NEA ad hoc meeting
Beyond 10km Optical 100 Gb/s PHYs
Pre-CFI consensus call
Nov 1st, 2017

Proposed agenda

- Approval of the Agenda
- Approval of the Oct 25th minutes
- IEEE patent policy reminder:
  - https://development.standards.ieee.org/myproject/Public/mytools/mob/preparslides.pdf
- IEEE Participation Requirements reminder
- Pre-CFI Consensus discussion:
  - Beyond 10km Optical 100 Gb/s PHYs

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Participation in any IEEE 802 meeting (Sponsor, Sponsor subgroup, Working Group, Working Group subgroup, etc.) is on an individual basis

- **Participants in the IEEE standards development individual process shall act based on their qualifications and experience. (https://standards.ieee.org/develop/policies/bylaws/sb_bylaws.pdf section 5.2.1)**
- **IEEE 802 Working Group membership is by individual; "Working Group members shall participate in the consensus process in a manner consistent with their professional expert opinion as individuals, and not as organizational representatives". (subclause 4.2.1 "Establishment", of the IEEE 802 LMSC Working Group Policies and Procedures)**
- **Participants have an obligation to act and vote as an individual and not under the direction of any other individual or group. A Participant's obligation to act and vote as an individual applies in all cases, regardless of any external commitments, agreements, contracts, or orders.**
- **Participants shall not direct the actions or votes of any other member of an IEEE 802 Working Group or retaliate against any other member for their actions or votes within IEEE 802 Working Group meetings, see https://standards.ieee.org/develop/policies/bylaws/sb_bylaws.pdf section 5.2.1.3 and the IEEE 802 LMSC Working Group Policies and Procedures, subclause 3.4.1 "Chair", list item x.**

By participating in IEEE 802 meetings, you accept these requirements. If you do not agree to these policies then you shall not participate.

(Latest revision of IEEE 802 LMSC Working Group Policies and Procedures: http://www.ieee802.org/devdocs.shtml)

CFI - 100GbE Beyond 10km Optical PHYs

Consensus Presentation

Background (to be removed for actual CFI)

- It is expected that, if successful, this CFI will expand the scope of the current "Beyond 10k" Study Group (http://www.ieee802.org/3/B10K/index.html)
  - A straw poll will be requested in the B10k study group in November to assess support from those participants to accept the increased scope if the CFI is successful.
  - Until then, we can only state we are requesting a new Study Group
- We anticipate that this would result in an expanded scope of: "Beyond 10km Optical PHYs for 50 Gb/s, 100 Gb/s, 200 Gb/s, and 400 Gb/s Ethernet"
- This CFI is focused only on the inclusion of the additional data rate into the B10k discussions
  - Therefore technology feasibility is discussed, but technology choices and trade-offs remain the domain of the Study Group, not the CFI

Supporters

Frank Chang	Inphi
Hai-Feng Liu	Intel
Kohichi Tamura	Oclaro
Ryan Yu	Molex
Scott Sommers	Molex
Curtis Knittle	CableLabs
Steve Swanson	Corning
David Ofelt	Juniper Networks
Scott Schube	Intel
Kohichi Tamura	Oclaro
Thananya Baldwin	Ixia
Jeffrey Maki	Juniper Networks
Kenneth Jackson	Sumitomo Electric
Mark Nowell	Cisco
Jerry Pepper	Ixia
Kent Lusted	Intel
Isono Hideki	Fujitsu
Patricia Bower	SocioNext
Vipul Bhatt	Finisar
David Lewis	Lumentum
Justin Abbot	Lumentum
Matt Brown	MACOM
Atul Gupta	MACOM
Chris Collins	MACOM
Brad Booth	Microsoft
Akinori Hayakawa	Fujitsu
Antonio Tartaglia	Ericsson
Matt Traverso	Cisco
Marek Hajduczenia	Charter Communications
Dave Chalupksy	Intel
Tom Williams	Acacia
Fabio Cavaliere	Ericsson
Tony Zortea	MultiPHY
Ilya Lyubomirsky	Inphi
Chan-Chih (David) Chen	Applied Optoelectronics
Eugene Dai	Cox Communications
James H. Chien	ZTE
Ted Sprague	Infinera
Fernando Villarruel	Cisco
Mark Gustlin	Xilinx
Alexander Umnov	Corning
John Johnson	Broadcom
Winston Way	NeoPhotonics
Shawn Esser	Finisar
Tom Palkert	Molex
Paul Brooks	Viavi
Tad Hofmeister	Google
Jörg-Peter Elber	Adva

Your name here??

Objective for this Meeting

- To *measure the interest* in starting a study group to address:
  - Beyond 10 km Optical PHYs for 100GbE
- We don't need to
  - Fully explore the problem
  - Debate strengths and weaknesses of solutions
  - Choose any one solution
  - Create PAR or five criteria
  - Create a standard or specification
- Anyone in the room may speak / vote
- RESPECT… give it, get it

Overview: Motivation

Applications have been identified that are looking for new Ethernet optical solutions at reaches greater than 10 km at 100 Gb/s

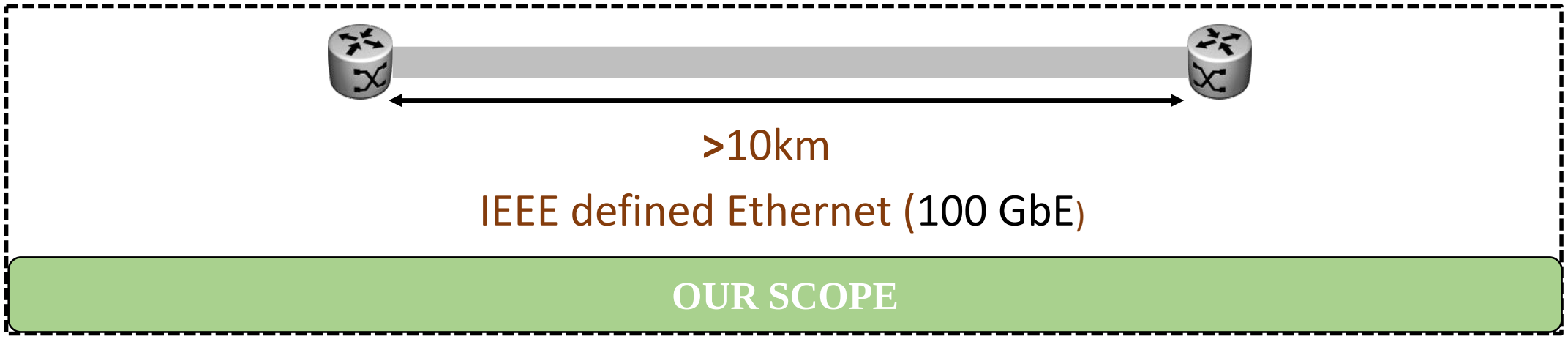
- Cable/MSO distribution networks
- Mobile backhaul aggregation networks

The existing “Beyond 10km Optical PHYs” Study Group has significant participation and energy around the already identified market applications @ 50 Gb/s, 200 Gb/s and 400 Gb/s.

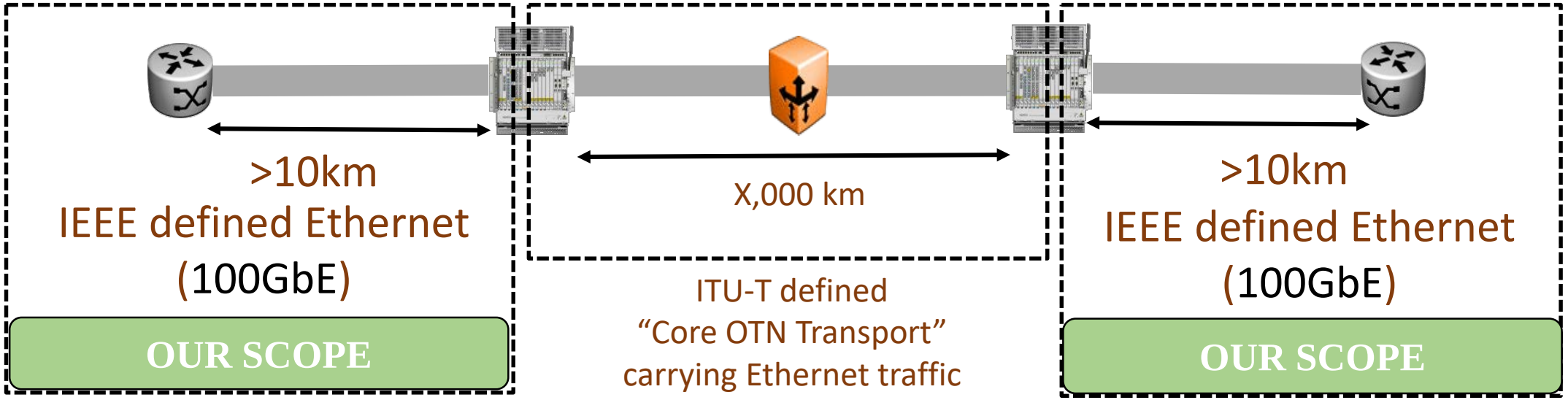
This CFI’s aim is to include 100 Gb/s into that effort

What Are We Talking About?

