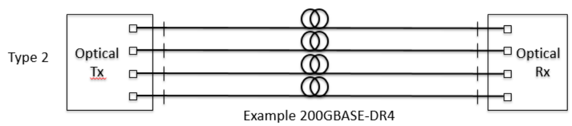
<tr><td>2</td><td>
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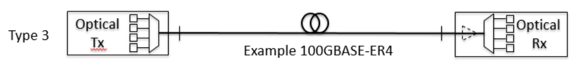
<tr><td>3</td><td>
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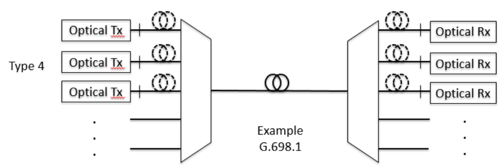
<tr><td>4</td><td>
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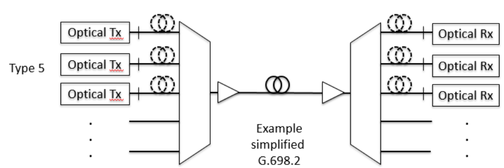
<tr><td>5</td><td>
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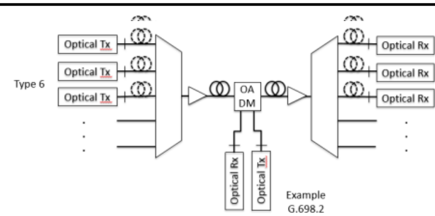
<tr><td>6</td><td>
</td><td></td><td>✓</td></tr>
</table>

