CFI Consensus - "Beyond 10km" PHYs

Draft Consensus Presentation

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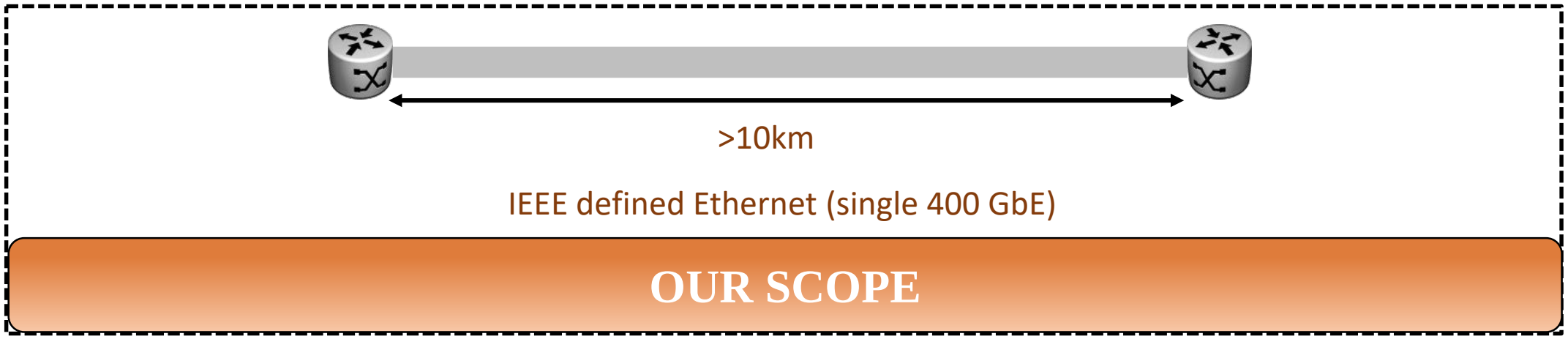
Objective for this Meeting

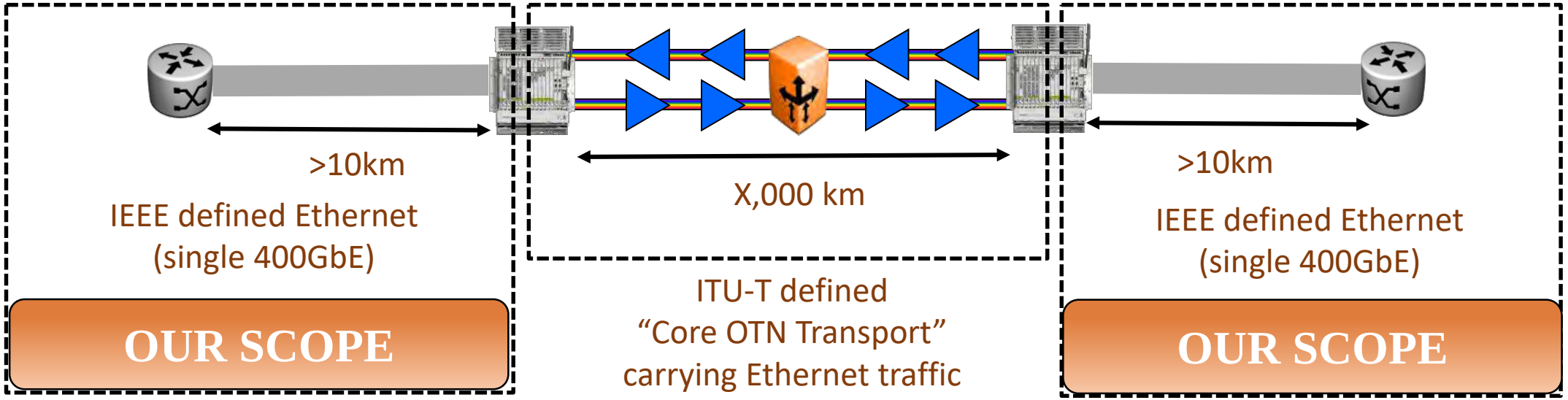
- To *measure the interest* in starting a study group to address:
  - Beyond 10 km Optics for 50GbE, 200GbE, and 400GbE PHYs
- We don't need to
  - Fully explore the problem
  - Debate strengths and weaknesses of solutions
  - Choose any one solution
  - Create PAR or five criteria
  - Create a standard or specification
- Anyone in the room may speak / vote
- RESPECT… give it, get it

What Are We Talking About?

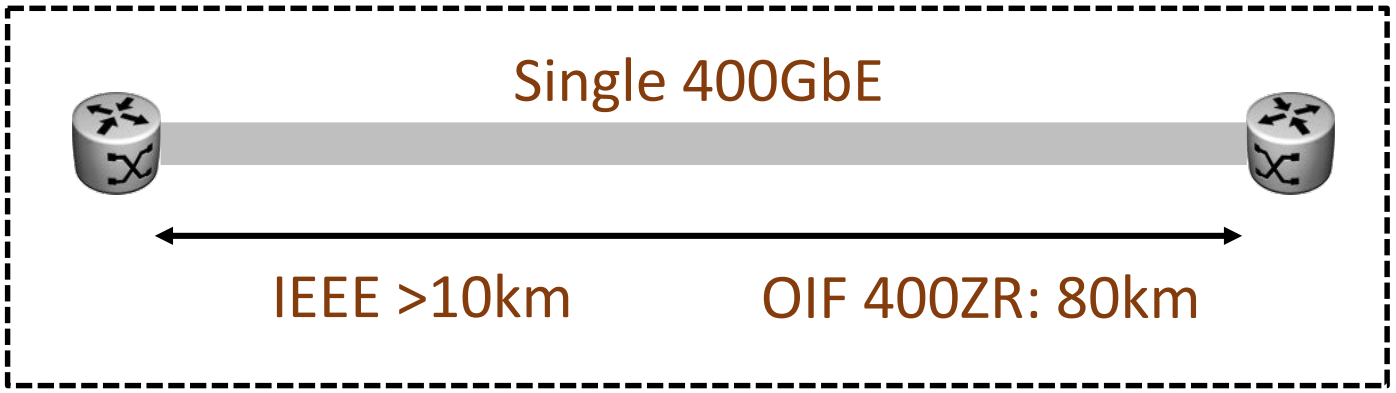
Scenario #1

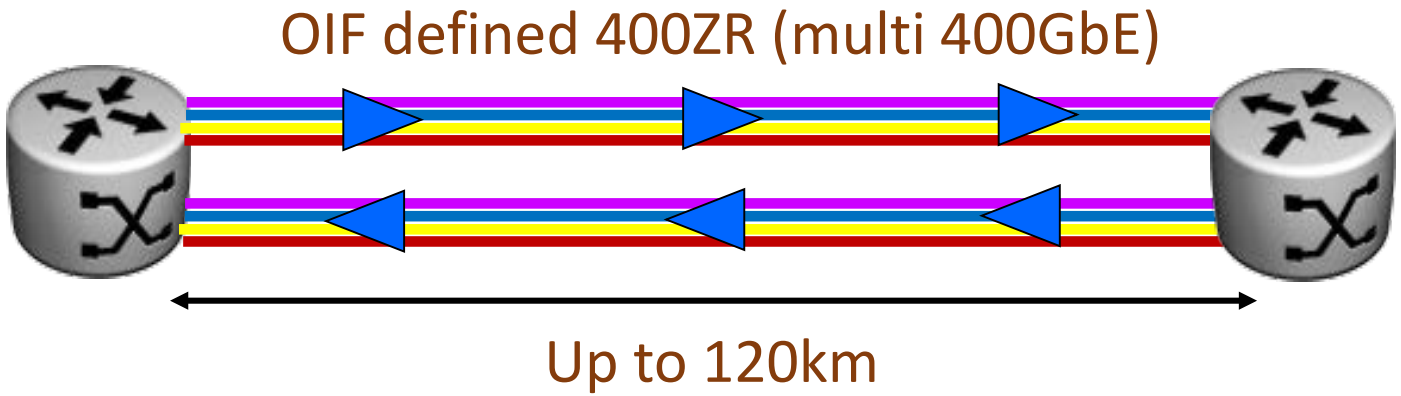


Scenario #2



400GbE and Potential Relationship to OIF 400ZR Data Center Interconnect (DCI) Solution





- **Coherent Optics is one potential solution to achieving reaches beyond 10km for 400GbE.**
- **It is not within the proposed scope of this effort to do a multi 400GbE coherent optical solution.**
- **It is recognized that a coherent solution developed by either organization could be leveraged for both application spaces.**

Agenda

- Addressing Reaches Beyond 10km
- The Technical Aspect- “Beyond 10km” PHYs

Addressing Reaches Beyond 10km

Today's P2P SMF Ethernet Family

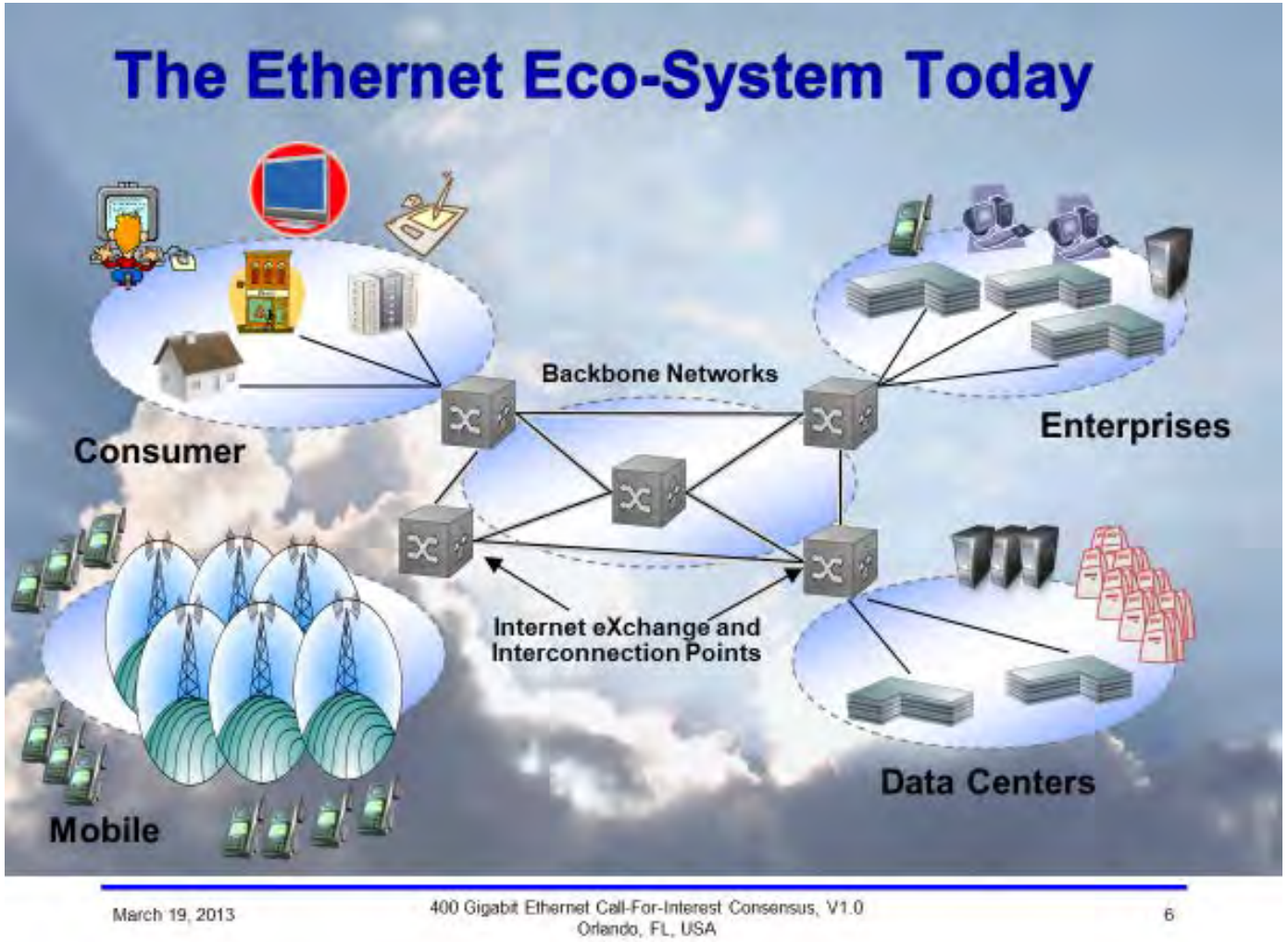
	500m PSM4	2km SMF	10km SMF	40km SMF
10GBASE-			LR	ER
25GBASE-			LR	ER
40GBASE-	PSM4	FR	LR4	ER4
50GBASE-		FR	LR	
100GBASE-	PSM4 DR	10X10 CWDM4 CLR4	LR4	ER4
200GBASE-	DR4	FR4	LR4	
400GBASE-	DR4	FR8	LR8	