Scenario #1



Scenario #2

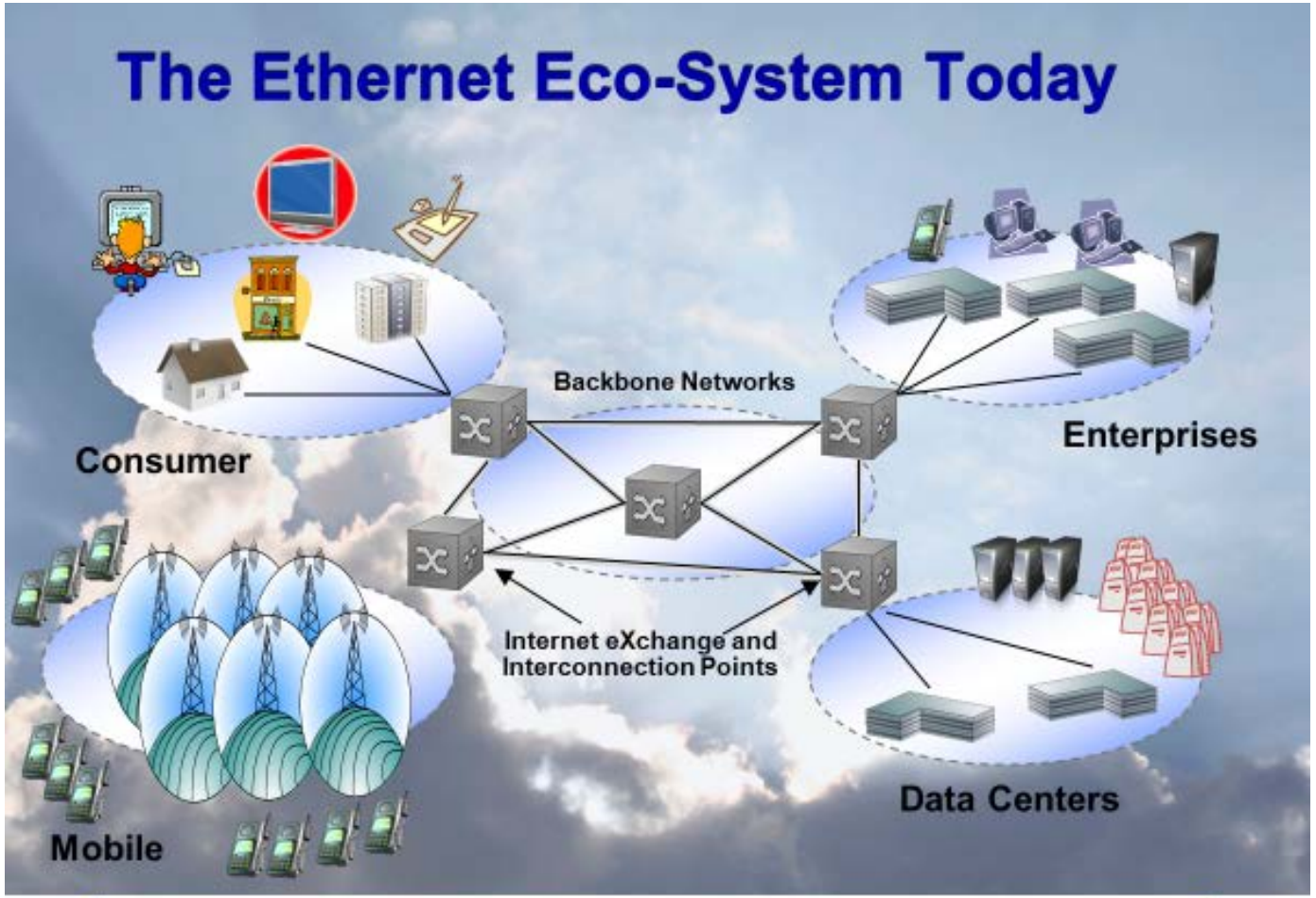


Agenda

- Market Drivers
- Technical Feasibility
- Why Now?
- Q&A Panel
- Straw Polls

Market Drivers for 100GbE beyond 10km

Beyond 10km Optics Throughout The Ecosystem



- Not “Data Center”
- Exists throughout the Eco-System
- 3 Million units for 40km and beyond shipped annually
- Continuing bandwidth growth factors resonate throughout the ecosystem
- Being addressed in B10K study group for 50 Gb/s, 200Gb/s, and 400 Gb/s
- This CFI’s goal is to add 100 Gb/s into that study group discussion

Today's Point-to-Point SMF Ethernet Family

	Lanes	500m	2km	10km	20km	40km	Up to 80km
1000BASE-	1		LX	LX10 / LH		EX	ZX
10GBASE-	1			LR		ER	ZR
25GBASE-	1			LR		ER	
40GBASE-	4	PSM4		LR4		ER4	
	1		FR				
50GBASE-	1		FR	LR			
100GBASE-	10		10X10				
	4	PSM4	CWDM4 / CLR4	LR4 / WDM4-10	WDM4-20	ER4 / WDM4-40	
	<4	DR					
200GBASE-	4		FR4	LR4			
400GBASE-	8		FR8	LR8			
	4	DR4					
	1						

Longer Reach Opportunity

Lane width Opportunity

Black Text — IEEE Standard
Red Text — In Standardization
Blue Text — Non-IEEE standard but complies to IEEE electrical interfaces

Addressed in Beyond 10km Study Group

Cable/MSO Migration Strategy

Hub **Optical Node** **Amp** **Tap** **Home**

Hybrid Fiber-Coax (HFC) CLASSIC

DWDM

FIBER
(RF Analog)

COAX

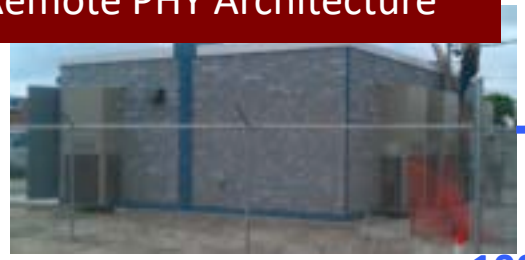
COAX

COAX

x 500

Driven by the requirement to support higher bandwidths and more endpoints the Cable market is undergoing an architecture migration. Analog optical distribution links are moving to digital @ 100 Gb/s and above to facilitate distribution to 10 Gb/s endpoints. Note, endpoint usage is <10Gbps initially with capacity for growth over lifetime.

Remote PHY Architecture



switch

DWDM

A
G
G

10 GbE

Ethernet
FIBER (Digital)
100 Gb/s & 200 Gb/s
40 - 80km

COAX

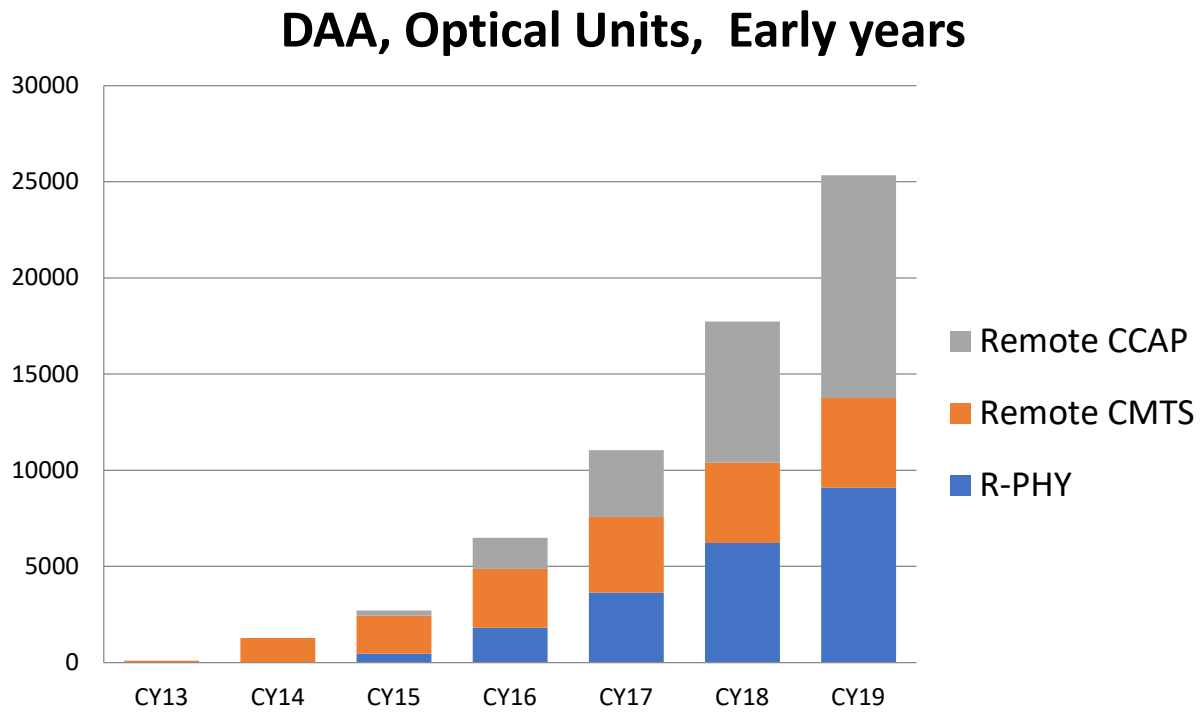
COAX

x 50

Key transition: field aggregation of 10G endpoints create need @ 100 Gb/s + backhaul

Hybrid Fiber Coaxial Market Evolution

- Distributed Access Architecture (DAA) Nodes: **12 M**
  - 10x scale vs. classic optical node
  - Not including China / India
  - Avg. homes passed / node: ~50
  - → **1.2 M** 100G backhaul lines to field aggregation points
- Evolution timeframe
  - 10 yr +
- Further Growth Potential: Mobile, business services



H.I.S. (Infonetics) Node Market Study 2015

NOTE 1: Graph derives 100G optical endpoint counts from node count in original market study (see back-up)

NOTE 2: Remote CCAP / CMTS / RPHY refer to separate breakpoints in the MAC and PHY range of the cable packet core (known as DOCSIS).