ITU-T G.698.2

Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces

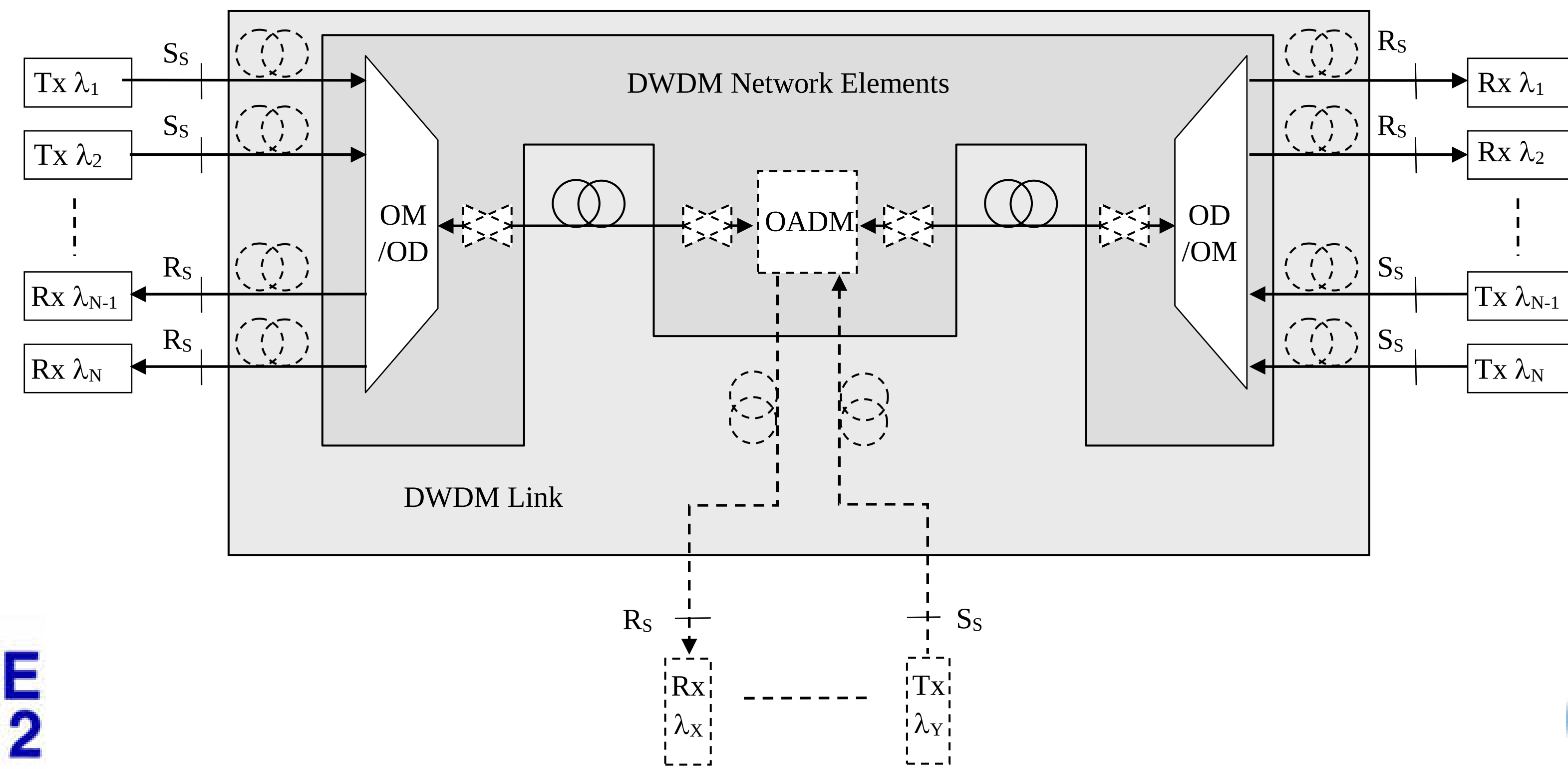
Bernd Teichmann

Editor of ITU-T G.698.2

G.698.2 Amplified multichannel DWDM applications with single channel optical interfaces

G.698.2 provides optical interface specifications towards the realization of transversely compatible DWDM systems primarily intended for metro applications, which include optical amplifiers, by using the “black link” methodology.

The „black-link“ approach is used to achieve multi-vendor interoperability by defining the optical specifications at the single channel reference points S_S and R_S like it is shown in the figure below for a linear „black-link“.



G.698.2 Figure 5-3 – Linear "black link" approach for bidirectional applications

G.698.2 Application Codes use Black Link approach

The in-force version of G.698.2 contains application codes for 2.5 Gbit/s and 10 Gbit/s DWDM interfaces. For the definition of the optical parameters of these application codes following so called "terms of refence" were used:

- A maximum black-link distance in the range of 200 to 450 km and
- 2 to 3 OADMs in series, not precluding operation on 6 to 7 OADMs.

- It was agreed to apply the same terms of reference for the development of the 100G DP-QPSK application code.
- The usage of the "black link" methodology is essential to allow for different implementations and design choices for the single channel TX and RX in conjunction with a wide variety of DWDM network elements and DWDM link designs.

Black Link specification methodology

- In G.698.2 the transmitter and the receiver optical specifications are only defined at the single channel reference points S_S and R_S .
- For the black link, containing DWDM network elements and the DWDM link, only a small set of parameters are defined (e.g. residual chromatic dispersion, polarization mode dispersion, crosstalk, OSNR penalty) while other details are kept undefined (like maximum fiber length or per channel power into the DWDM link)
- The approach to define only an essential number of DWDM link parameters maximizes the application space and avoids the need for many different application codes depending on the proprietary DWDM link design or DWDM network element structure (precise fiber length, type of optical amplifier, amplifier spacing, topology of the DWDM network element).

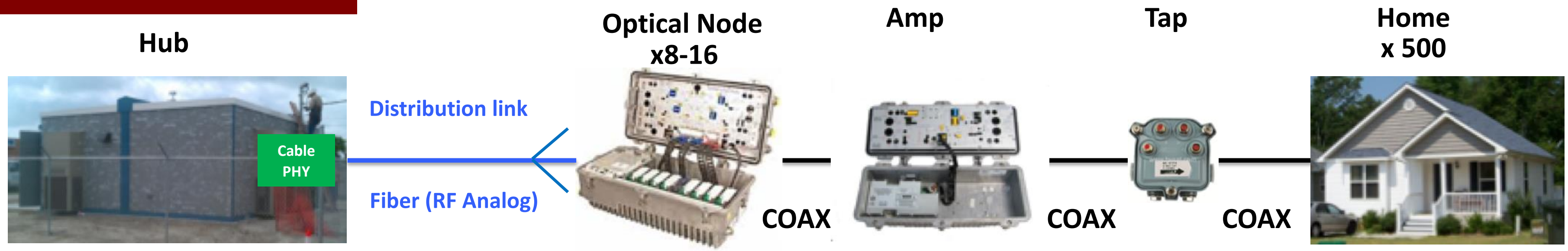
http://www.ieee802.org/3/B10K/public/17_11/stassar_b10k_01a_1117.pdf to the b10k meeting in Orlando, November 2017, provided additional details to the "black-link" specification methodology and the black link parameters in G.698.2