Black Text IEEE Standard

Red Text In Standardization

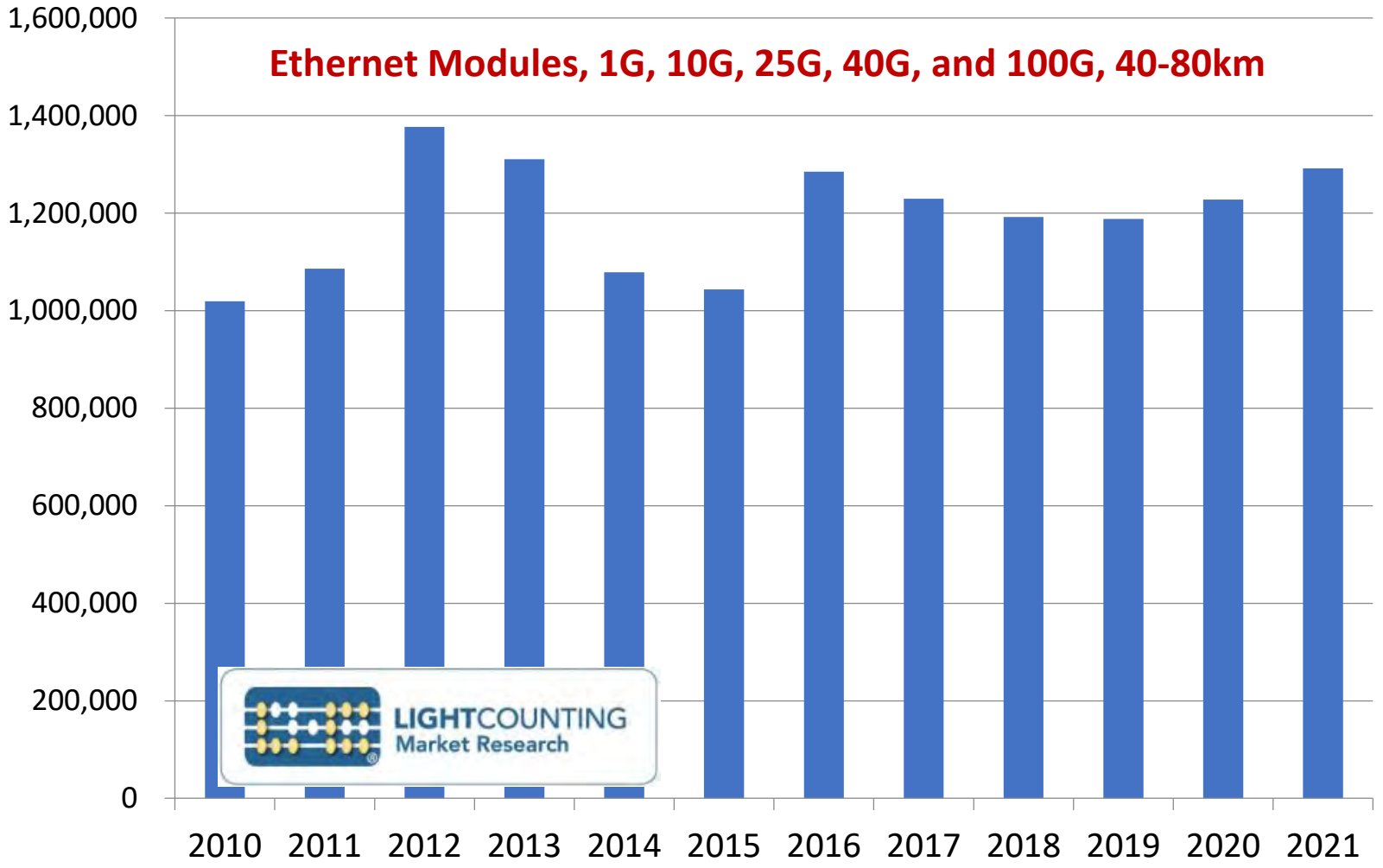
Blue Text Non-IEEE standard but complies to IEEE electrical interfaces

Beyond 10km Optics Throughout The Eco-System



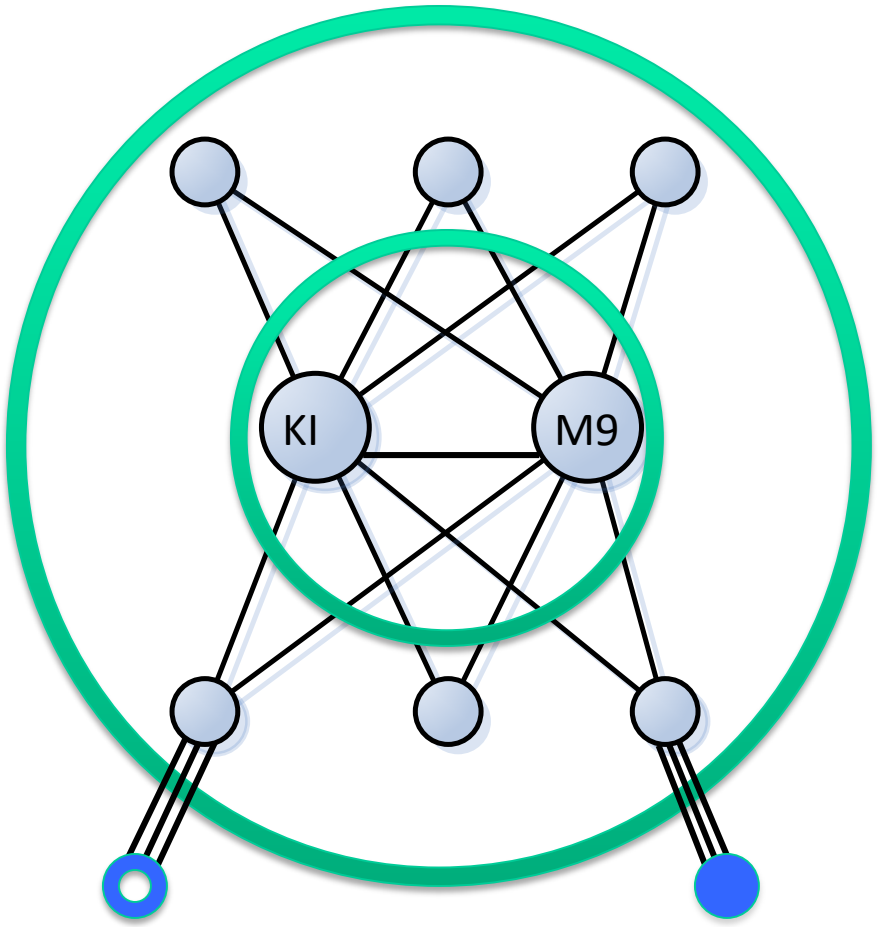
- Not “Data Center”
- Exists throughout the Eco-System
- 3M units for 40km and beyond shipped annually (see next page)
- Continuing bandwidth growth factors resonate throughout the ecosystem
- Not targeted by Ethernet standards for 50GbE, 200GbE, and 400GbE