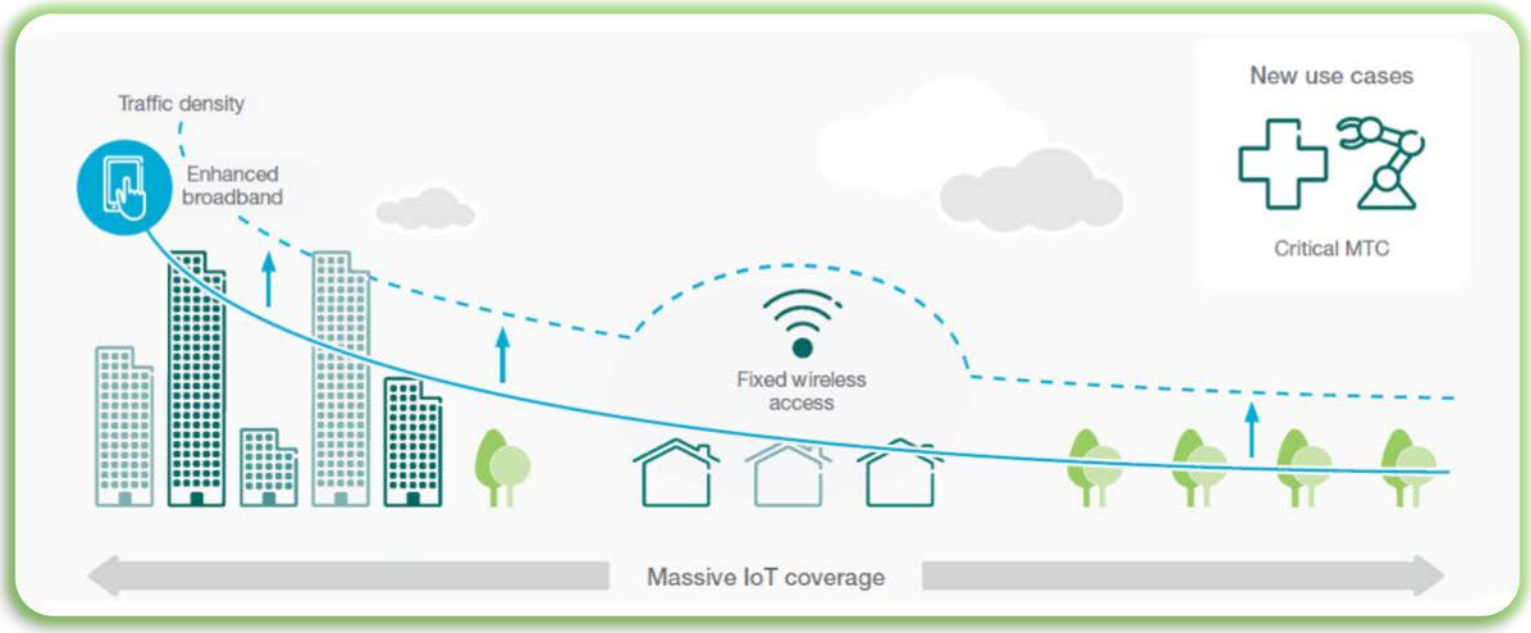
- CMTS – Cable Modem Termination System (Includes DOCSIS MAC/PHY and subscriber management)
- CCAP – Converged Cable Access Platform (Includes DOCSIS MAC/PHY)
- Remote PHY – only DOCSIS PHY included

Evolution of DOCSIS Architectures:
https://www.nctatechnicalpapers.com/Paper/2015/2015-evolution-of-cmts-ccap-architectures

Mobile Backhaul capacity segmentation

5G transport: an evolution, not a revolution

5G capacity drivers



Backhaul capacity requirements per radio site

Advanced mobile broadband	2016	2021
80% of sites	90 Mbps	300 Mbps
20% of sites	300 Mbps	1 Gbps
Few % of sites	1 Gbps	3-10 Gbps

Courtesy of Antonio Tartaglia, Ericsson

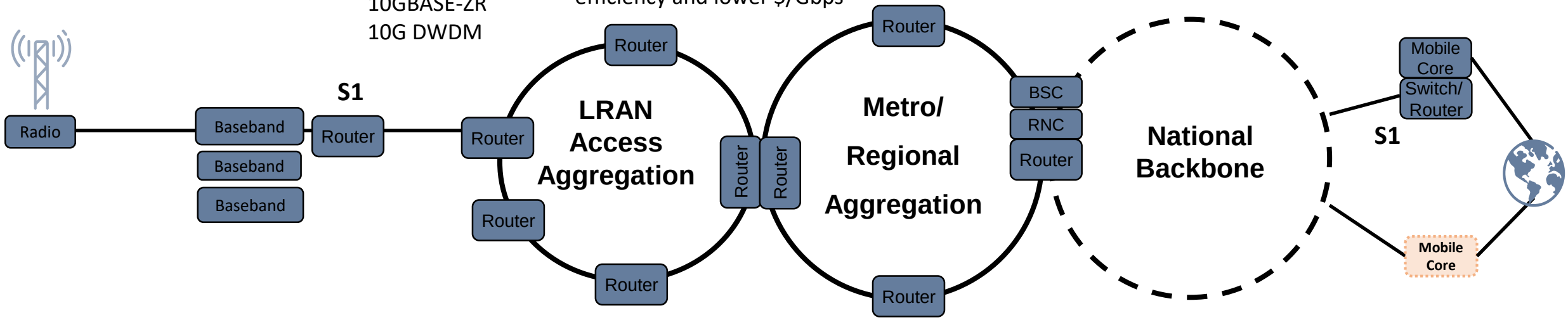
5G backhaul Capacity through 2021
evolution, not revolution

10G
10GBASE-LR
10GBASE-ER
10GBASE-ZR
10G DWDM

100G
100GBASE-ER4 / 4-WDM-40
100G "-ZR"
100G DWDM (DirDetect or coherent)
200G DWDM coherent for spectral efficiency and lower $/Gbps

=> opportunity for standard interfaces with improved cost structure

=> opportunity for new standard interfaces



Continued growth of 10G and 100G interfaces more connections, better utilized

- 50G and 200G might play a longer term role

Courtesy of Antonio Tartaglia, Ericsson

- In the lower aggregation tiers, 40km 'grey' direct-detect interfaces are expected to have continued traction
- Up in the tiers, 80km/ "-ZR" without external EDFAs expected to become popular (coherent being the most natural fit)
- DWDM may come into the picture, even in lower tiers, to solve specific network design challenges (fiber exhaust problems , "router optical bypass", …)