MSO Network Evolution

Gary Nicholl, Fernando Villarruel
Cisco Systems

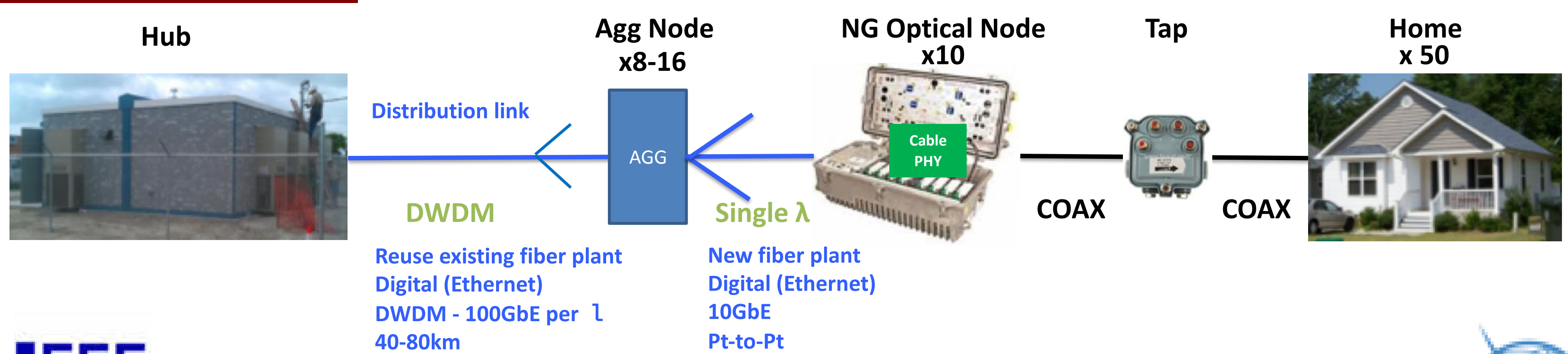
MSO Network Migration

Current HFC Architecture



To support higher bandwidths and more endpoints the Cable market is undergoing an architecture migration.
Analog optical distribution links are moving to digital (Ethernet) @ 100 Gb/s and above to facilitate distribution to 10 Gb/s endpoints.

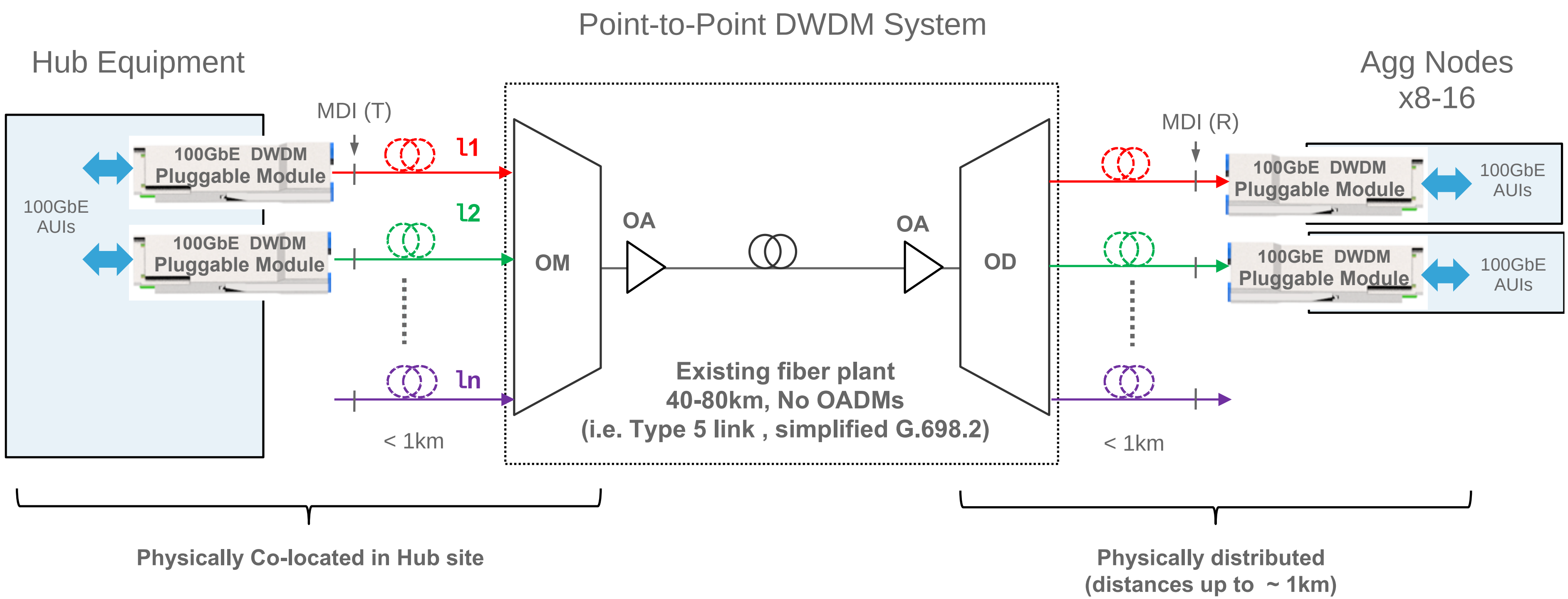
NG HFC Architecture



IEEE 802

NG HFC Architecture

Distribution Link Details



For clarity, only one direction of transmission is shown

Distribution Link Requirements

- Re-use existing fiber plant (fiber constrained)
- Topology: Point-to-point
- Distance: 40-80km
- Capacity: 100GbE per wavelength (potentially higher speeds in future)
- Multiple wavelengths (i.e. channels) per fiber
- Wavelength spacing: according to ITU DWDM grid (100 GHz spacing)
- Compatible with DWDM Infrastructure (i.e. black link)
  - Optical Link Type 5

Key Points

- Cable (MSO) market is undergoing an architecture migration
- Moving from analog fiber distribution to digital fiber distribution based on Ethernet
- Drives a requirement to be able to multiplex multiple 100GbE signals (and potentially higher speed in future) onto a single fiber using DWDM
- MSO requirements in these respects are not unique and aligned with similar trends occurring within the industry, e.g. DCI (Data Center Interconnect), OIF 400G ZR project, etc.