Annual Shipments for 40km+ Applications



- For 100GbE, 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

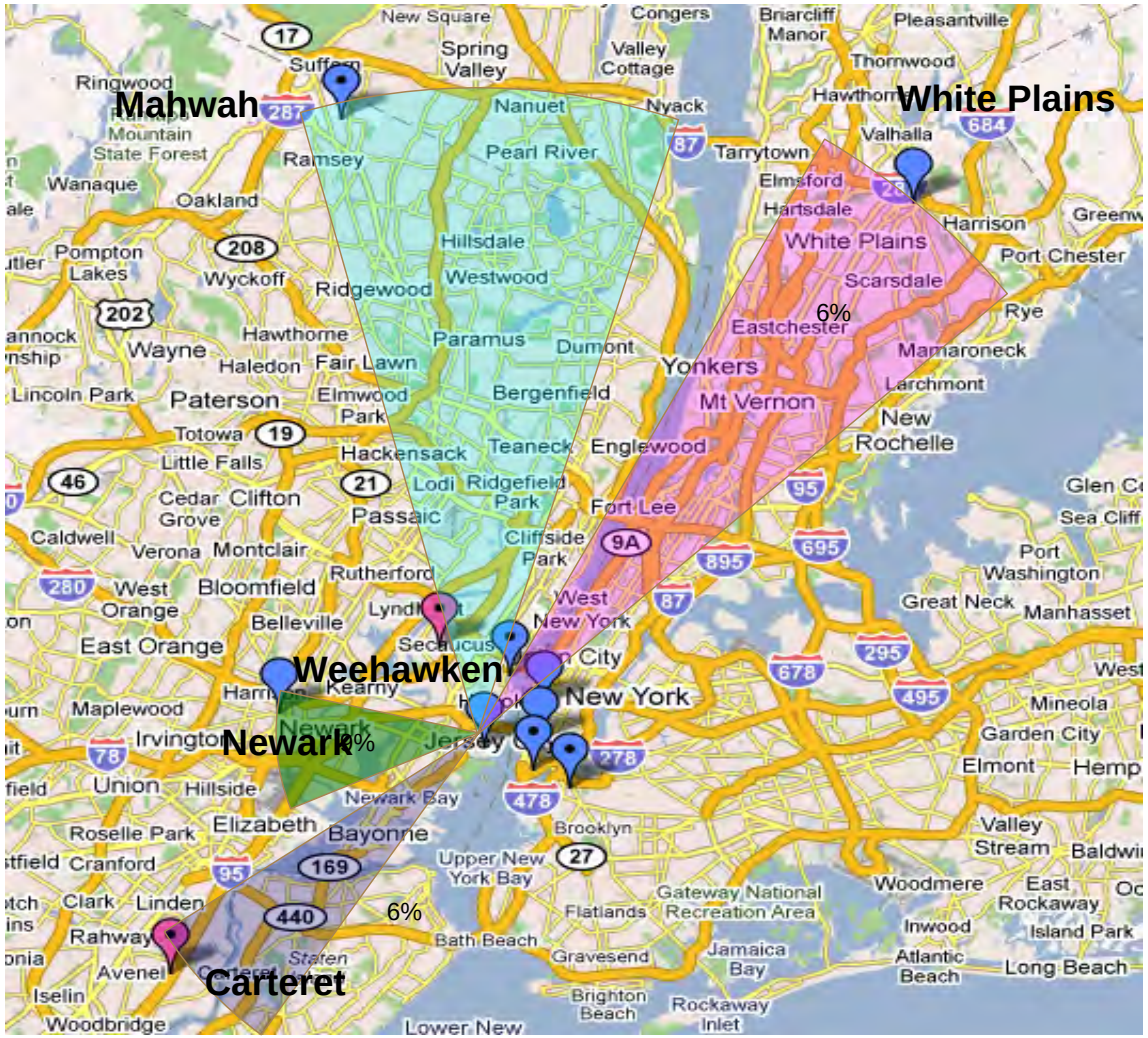
MSK-IX & Geographical Challenges



Courtesy: Alexander Ilin, MSK-IX

- MLAG interaction between KI & M9 (~40km distance)
- Passive 10G DWDM solution between core, predictable network size
- Smooth migration from old equipment to a new one
- Ring-topology concept:
  - Tier 0 – connect core to each other,
  - Tier 1 – core datacenters and switches,
  - Tier 2 – edge datacenters.
- Current capacity between several Tier1 switches and Core: 640Gbps (n x 10G) with Future plans 100G+ links between them.
- Need solution for 100G+ optical transceivers between Core & Tier1 up to 40 km

NY, USA Financial Industry & Geographical Challenges



Note: All locations a for illustration purposes only and do not reflect actual locations

Weehawken, NJ

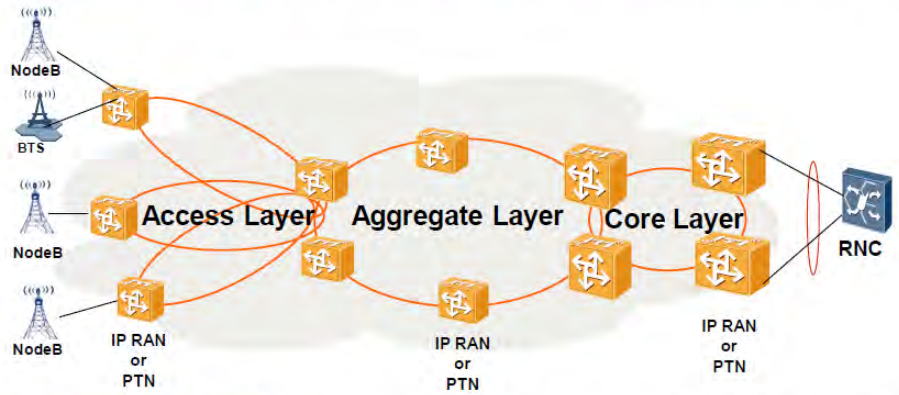
- Carrier Access (Global) / Co-location Facility
- Used extensively by Financial Industry to support:
  - Connections to carrier access & hosting centers
  - Connections to "Execution Venues"
- Connections (Line of Sight)
  - Newark, NJ (16 km)
  - Carteret, NJ (32 km)
  - White Plains, NY (40 km)
  - Mahwah, NJ (42km)

Source: Andrew Bach, Independent

Note – Content currently in development and may be updated

Mobile Backhaul Demand for Beyond 10km

40km Reach in Mobile Backhaul Network



- In huang_ecdc_01_0716 and observation from shipment in Carrier network, 40km volume is increasing

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%

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Source: Xinyuan Wagng Huawei,
http://www.ieee802.org/3/ad_hoc/ngrates/public/16_09/wang_ecdc_01_0916.pdf

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				
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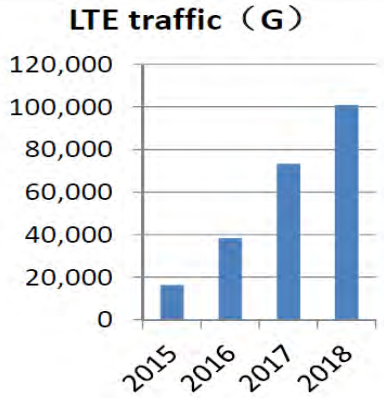
10GE distribution	0.28%	44.46%	44.05%	11.20%
100GE distribution (more than 15K modules)	0	56.43%	34.59%	8.97%

- 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.



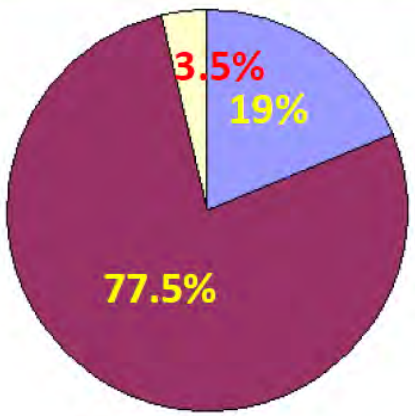
Source: Huang/ Cheng, China Mobile,
http://www.ieee802.org/3/ad_hoc/ngrates/public/16_07/huang_ecdc_01_0716.pdf

CAICT 中国信通院

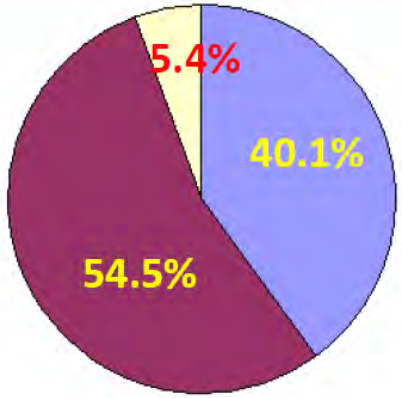
Aggregation node distance from actual networks

As metro core usually use WDM/OTN to extend reach distance of Ethernet interface, therefore current aggregation layer transmission distance is crucial to the future higher bitrate interface, such as 200GE and 400GE,etc.

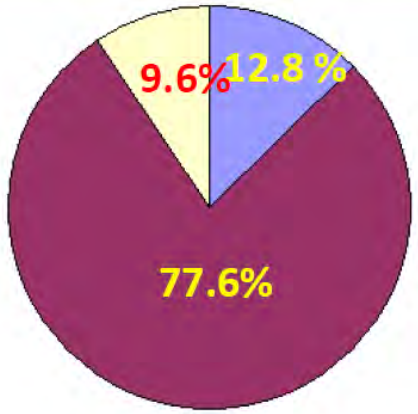
Furthermore, each metro network may has its own distribution characteristic of reach distance, and some metro aggregation layer node distance from actual networks in China are investigated, and these nodes would has the requirement to deploy link capability more than 10GE.



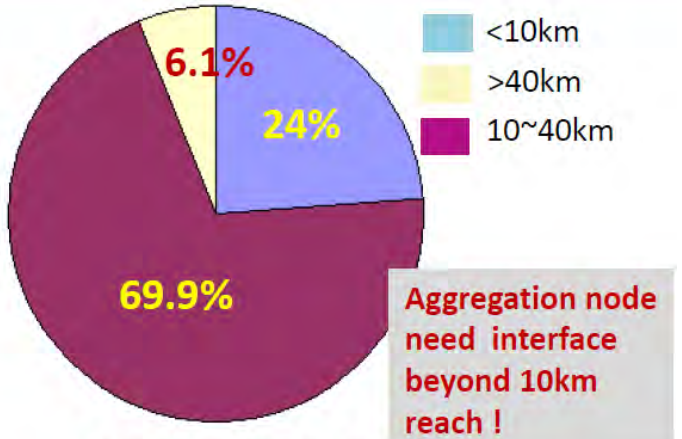
Province A some metro aggregation layer reach distribution



Province B some metro aggregation layer reach distribution



Province C some metro aggregation layer reach distribution



Some metro aggregation layer reach distribution (ave.)

Aggregation node need interface beyond 10km reach !

IEEE 802.3 NG-ECDC Ad Hoc, July, 2016 , San Diego

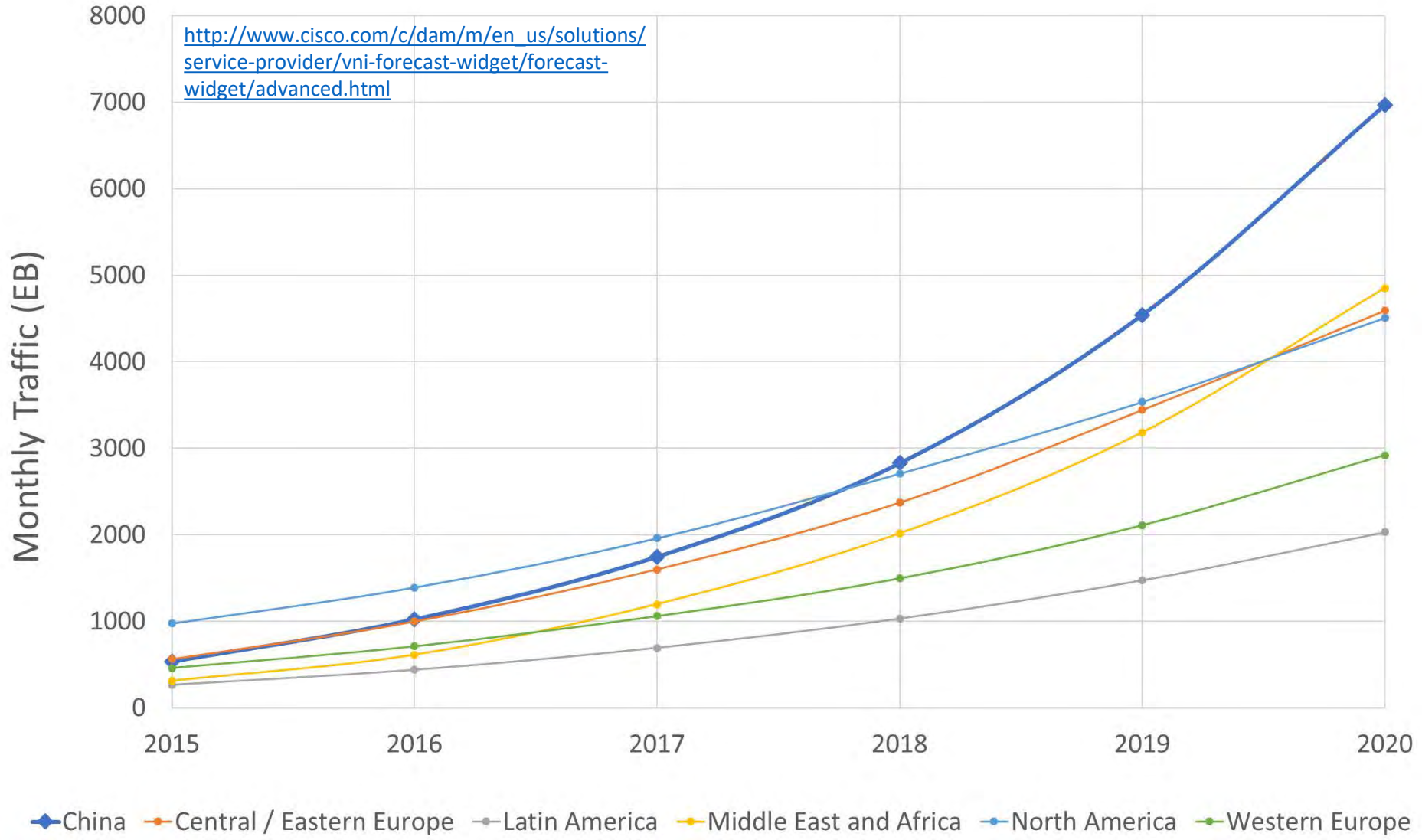
Source: Wenyu Zhao, CAICT<
http://www.ieee802.org/3/ad_hoc/ngrates/public/16_07/zhao_ecdc_01_0716.pdf