Mobile Backhaul Demand for Beyond 10km

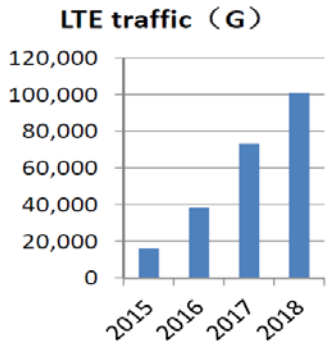
Not all geographies are the same

Present status and forecast

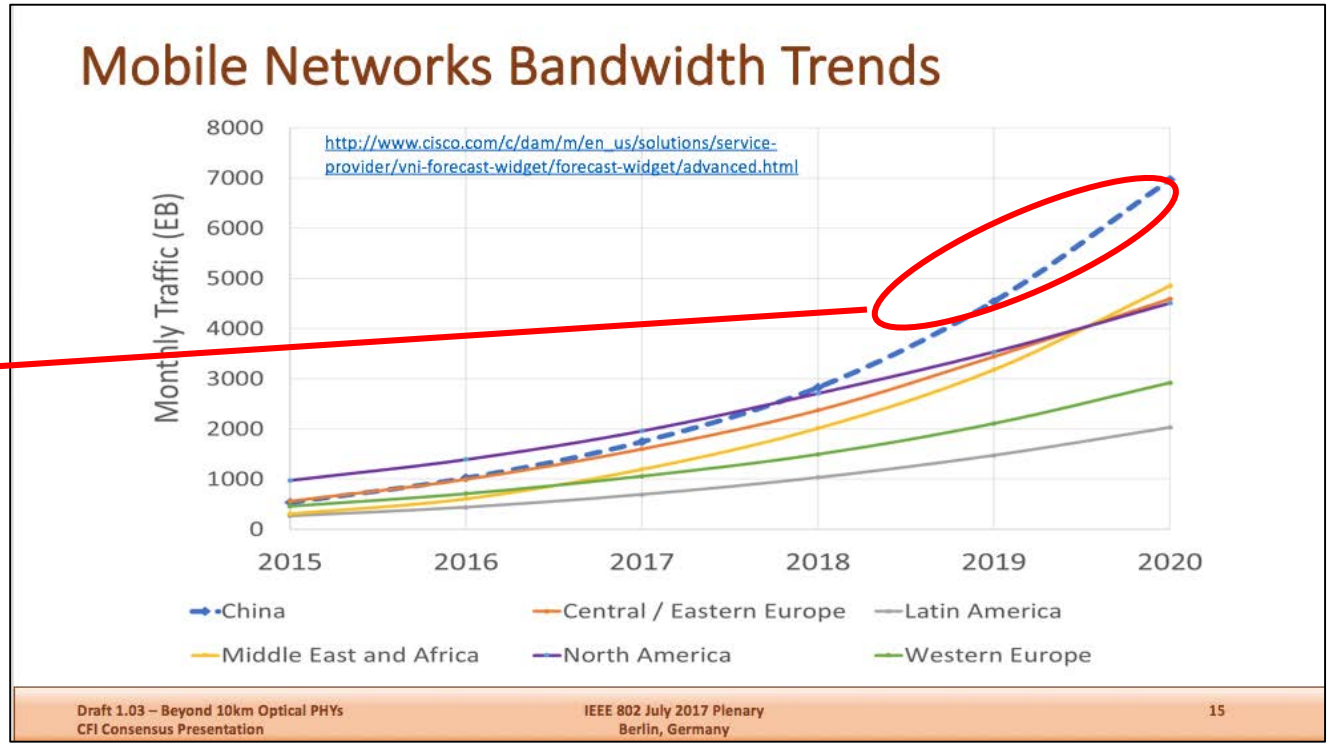
- According to our survey, long distance module is a mandatory requirement for us

Statistics for 10GE & 100GE Modules used in PTN, as of June, 2016				
Transmission Distance	**<2km**	**10km**	**40km**	**80km**
10GE distribution	0.28%	44.46%	44.05%	11.20%
100GE distribution (more than 15K modules)	0	56.43%	34.59%	8.97%

- According to the increase of LTE traffic, as LTE backhaul network, PTN will face 4~5 times traffic in 2017 or 2018.
- Then we will have to use 400GE interface in the same scenario and take the same percentage with 100GE and 10GE.
- In 2018~2019, we expected the requirement for 400GE ER modules will be more than 10K.



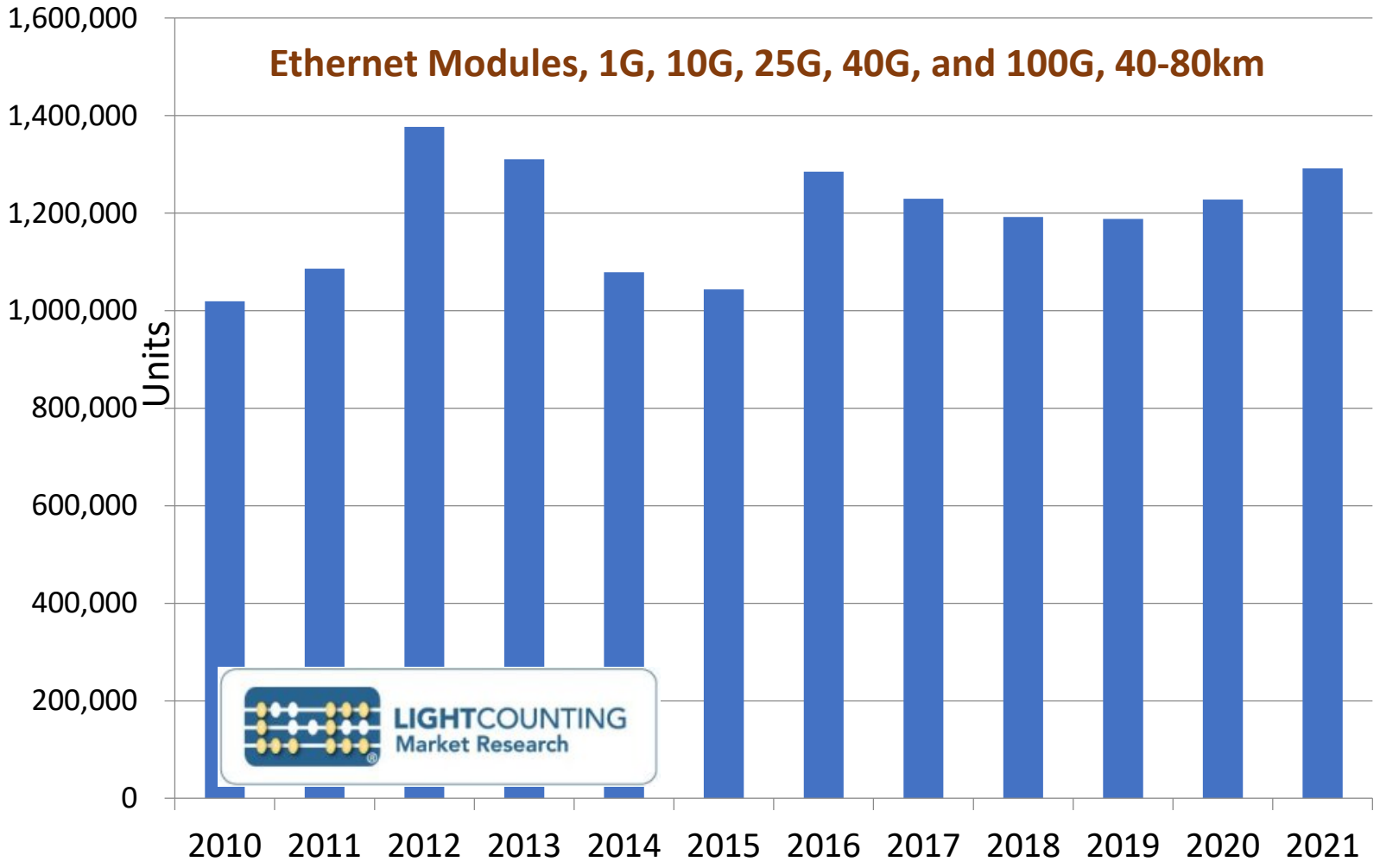
Source: Huang/ Cheng, China Mobile,
http://www.ieee802.org/3/ad_hoc/ngrates/public/16_07/huang_ecdc_01_0716.pdf



Source: B10k CFI
http://www.ieee802.org/3/cfi/0717_1/CFI_01_0717.pdf

- Previous B10k CFI focused on Chinese Mobile Backhaul market requirements. 50 Gb/s & 200 Gb/s clearly identified as requirements
- Different geographies are seeing different growths on the bandwidth drivers indicating 100 Gb/s needed