Beyond 10 km – Industry Efforts

Jeffery Maki

Juniper Networks

Agenda

- Interop Field Trials
- OIF Interoperable 400G
- Form Factor Options

Line-Side DWDM Interop Field Trials

Th1D.5.pdf OFC 2017 © OSA 2017

Multi-Vendor 100G DP-QPSK Line-Side Interoperability Field Trial over 1030 km

Nestor Garrafa[(1)], Omar Salome[(1)], Thomas Mueller[(2)], Oscar Pache Carcelen[(2)], Gianluca Calabretta[(3)], Nacho Carretero[(3)], Gabriele Galimberti[(3)], Steven Keck[(2)], Víctor López[(4)], Dirk van den Borne[(2)]

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[(3)] Cisco Systems Inc., Via S. Maria Molgora, 48 C, Vimercate, MB 20871, Italy (gcalabre@cisco.com, ggalimbe@cisco.com)
[(4)] Telefónica Global CTO, Ronda de la Comunicación 2, 28050 Madrid, Spain (victor.lopezalvarez@telefonica.com)

Abstract: We discuss a multi-vendor line-side interoperability field trial using Juniper and Cisco 100G coherent DWDM routers interfaces. The field trial demonstrates 100G DP-QPSK transmission over a 1030-km link from Boca Raton to Jacksonville uses the HG-FEC line-side interoperability mode for 100G coherent DWDM transceivers.

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

- HG-FEC in differentiated DSP implementations

A216 J. OPT. COMMUN. NETW./VOL. 10, NO. 2/FEBRUARY 2018 Filer *et al.*

Toward Transport Ecosystem Interoperability Enabled by Vendor-Diverse Coherent Optical Sources Over an Open Line System

Mark Filer, Hacene Chaouch, and Xiaoxia Wu

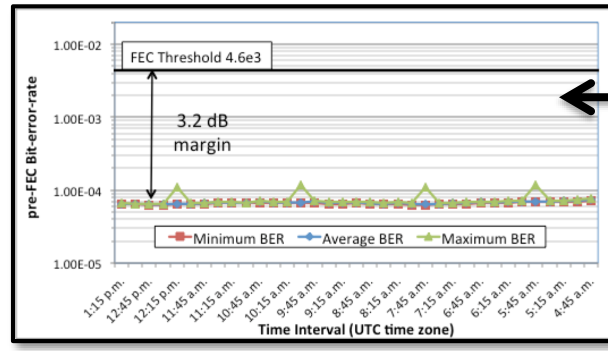
***Abstract*—Optical line-side interoperability is a critical component for enabling cloud service providers to deploy capacity at scale with a diverse supply chain. Historically, vendor-locked line systems and proprietary coherent digital signal processing (DSP) technologies have been barriers**

Because of this rapid evolution, coherent transceivers have made little progress toward line-side signal interoperability [3–5]. Each coherent digital signal processor (DSP) supplier has improved performance and feature sets with

- SD-FEC in common DSP but otherwise differentiated implementations

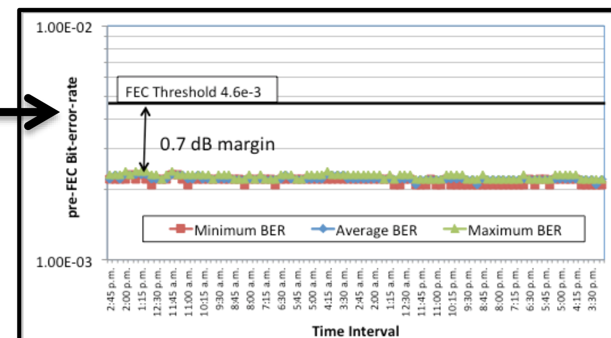
100G Line-Side DWDM Interoperability

- Native integration of HG-FEC mode into next-generation DSP ASICs
- System-vendor ASICs and merchant silicon
- Successful multi-vendor interop over 1,000 km
- Trials in customer labs and field trials between **Juniper, Cisco, Nokia and Huawei**
- Strong adoption by major carriers worldwide
- Examples: Terastream, OpenROADM