Summary Observed Reaches - Telecom

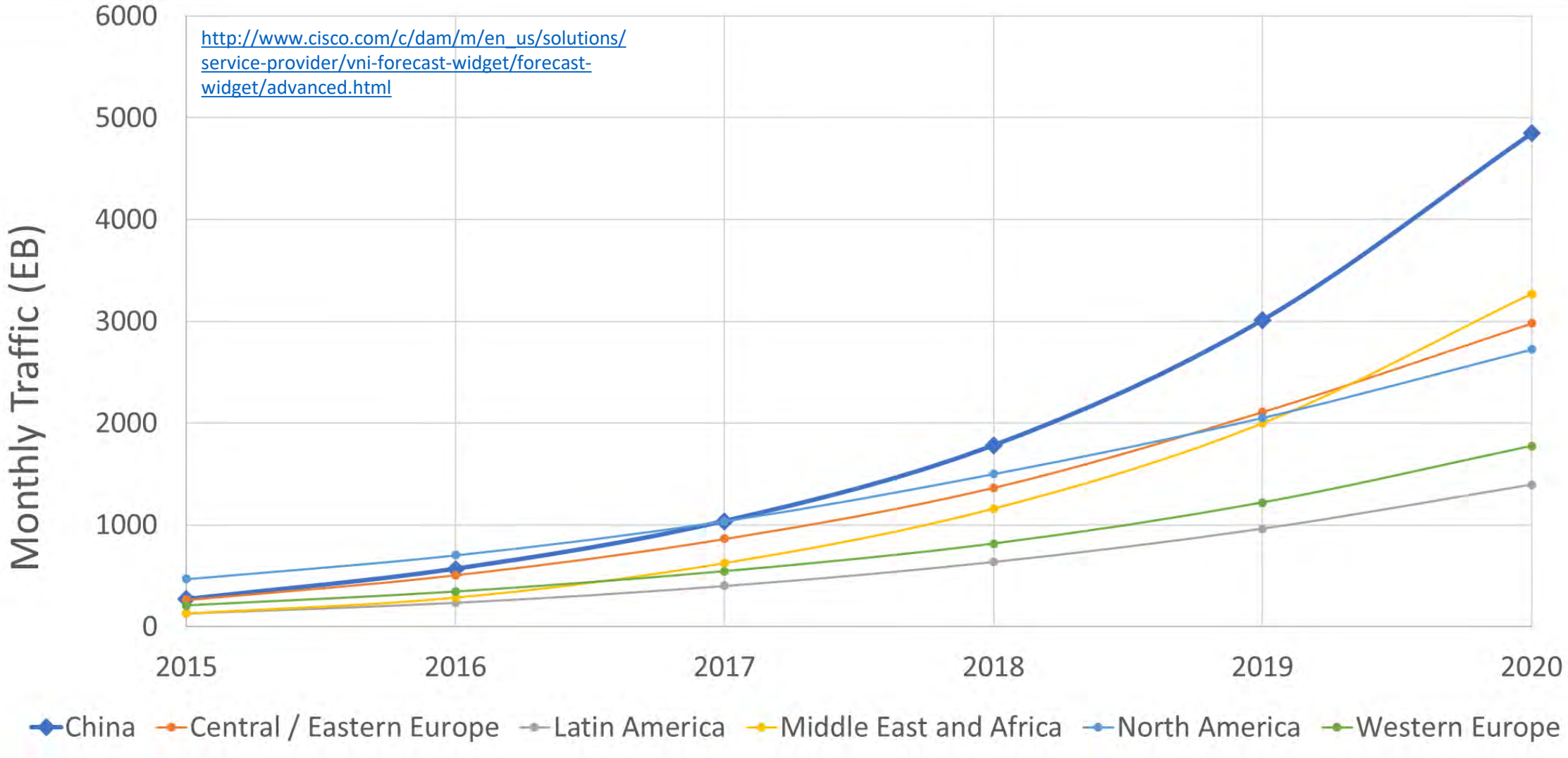
Source		<2km	10km	40km	>40km	80km
China Mobile *	10GbE	0.3%	44.5%	44.1%	-	11.2%
	100GbE	0	56.4%	34.6%	-	9.0%
CAICT Aggregation Nodes **	Province A	-	19.0%	77.5%	3.5%	-
(200GbE / 400GbE)	Province B	-	40.1%	54.5%	5.4%	-
	Province C	-	12.8%	77.6%	12.8%	-
	Province D	-	24%	69.9%	6.1%	-
LightCounting	10 GbE	- ***	93%	5.4%	-	1.6%
	10 GbE Telecom	0	76%	17%	-	7%

* - Source: Huang/ Cheng, China Mobile, http://www.ieee802.org/3/ad_hoc/ngrates/public/16_07/huang_ecdc_01_0716.pdf
** - Source: Wenyu Zhao, CAICT< http://www.ieee802.org/3/ad_hoc/ngrates/public/16_07/zhao_ecdc_01_0716.pdf
*** - 10GLR "Subspec" volume not included for this analysis