Annual Shipments for 40km+ Applications



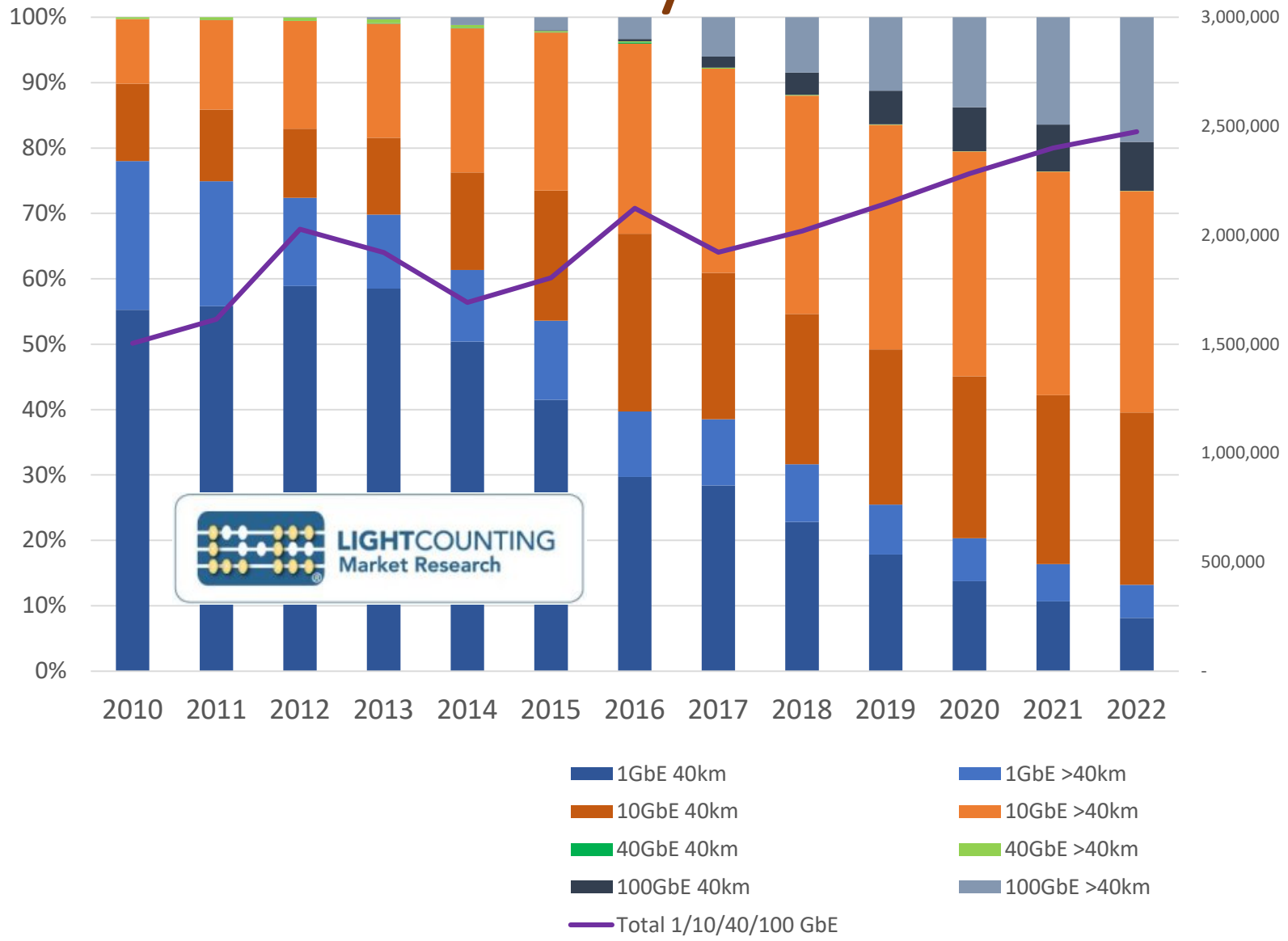
- For 100 GbE, 40km, LightCounting projects a market that will roughly triple in value from 2017 to 2021.
- SONET 40-80km shipments represent another half-million units in 2016. SONET is transitioning to Ethernet.
- 1 / 2.5 / 10 Gb/s DWDM / CWDM 40km & 80km optics will exceed 1M units this year and growing
- Totals are for merchant supplier shipments. Captive supply could add another half-million units.

Data courtesy of LightCounting

Optical Module Volumes: 40km and Beyond 40km

LightCounting forecast for optical modules for Ethernet and non-Ethernet applications

- Totals are for merchant supplier shipments
- The market for 40km and >40km optical modules continues to grow
- The >40km market space for both 10Gb and 100Gb is significant and growing faster than the 40km



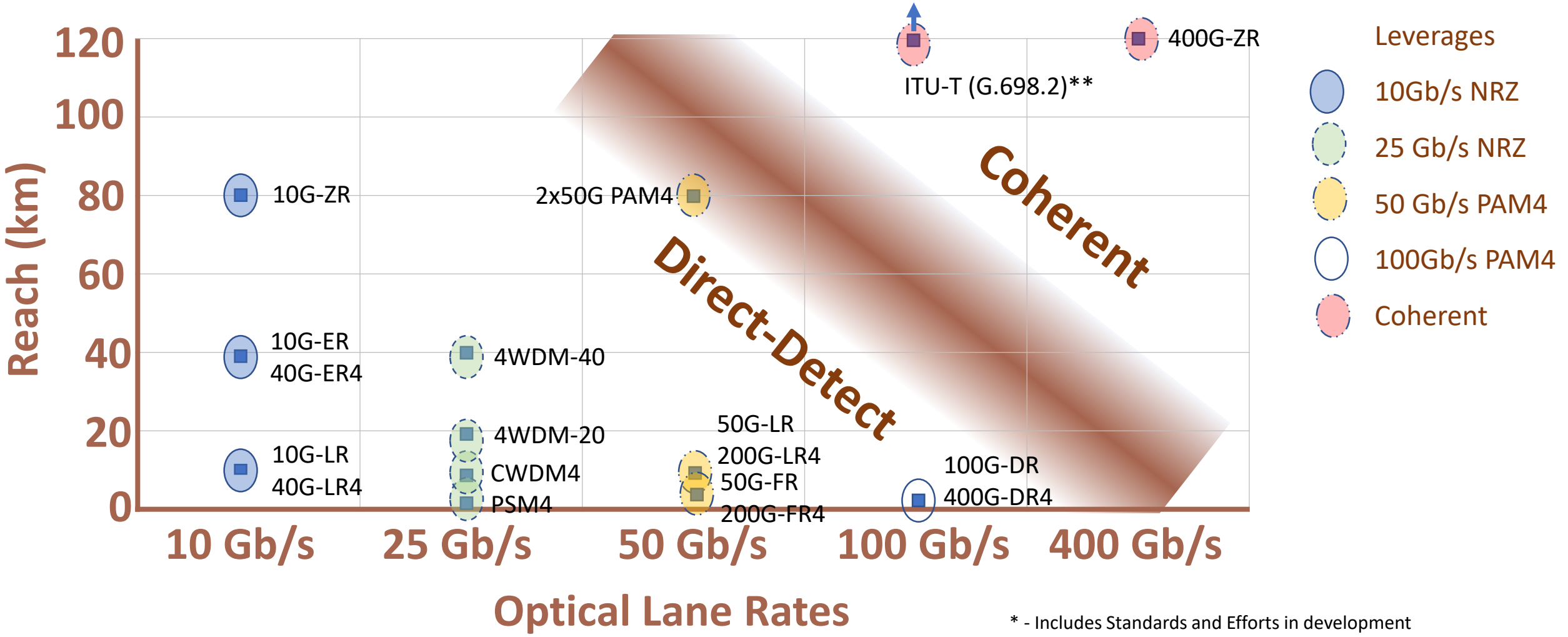
Data courtesy of LightCounting

Summary

- New markets coming to Ethernet where > 10km is important
  - Cable/MSO networks migrating architectures towards Ethernet
    - No Ethernet solution exists for 100 Gb/s 40-80km
  - Emerging applications to drive future traffic over mobile networks
  - Drivers for Mobile Traffic differ in different regions of the world. Network topologies are similar, timing around deployment of rates will follow capacity demands
  - Direct detect, coherent and DWDM all potential solutions the market is looking for
- Established Ethernet market shows use case for >10 km
  - 3 Million units (GbE to 100GbE) for 40km and beyond shipped annually
  - Bandwidth growth throughout ecosystem
  - “Geographically challenged” applications exist throughout Ecosystem
  - > 40km forecasts growing faster than 40 km