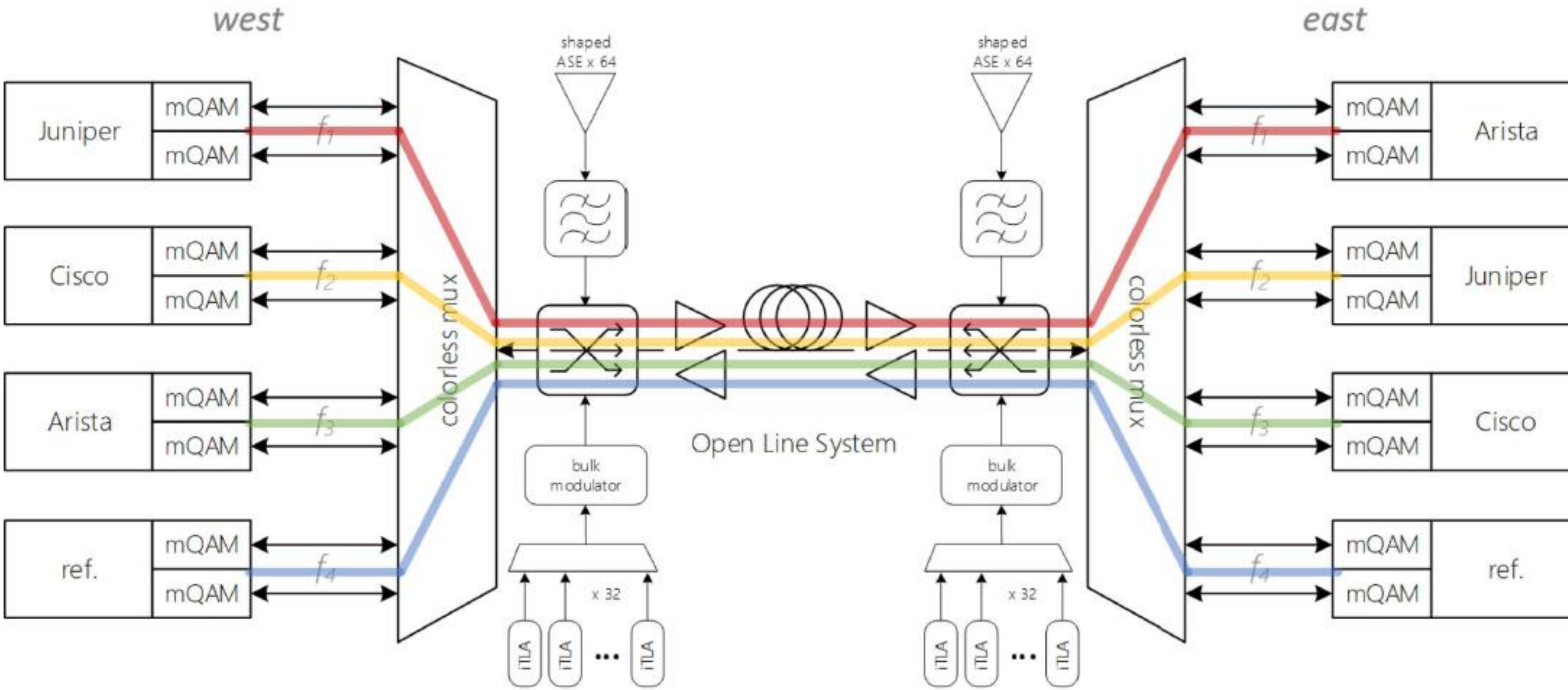
1040 km dispersion-unmanaged LEAF link

1235 km dispersion-managed SSMF link



150G & 200G Line-Side DWDM Field Trial

- Interoperability among Juniper, Cisco and Arista on Long-Haul Network



- Open line system consists of hybrid Raman/EDFA for long spans, EDFA only for shorter spans, and flex-grid ROADMs
- 150G 8QAM transmission over 2000km LEAF fiber, 104 channels total, 37.5GHz spacing
- 200G 16QAM transmission over 1000km LEAF fiber, 104 channels total, 37.5GHz spacing

Data Center Interconnects (DCI)
(Inter-Data Center – Between Data-Center Locations)

- Industry consensus to prepare a specification for 400G coherent interoperability
  - OIF Project: 400ZR
    - DWDM optically amplified links up to 120 km targeted as priority
    - Client/gray unamplified links up to 40 km, possibly more
  - Ethernet PHY
    - Will use Extender Sublayer of 802.3bs with FEC degrade signaling to support fast reroute
- Related OIF Projects
  - IC-TROSA for coherent to enable implementations
    - Digital Coherent Optics (DCO): Coherent DSP is inside the optical module
    - Analog Coherent Optics (ACO): Coherent DSP is outside of the optical module
  - 400G CFP2-DCO electromechanical definition