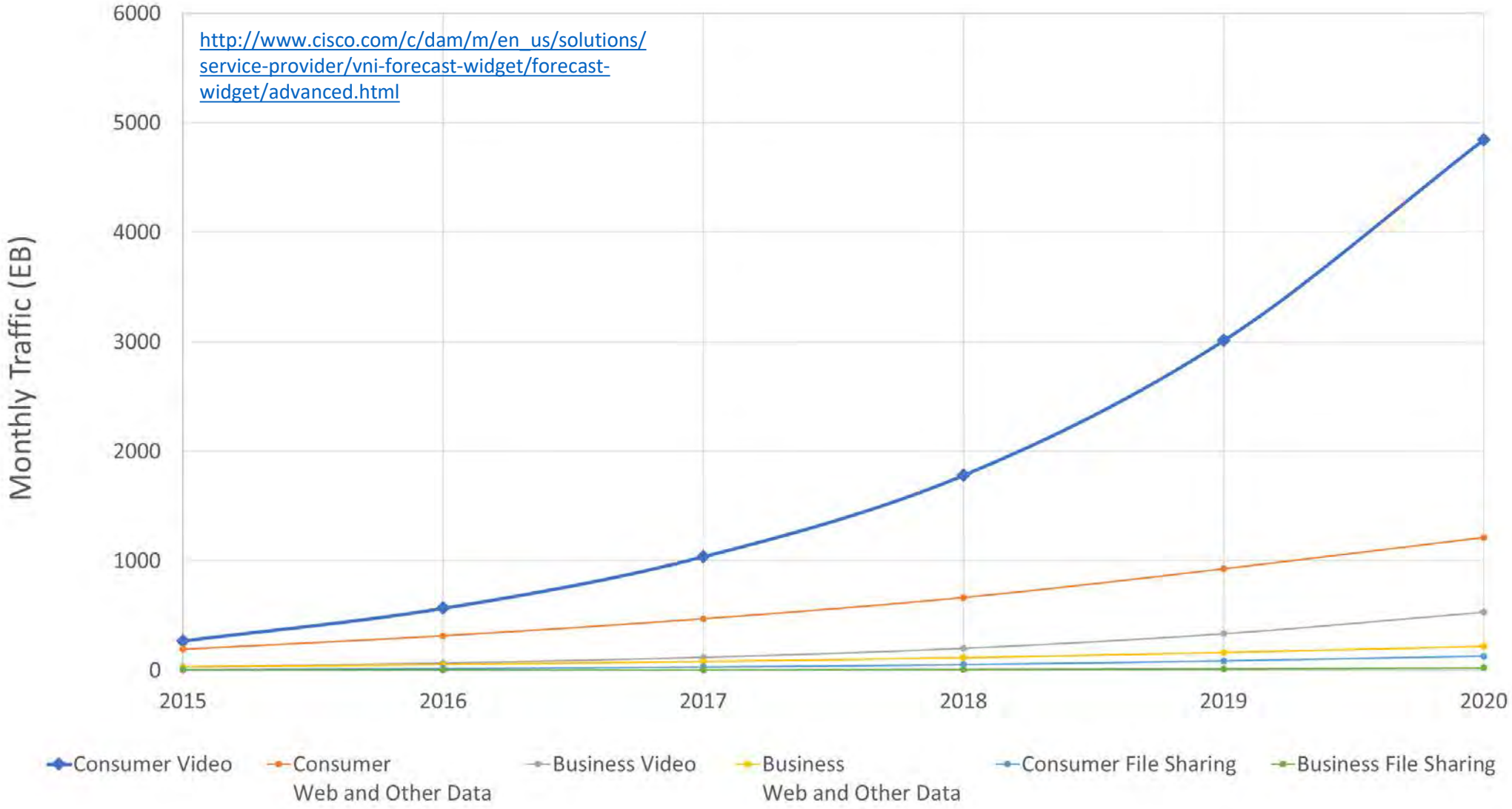
Mobile Networks Bandwidth Trends



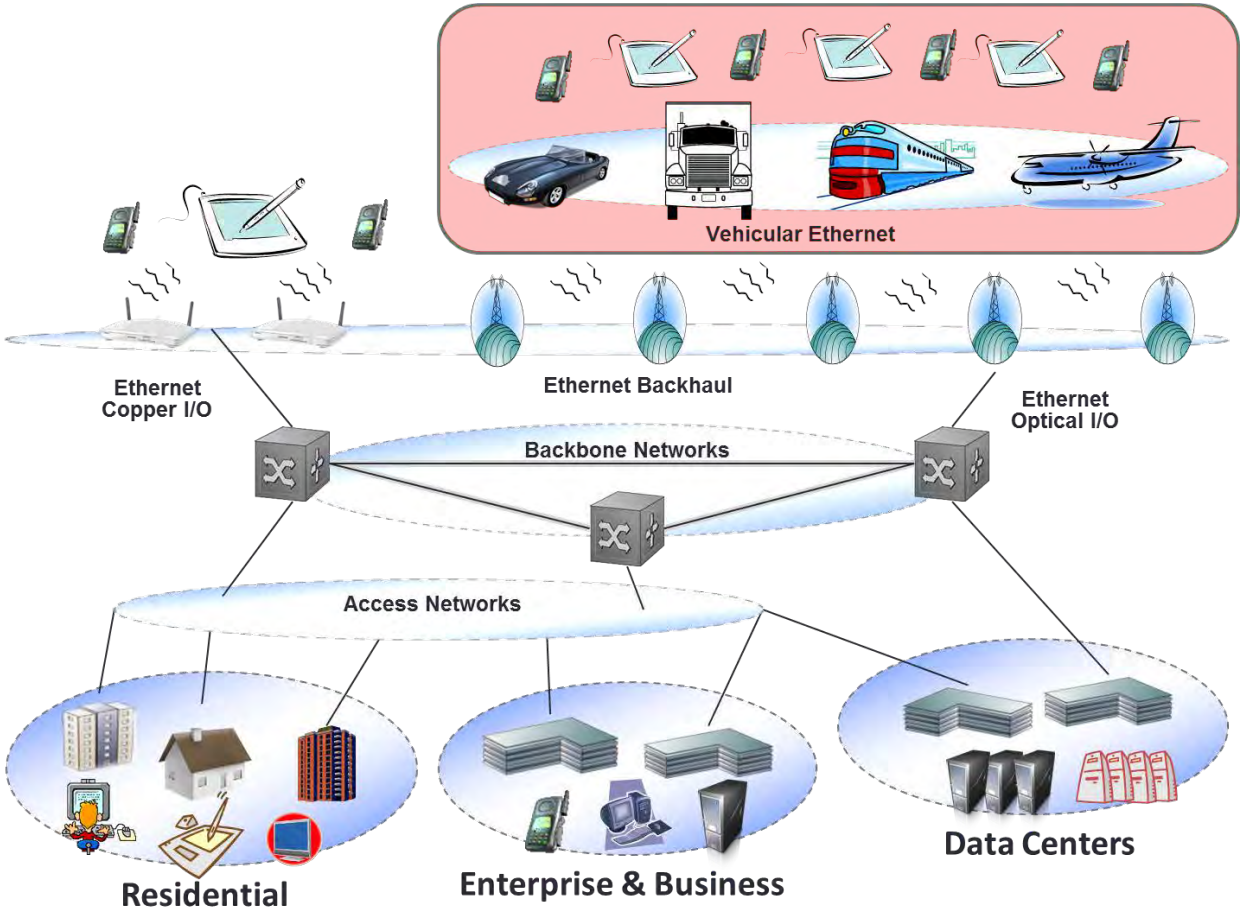
Consumer Video on Mobile Networks



Mobile Networks - Application Bandwidth - China



Emerging Bandwidth Driver - Connected Cars



- 802.3 BWA Growth
  - Increased # users
  - x Increased access rates / methods
  - x Increased services

  BANDWIDTH EXPLOSION
- 2019- 117 Million Vehicles to be produced *
- Vehicular access ?
  - Car Cellular Connection(s)
  - Passenger cell Phone
- Applications –
  - Automotive navigation / real time in-car data sharing
  - Automotive (firmware update/ regulatory)
  - Infotainment
  - Emerging Applications TBD

Source: carlson_400_01_1113.pdf

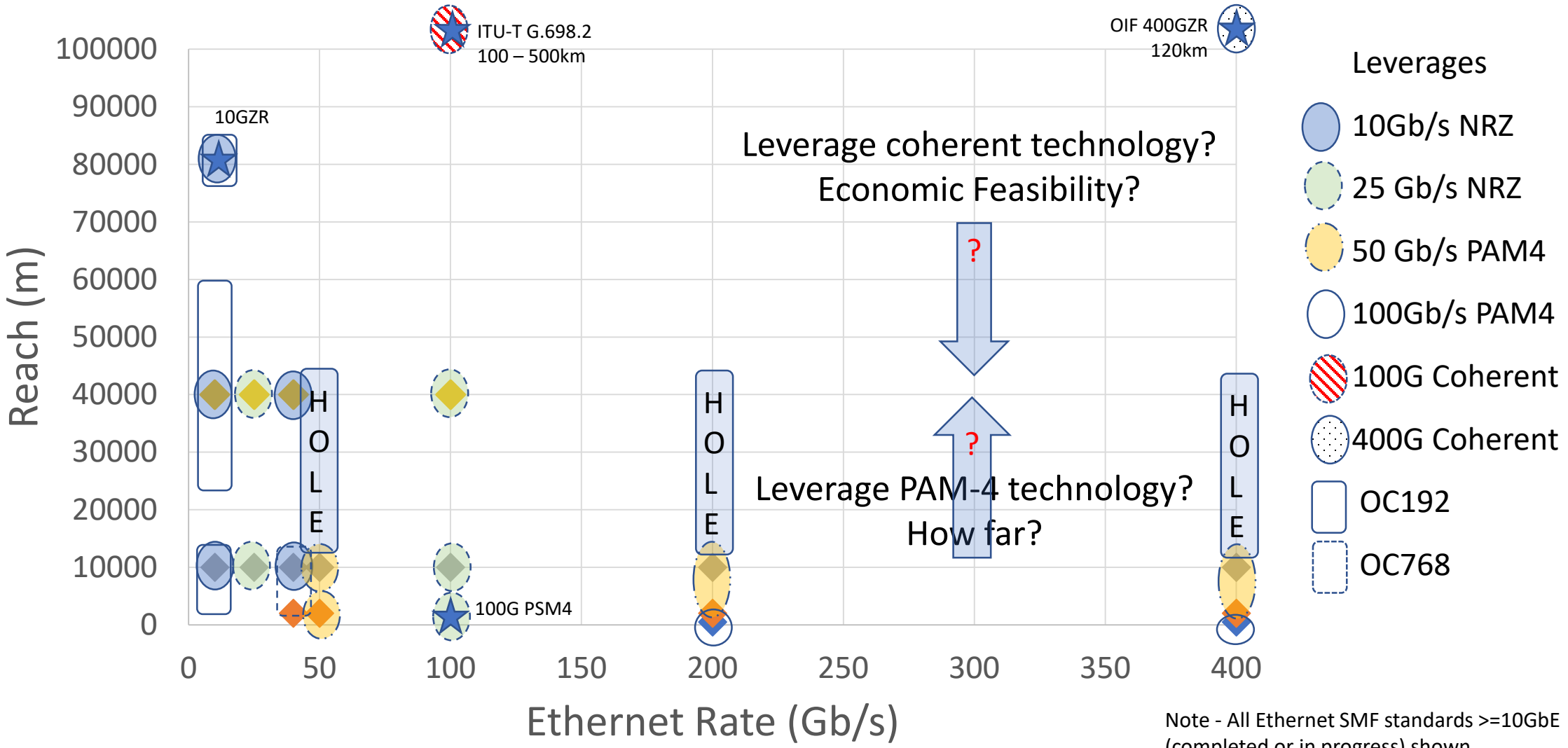
* CFI Multi-Gig Automotive Ethernet PHY

Summary

- 3M units (GbE to 100GbE) for 40km and beyond shipped annually
  - Not a data center application!
  - Bandwidth growth throughout EcoSystem
- "Geographically challenged" applications exist throughout Ecosystem
  - Internet Exchanges
  - Financial Industry
  - Mobile Backhaul
- China – Mobile Networks
  - Traffic in China alone exceeds other regions of the world
  - Consumer video driving application
- Emerging applications to drive future traffic over mobile networks

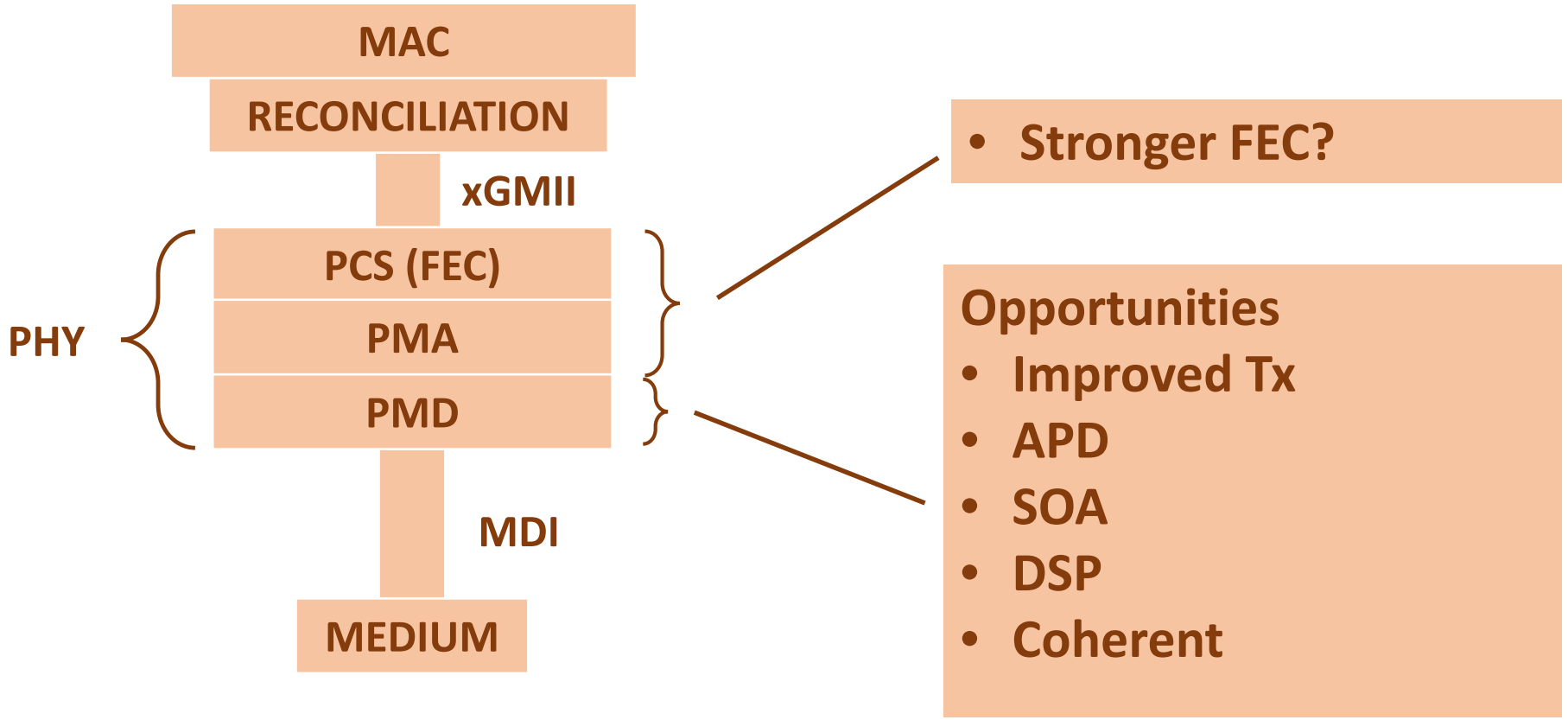
The Technical Aspect- “Beyond 10km” PHYs

Industry P2P Optical Standards and Solutions

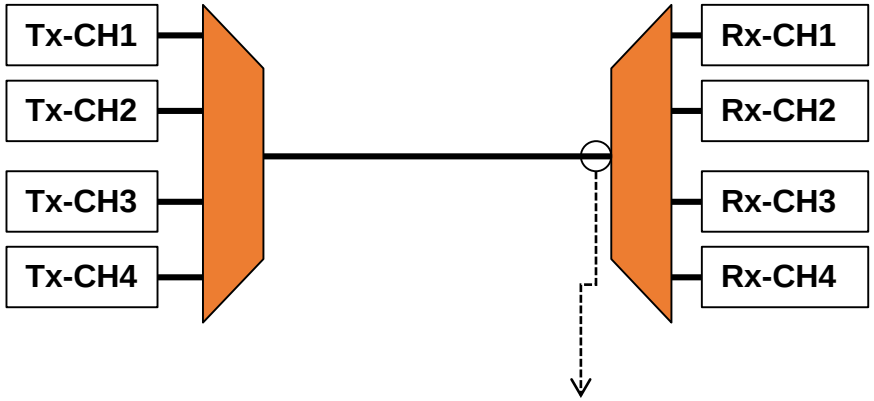


Note - All Ethernet SMF standards >=10GbE (completed or in progress) shown.