Technical Feasibility
100GbE Beyond 10km Optical PHY

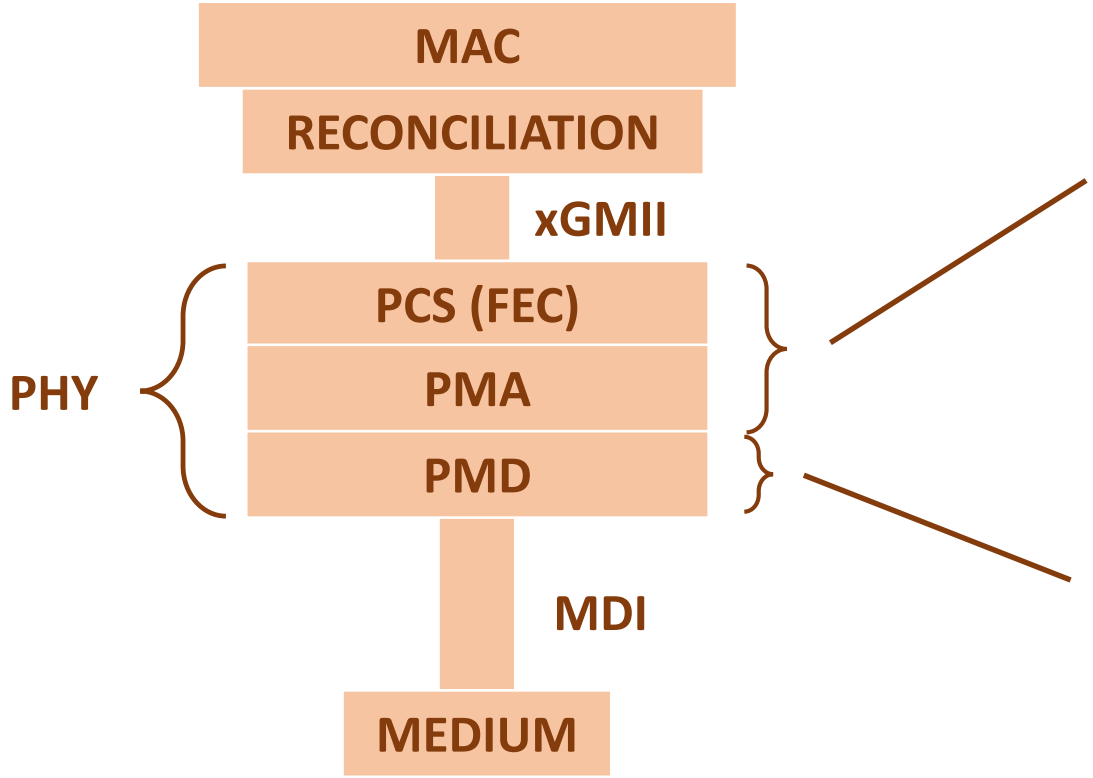
The SMF Optical Landscape *



* - Includes Standards and Efforts in development

** https://www.slideshare.net/ITU/itut-study-group-15-introduction.

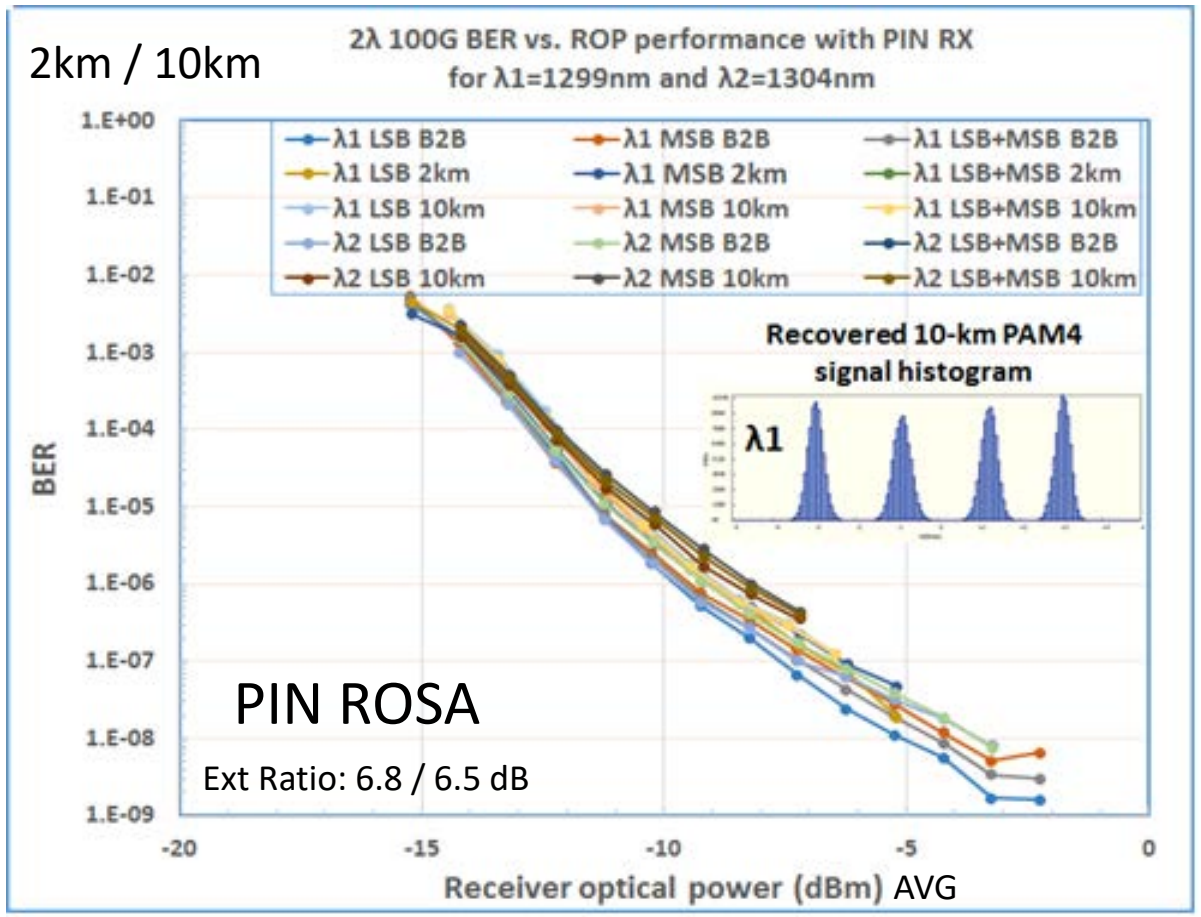
An Ethernet Overview of the Problem

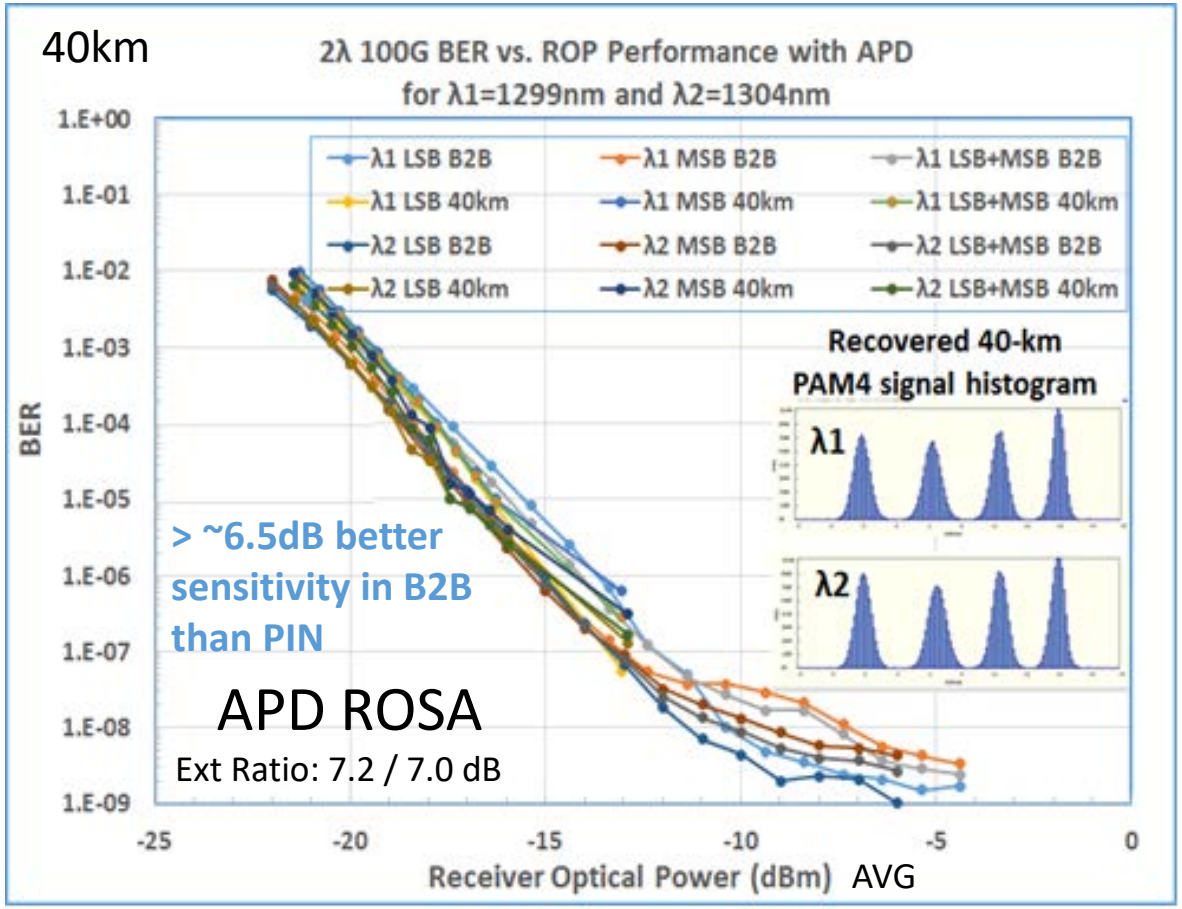


Approaches to Longer Reach

- Stronger FEC
- Improved Tx / Rx
- APD
- DSP
- Coherent
- Other (SOA, ….)

Impact of Use of APD (2λ @ 51.5625 Gb/s PAM4)