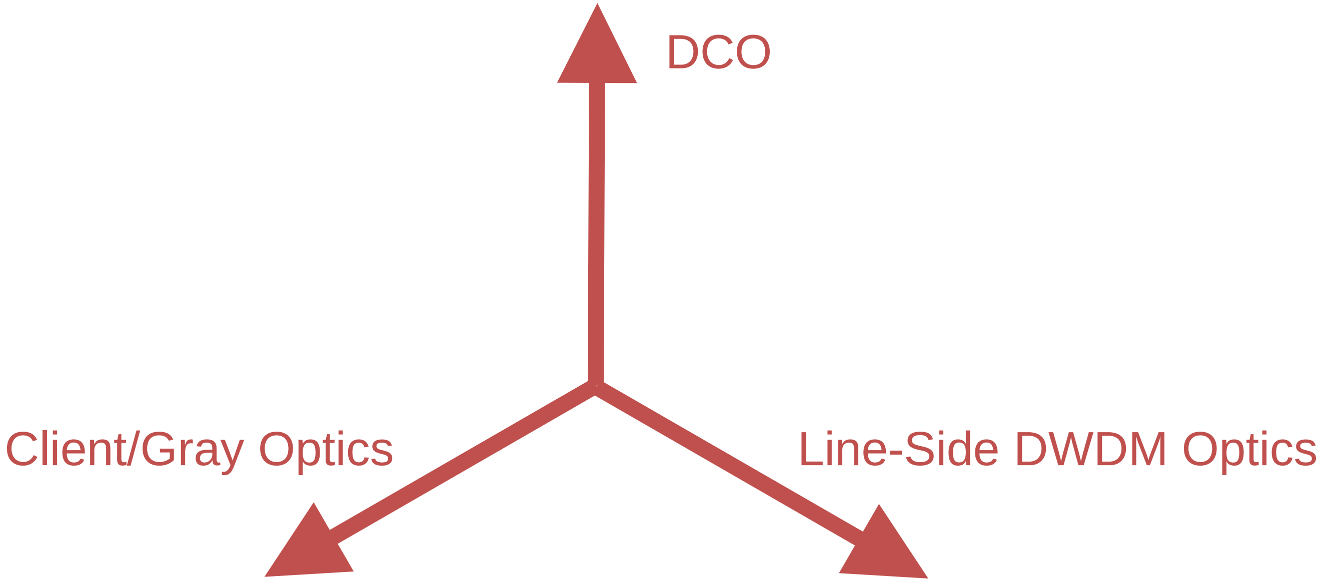
OIF Definition of 400ZR Ethernet

	400ZR Loss-Limited Link	400ZR DWDM OSNR-Limited Link
PCS	400GE	400GE
Frequency Tolerance	+/- 20 ppm	+/- 20 ppm
Timing Transparency	Yes	Yes
Modulation	16QAM	16QAM
Baud Rate	~64Gbaud	~64Gbaud
Distance	40 to 80 km	80 to 120 km
Link Type	Unamplified	Amplified
Link Condition	12 dB loss	Mux/Dmux

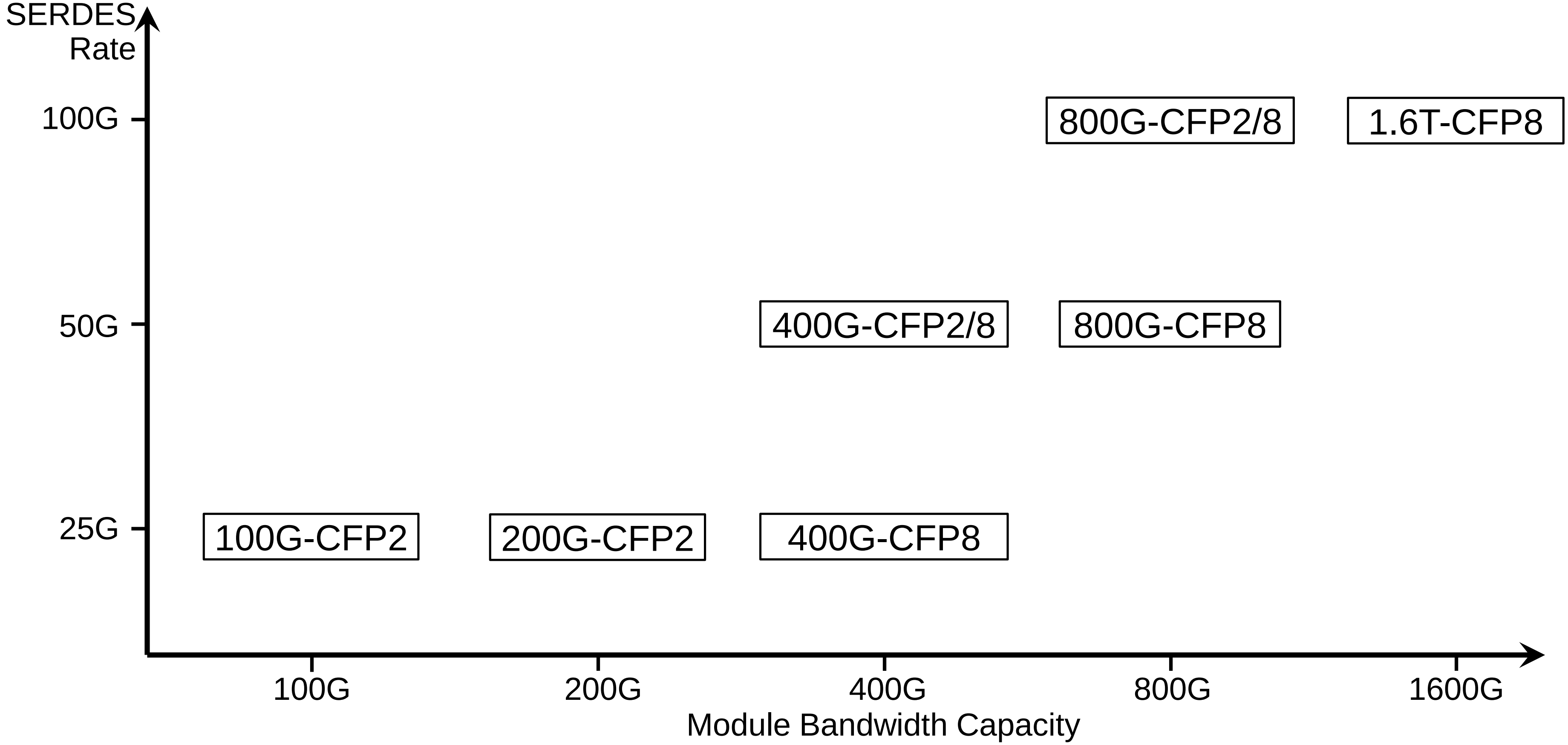
- More specs pending future liaison and publication