An Ethernet Overview of the Problem



4X50G PAM4 System Performance: BER



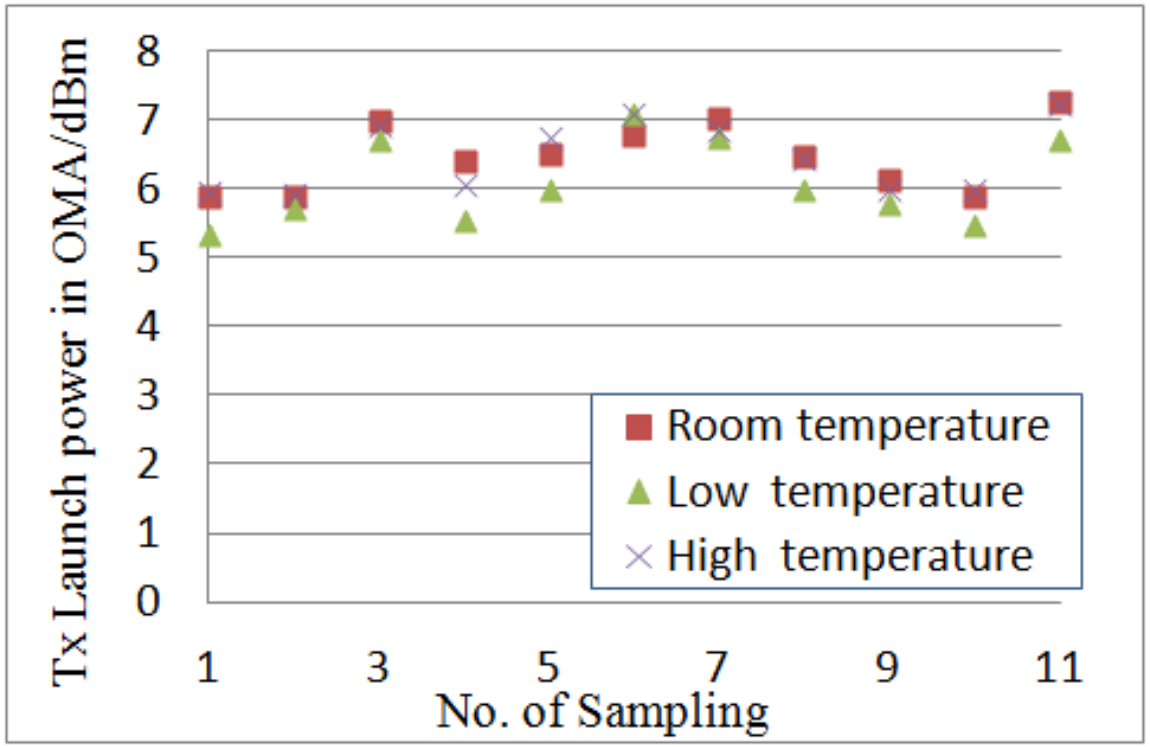
- Test method
  - Online test
  - All of optical devices are commercially available
  - Tx power (OMA) was adjusted to 5dBm

- Best/Worst case of BER test result of 11 random samples

	Tx Power (OMA dBm)	Rx Sensitivity (OMA dBm)	Budget (dB)	Temp (℃)	BER
Sample 1	5	-18.6	23.6	25	2.4E-4
Sample 2	5	-17.9	22.9	25	2.4E-4

Source: Xu Yu, Huawei

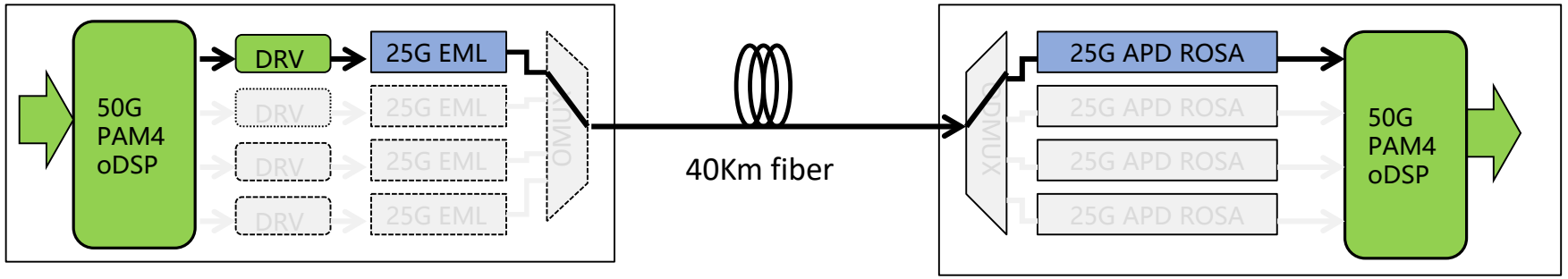
Tested Result of Transmitter Output Power



- 11 samples were tested in whole temperature range
- All of TX output power are higher than 5dBm, even under worst case.

Source: Xu Yu, Huawei

1X50G PAM4 System Performance: Dispersion Penalty



Suggested wavelength assignments:
Same wavelength as 50GBASE-LR

Lane	Center Wavelength	Wavelength Range
CH	1311nm	1304.5 to 1317.5 nm

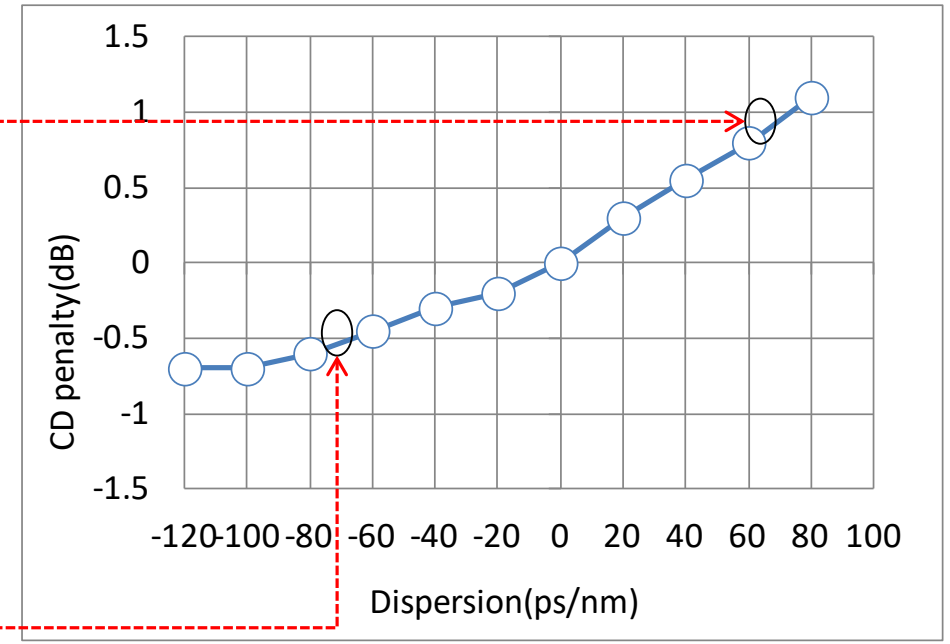
Worst case dispersion analysis:

$$Dispersion\ min.: 0.2325 * \lambda * \left[1 - \left(\frac{1324}{\lambda}\right)^4\right]$$

$$Dispersion\ max.: 0.2325 * \lambda * \left[1 - \left(\frac{1300}{\lambda}\right)^4\right]$$

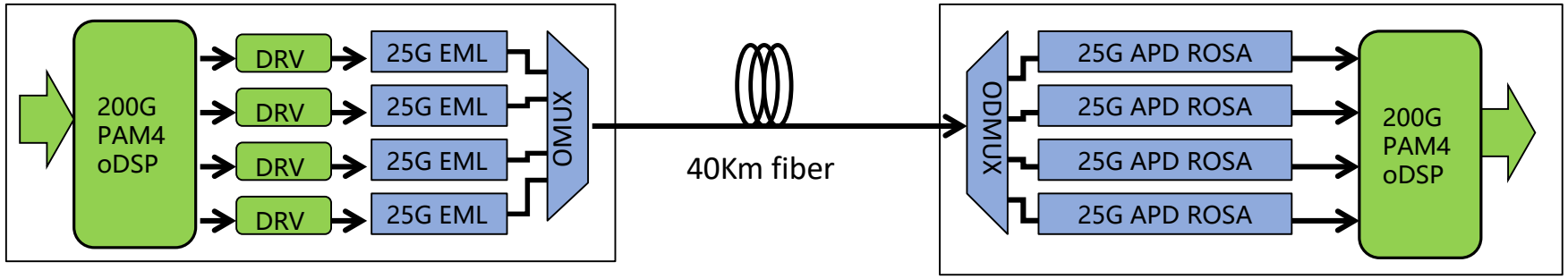
Item	Wavelength (nm)	Dispersion (λ_0=1300) ps/nm	Dispersion (λ_0=1324) ps/nm
1	1317.5	**+63.81**	--
2	1304.5	--	**-74.18**

Dispersion Penalty @2.4E-4



Source: Xu Yu, Huawei

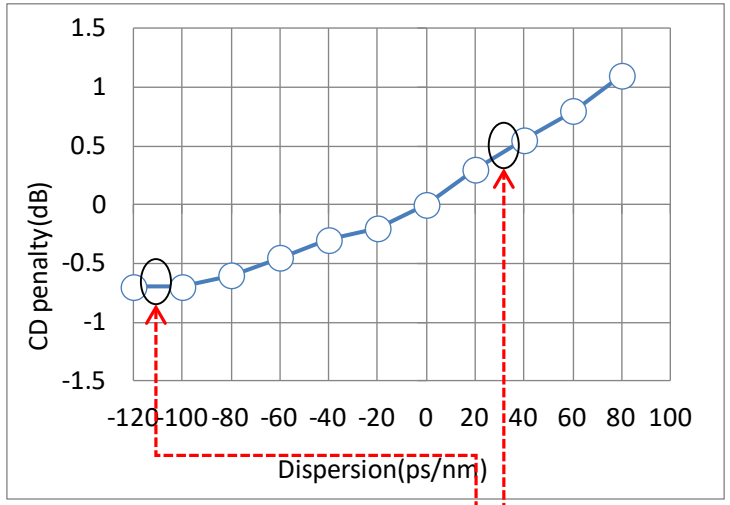
4X50G PAM4 System Performance: Dispersion Penalty