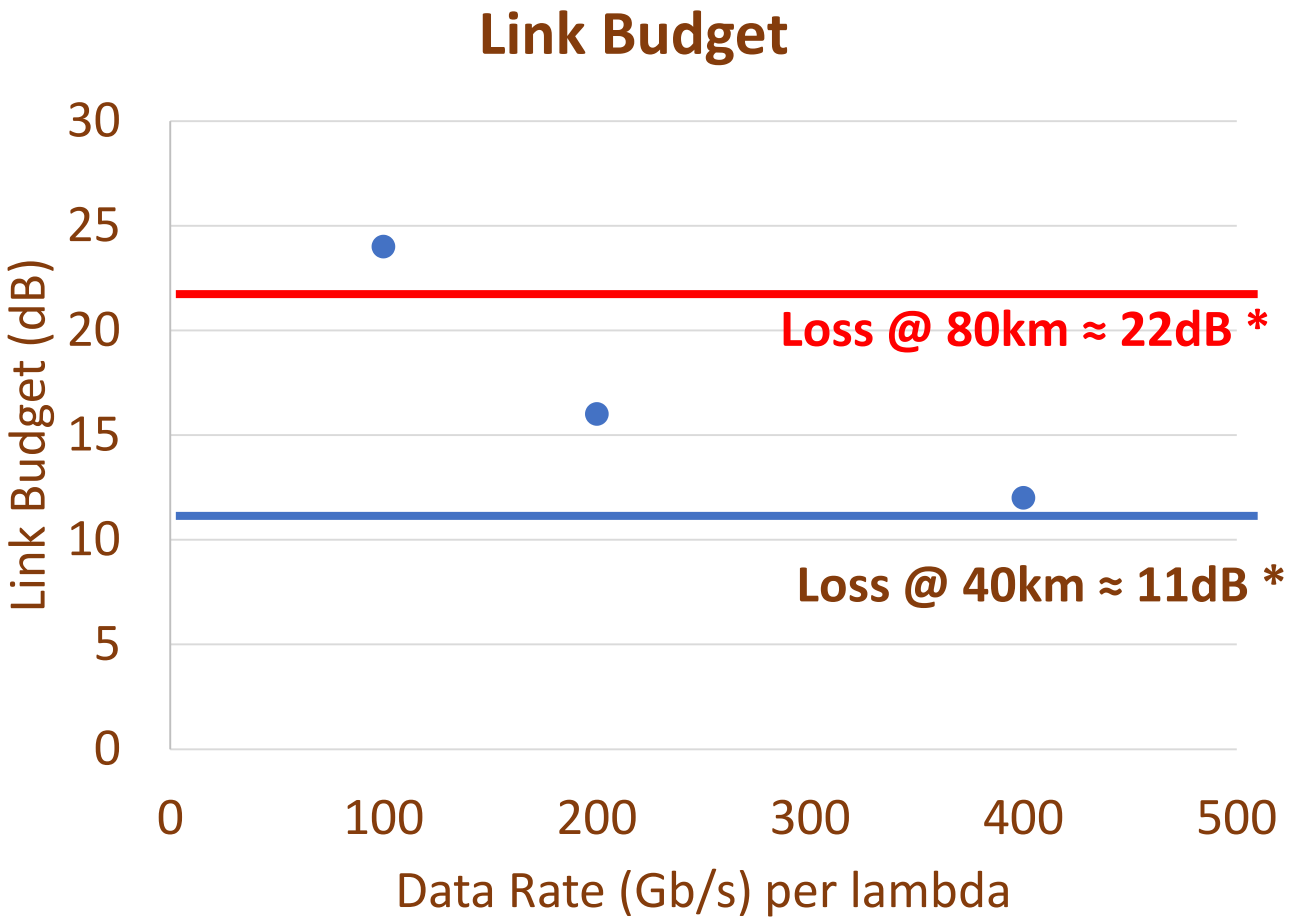




Data: PRBS31
Used actual chip implementation with real-time Rx DSP **with 10+ taps FFE** embedded inside the silicon

Source: Frank Chang, Inphi, "OFC 2016: Link Performance Investigation of Industry First 100G PAM4 IC Chipset with Real-time DSP for Data Center Connectivity ", OFC'16 Th1G.2

Targeting >10km with Coherent Technology



Assumptions

- Modulation Format
  - 100G – QPSK @ ~30Gbaud
  - 200G – 16QAM @ ~30Gbaud
  - 400G – 16QAM @ ~60Gbaud
- Tx and Rx power levels achievable with high yield and multiple optical technologies
- Note – Longer reach, i.e., higher link budgets, can be supported by transmit SOA/EDFA or with additional amplification

* - http://www.ieee802.org/3/ba/public/tools/Fibre_characteristics_V_3_0.xls

Source: Tom Williams, Acacia

100 Gb/s Coherent Technology

Coherent technology has been under development for greater than 10 yrs with initial market deployments since 2008.

Significant industry standardization efforts at both ITU and OIF

ITU:

Recommendation ITU-T G.698.2 revision in progress http://www.ieee802.org/3/minutes/nov17/incoming/ITU_SG15-LS-73_to_IEEE_802d3.pdf

OIF:

OIF-HBPMQ-TX-01.0 – Implementation Agreement for High Bandwidth Integrated Polarization Multiplexed Quadrature Modulators *(December 2016)*

OIF-PMQ-MTX-01.0 – Implementation Agreement for Integrated Polarization Multiplexed Quadrature Modulated Transmitters for Metro Applications *(September 2015)*

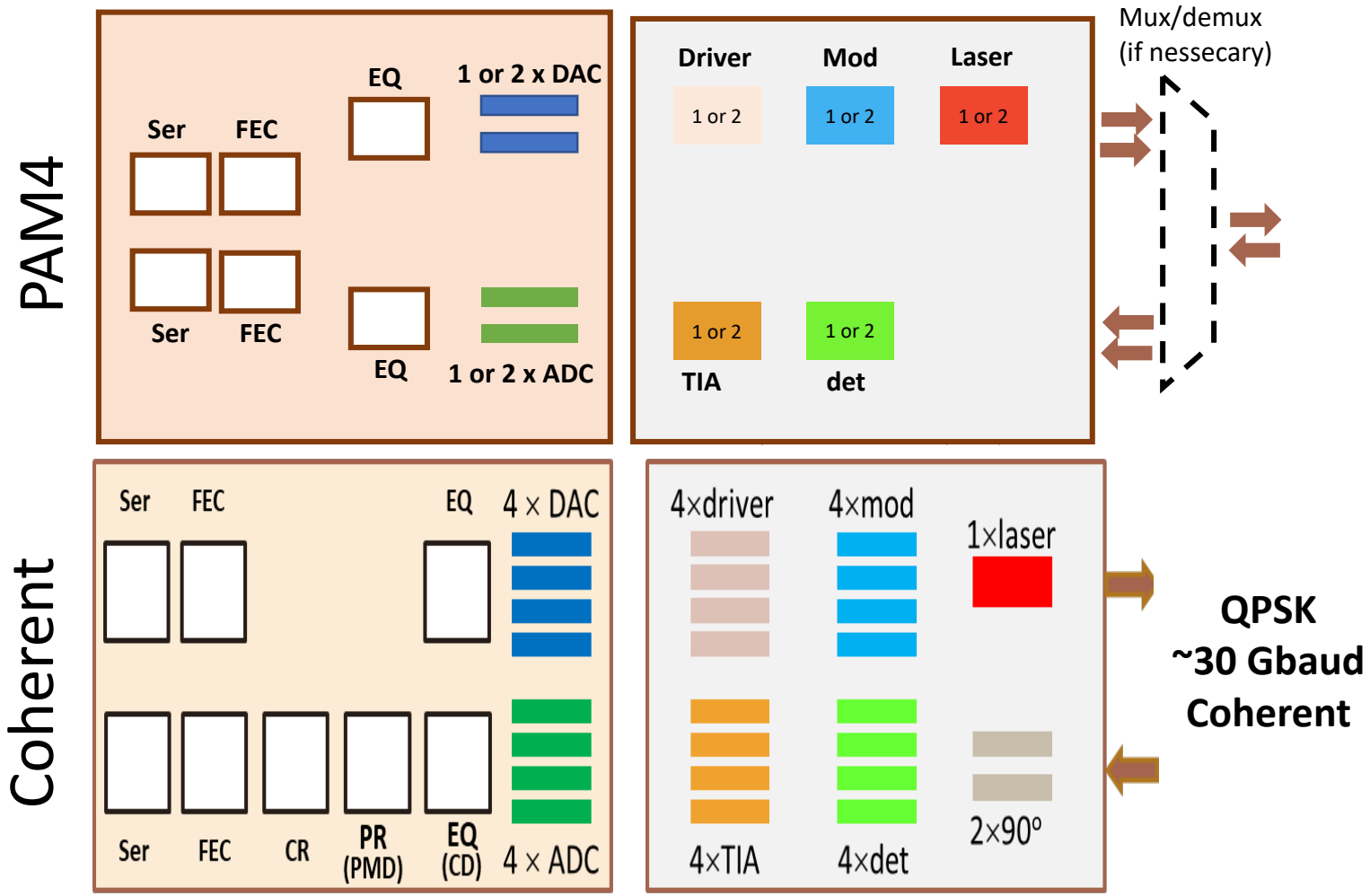
OIF-PMQ-TX-01.2 – Implementation Agreement for Integrated Polarization Multiplexed Quadrature Modulated Transmitters *(May 2015)*

OIF-DPC-MRX-02.0 – Implementation Agreement for Integrated Dual Polarization Micro-Intradyne Coherent Receivers *(June 2017)*

OIF-DPC-RX-01.2 – Implementation Agreement for Integrated Dual Polarization Intradyne Coherent Receivers *(November 2013)*

OIF-CFP2-ACO-01.0 – Implementation Agreement for Analogue Coherent Optics Module(January 2016)

Implementation Cost Considerations



Implementation costs need to be studied –

- Inclusion of components
- Number of components
- Operation rate of components
- Specifications of components

Source: Tom Williams, Acacia

Technical Feasibility of Beyond 10km 100 Gb/s Optical PHYs

- Growing evidence of different ways to support reaches beyond 10km for 100GbE
  - PAM4 (Direct Detect) test data for 40km provided
    - Higher Power EML Transmitters, APDs, Advanced DSP, FEC
  - Coherent Optics
    - Shipping today
    - Industry development efforts that may be leveraged.
      - ITU-T (ITU-T G.698.2)
- Same technology options already under consideration in Beyond 10k Study Group
- Technologies are always evolving toward narrower lane widths – both electrically and optically.
  - Enable reductions in cost, power etc
  - Aligns with host SerDes roadmap

Real challenge – determining the right solution for the right reach / rate!