DCO – Digital Coherent Optics

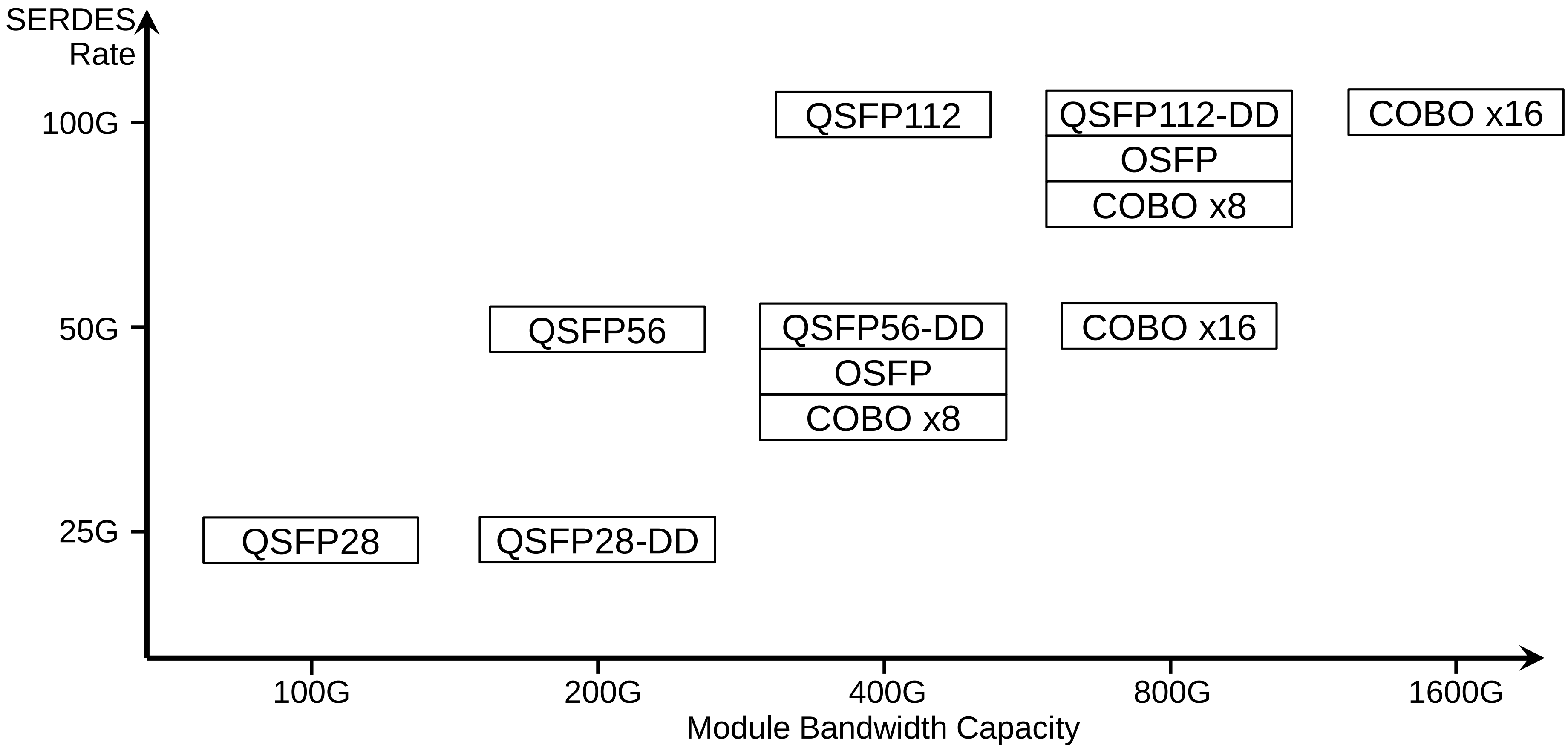
- Gaining particular interest and investment for use in data-center switches
- Can be used for client optics and line-side DWDM