Suggested WDM assignments:
Same wavelength as 200GBASE-LR4

Lane	Center Frequency	Center Wavelength	Wavelength Range
L0	231.4THz	1295.56nm	1294.53~1296.59 nm
L1	230.6THz	1300.05nm	1299.02~1301.09nm
L2	229.8THz	1304.58nm	1303.54~1305.63nm
L3	229THz	1309.14nm	1308.09~1310.19nm

Dispersion Penalty @2.4E-4



Worst case dispersion analysis:

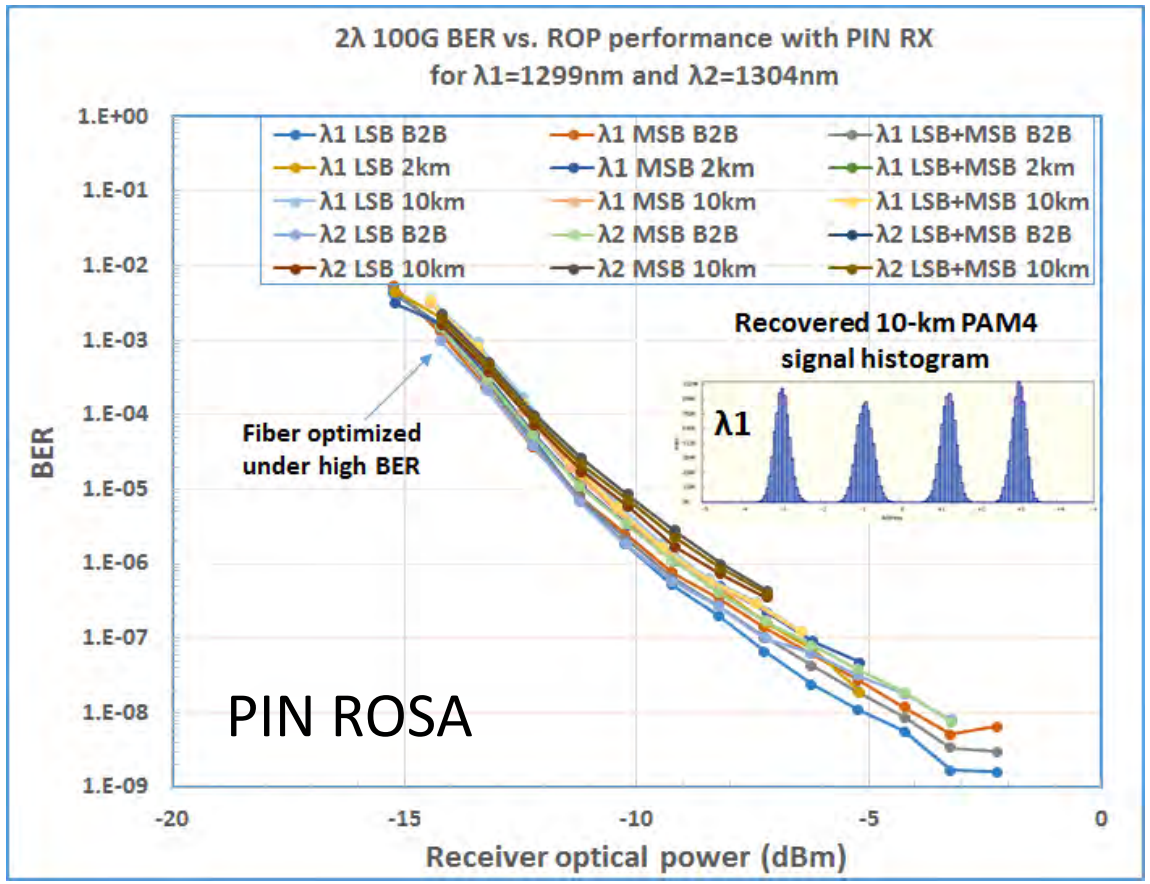
$$Dispersion\ min.: 0.2325 * \lambda * \left[1 - \left(\frac{1324}{\lambda}\right)^4\right]$$

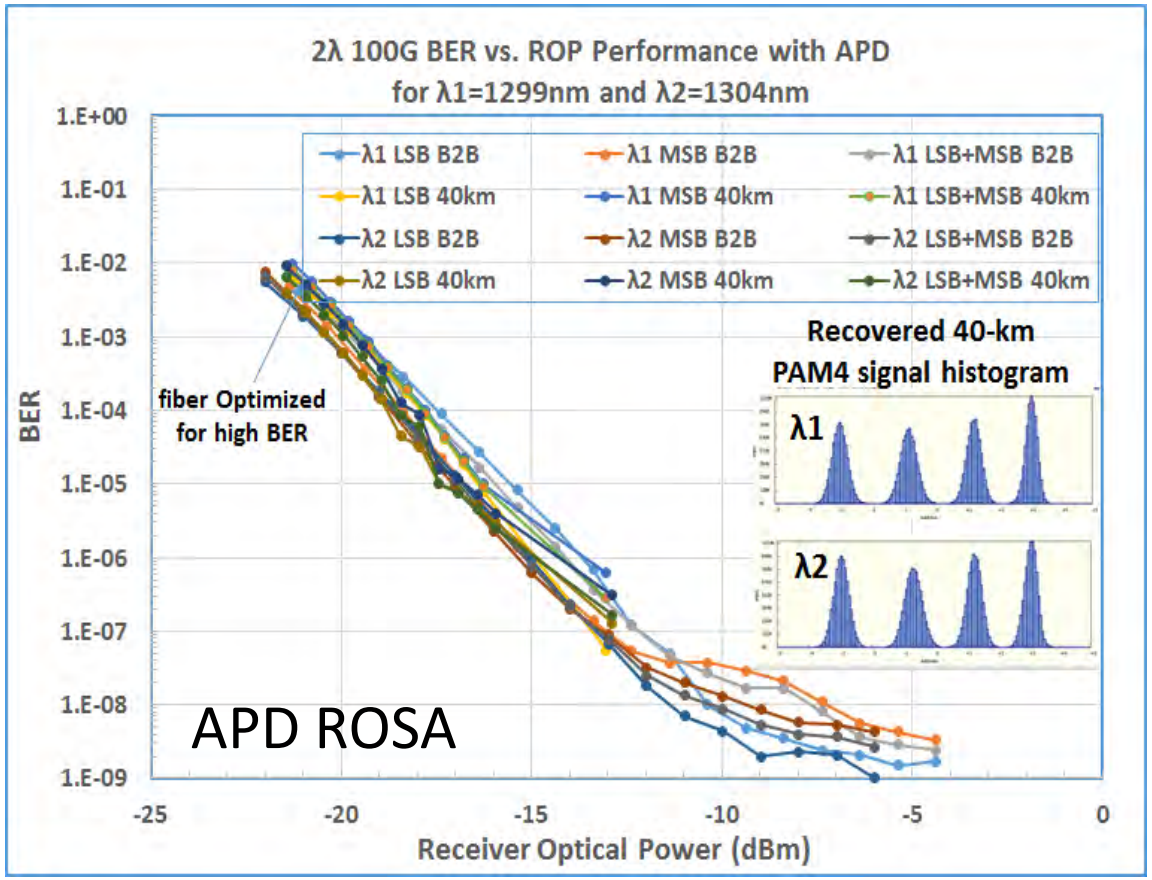
$$Dispersion\ max.: 0.2325 * \lambda * \left[1 - \left(\frac{1300}{\lambda}\right)^4\right]$$

Lane	Wavelength (nm)	Dispersion (λ0=1300) ps/nm	Dispersion (λ0=1324) ps/nm
L0	1294.53	--	**-113.43**
L3	1310.19	**+37.47**	--

Source: Xu Yu, Huawei

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

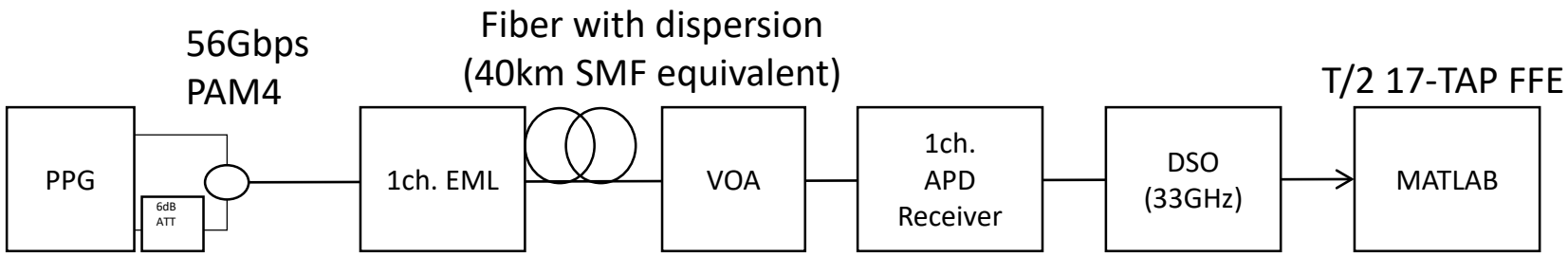


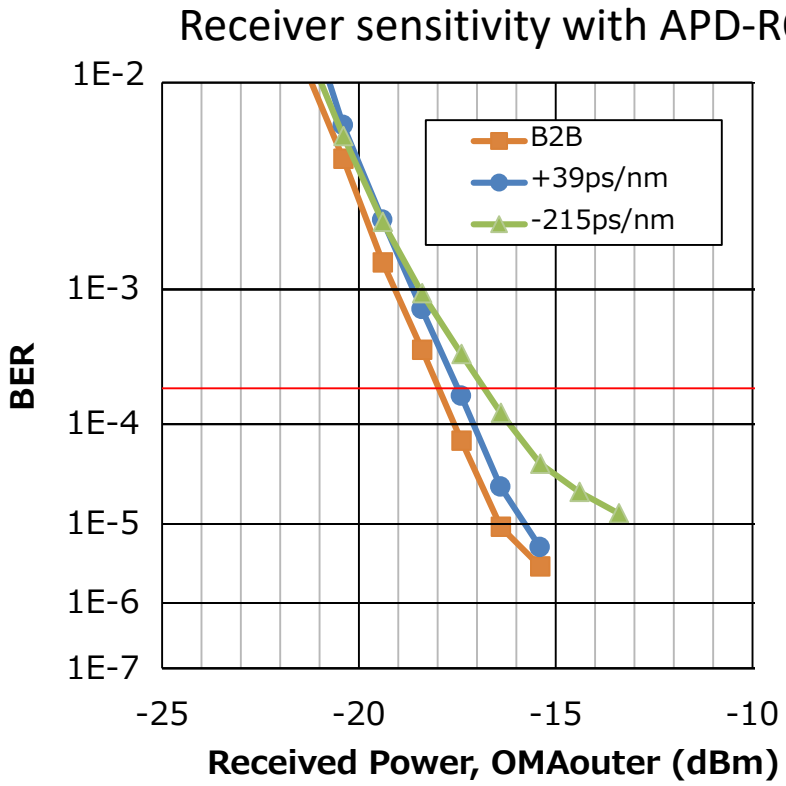


Data: PRBS^31
Used actual chip implementation with real-time DSP embedded inside the silicon

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

Receiver sensitivity with APD ROSA





56G PAM4 reach extension is achieved.