Why Now?

Why Now?

- Opportunity to align with the Beyond 10km Study Group effort underway for 50GbE, 200GbE, and 400GbE
- Existing 100 GbE solution for 40km (100GBASE-ER4) does not fully address the market
  - No solution for up to 80km nor compatible with a DWDM deployment
  - Newer technologies available to potentially cost reduce even 40 km solution
- New markets with 100 GbE focus – example MSO
- Numerous applications for > 10km Optical PHYs
  - Everywhere - ≈3M units shipped annually addressing 40+km
  - Not same volumes as Data Center – but relevant to overall ecosystem
  - 100 GbE is the latest rate growing into this space

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Your name here??

Straw Polls

Straw Poll 1: Call-For-Interest

- Should a Study Group be formed to consider Beyond 10km Optical PHYs for 100GbE?

Y: N: A:

Room Count:

Straw Poll 2: Scope

- I would support expanding the scope of the existing Beyond 10km Study Group to include 100GbE.

Y: N: A:

Room Count:

Participation

- I would participate in the “Beyond 10km Optical PHYs for 100GbE” Study Group in IEEE 802.3.

Tally:

- My company would support participation in the “Beyond 10km Optical PHYs for 100GbE” Study Group in IEEE 802.3.

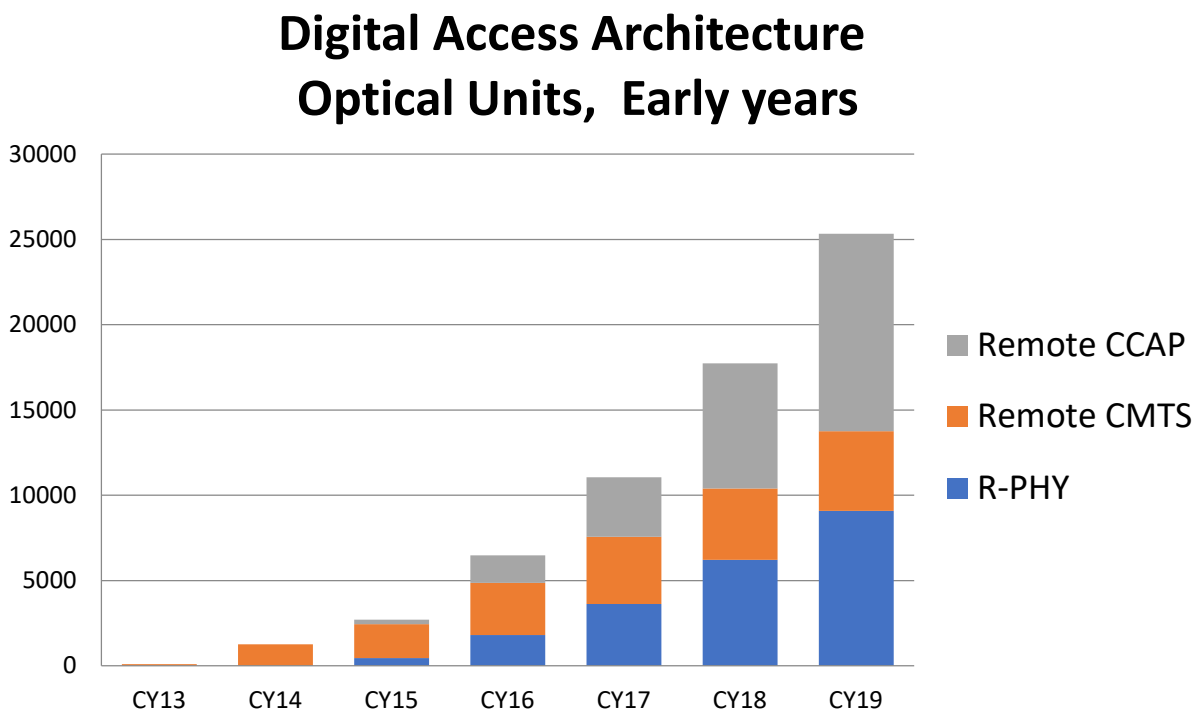
  Tally:

Future Work

- Look for indication from current Beyond 10k Study group that if this CFI is successful, that there is interest in expanding the scope to include this work
- Ask 802.3 Working Group on Thursday to form a Beyond 10km 100 GbE Optical PHYs Study Group
- Let 802.3 Working Group determine how this will go forward if successful
- If approved, on Friday
  - 802 EC

Backup

Distributed Access Architecture – more details



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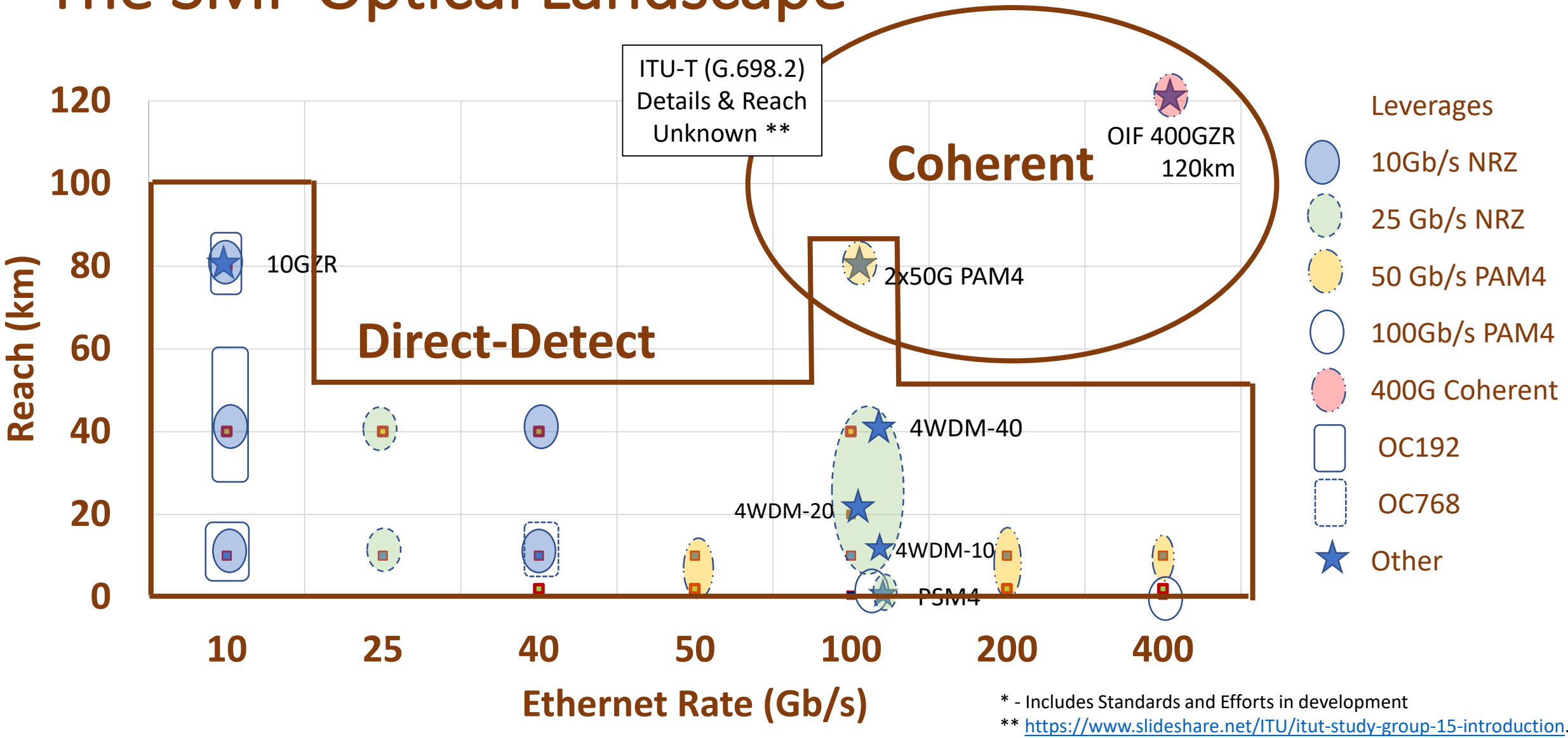
- CMTS – Cable Modem Termination System (Includes DOCSIS MAC/PHY and subscriber management)
- CCAP – Converged Cable Access Platform (Includes DOCSIS MAC/PHY)
- Remote PHY – only DOCSIS PHY included

Number of 100G optical units is derived from the node analysis in the Infonetics Study with these assumptions:

- ~12 nodes are aggregated onto a single 100 Gb/s distribution link
- Each link has 2 endpoints
- Each node is connected to the aggregation point @ 10 Gb/s
  - Current node bandwidth is @ 1-3 Gb/s
  - 10 Gb/s provides future headroom
- Redundancy is not included in numbers as this isn't a universal architecture amongst MSO's

The SMF Optical Landscape *



* - Includes Standards and Efforts in development
** https://www.slideshare.net/ITU/itut-study-group-15-introduction.