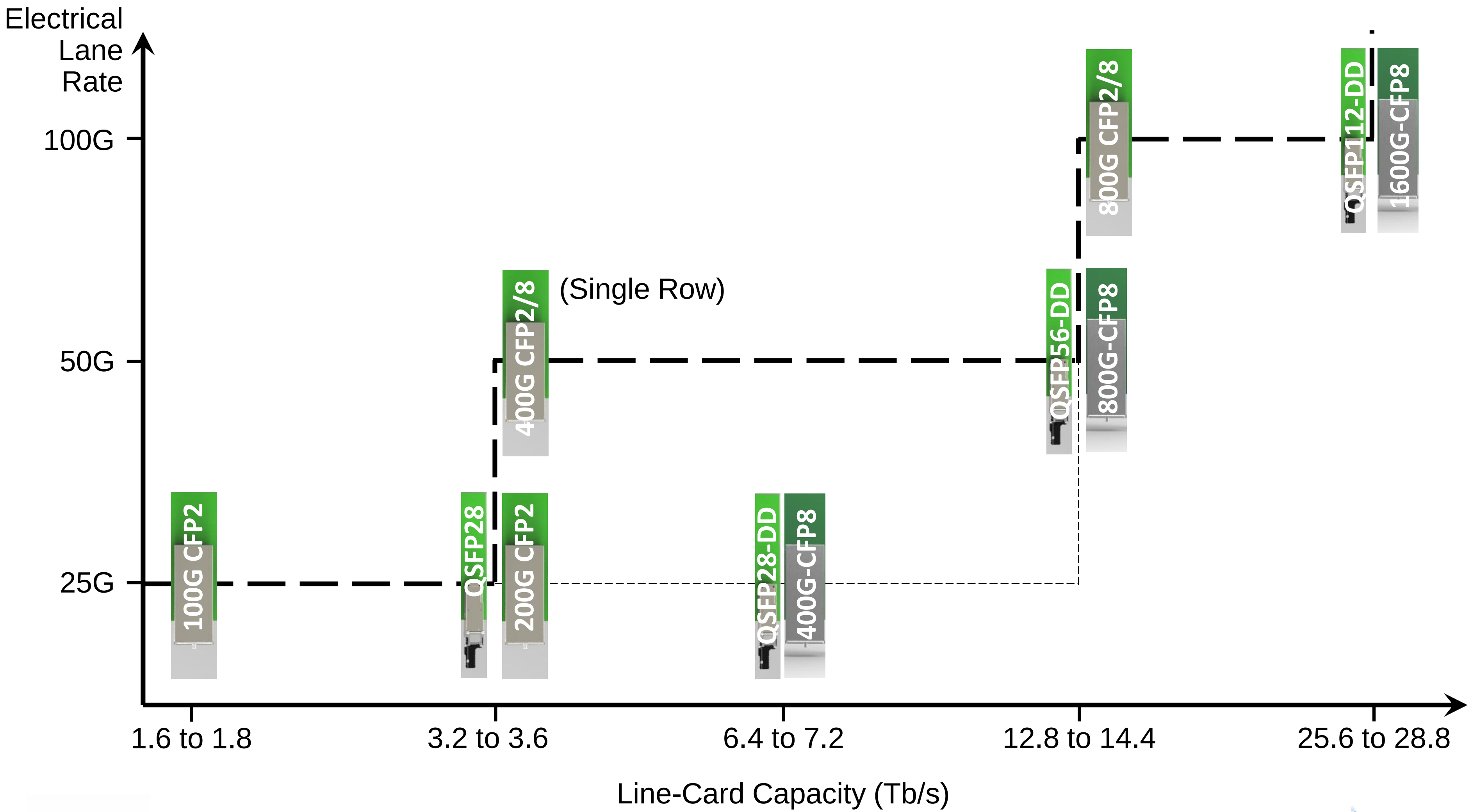
CFP MSA Form Factors for ZR/Metro/LH



Data Center Switch Form Factors for ZR



Potential Bandwidth Density Progression



ITU

Discussion