APD receiver can achieve rec. sensitivity of
-16.7 dBm for the worst case dispersion(neg.)*
-18.0 dBm for the worst case dispersion (B2B)
(* assumed 8-lane LAN-WDM over SMF)

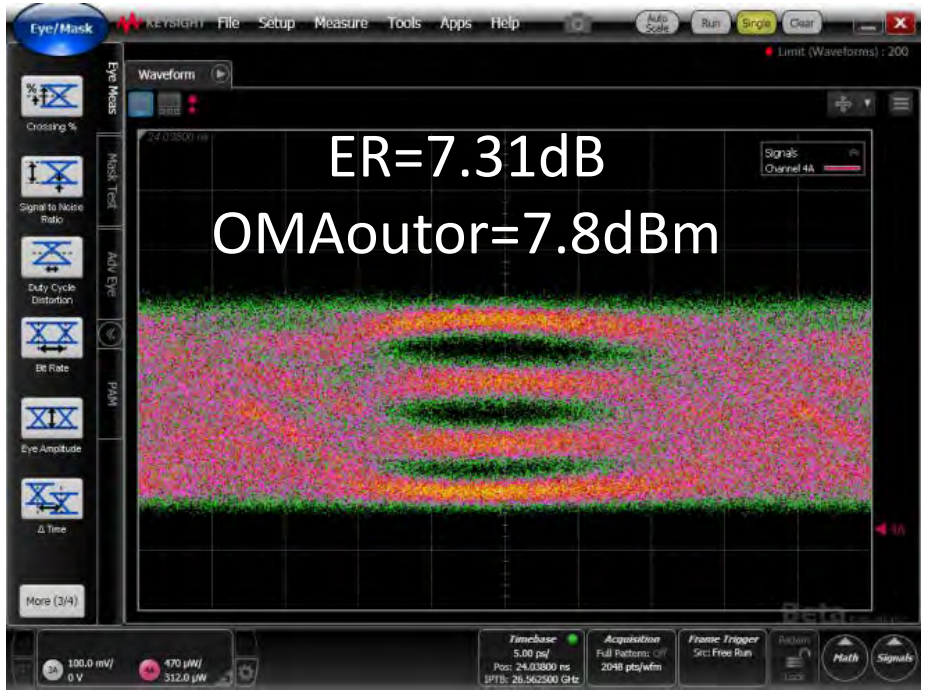
Assuming KP4 FEC but still 56Gpps can
Accommodate stronger FEC overhead.

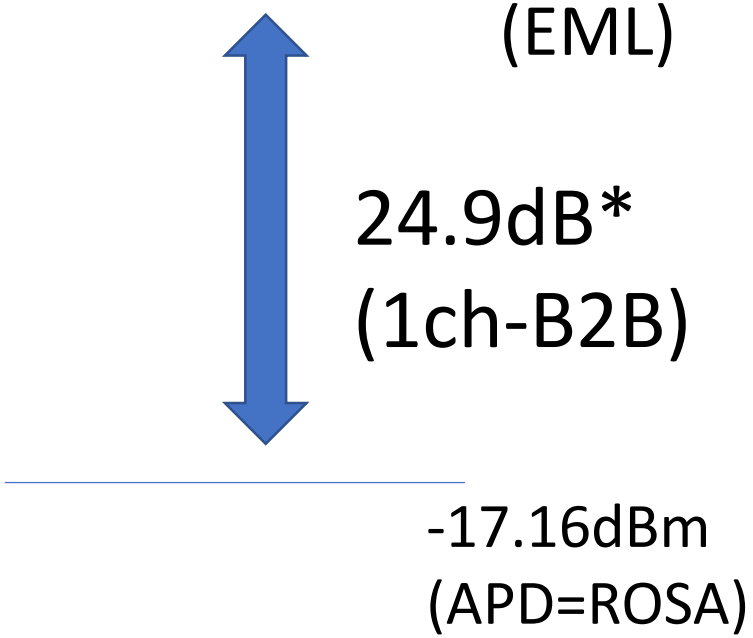
Source: Yoshiaki Sone, NTT

Link budget example with High-power EML

Evaluation result using high power EML and APD-ROSA
Link-budget=24.9dB (1ch B2B, KP4 FEC limit)

PAM4 tx eye with high power EML





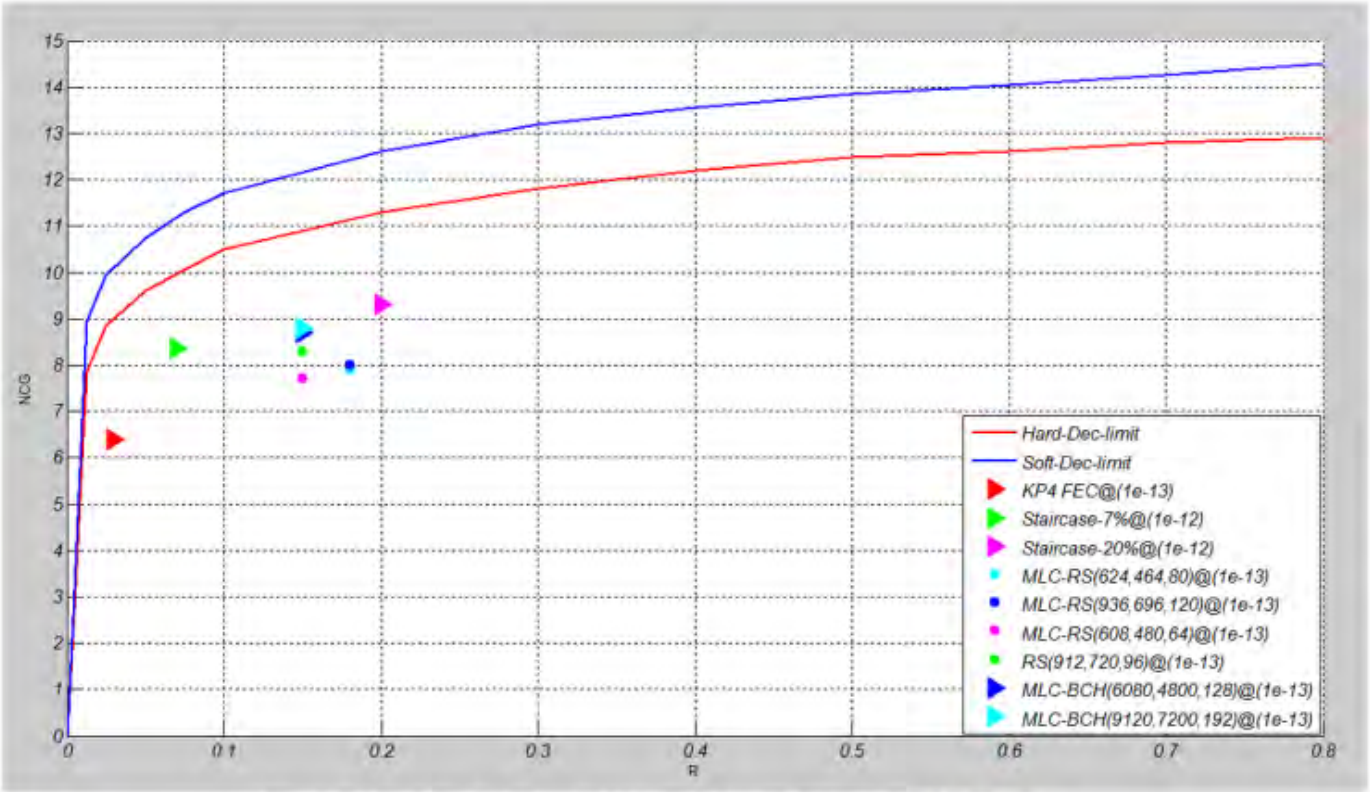
* WDM mux/demux loss is not included

Source: Yoshiaki Sone, NTT

Beyond 10km :Stronger FEC

Several Potential HD-FECs with 8-9dB NCG can help to achieve beyond 10km 400GbE

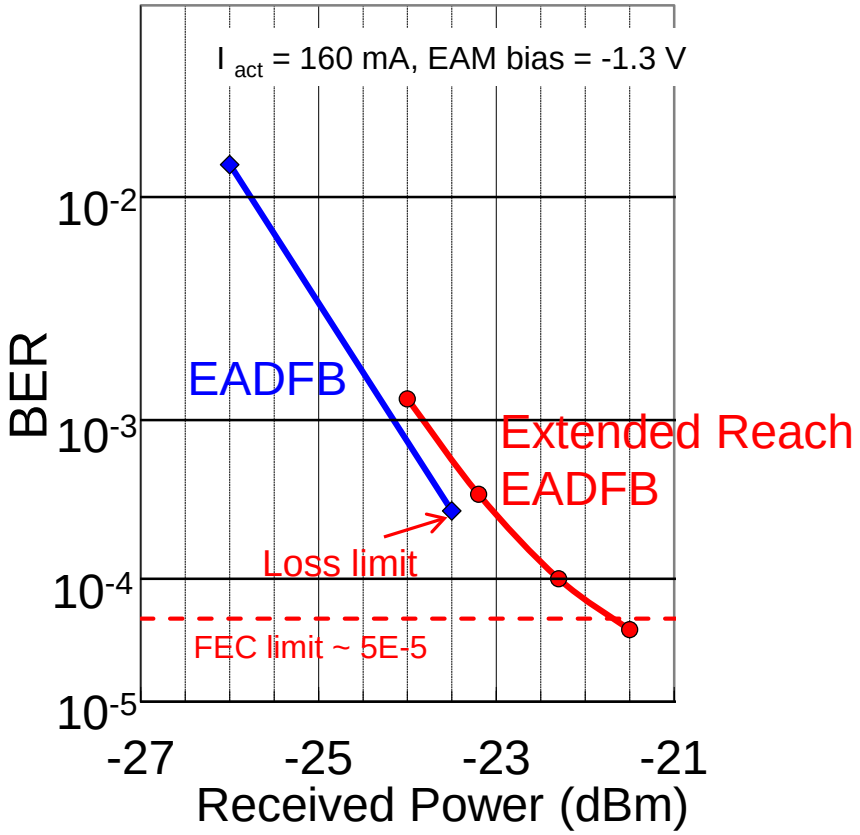
RS-FEC, BCH-FEC, MLC-FEC or Staircase FEC. (wang_ecdc_01_0316)

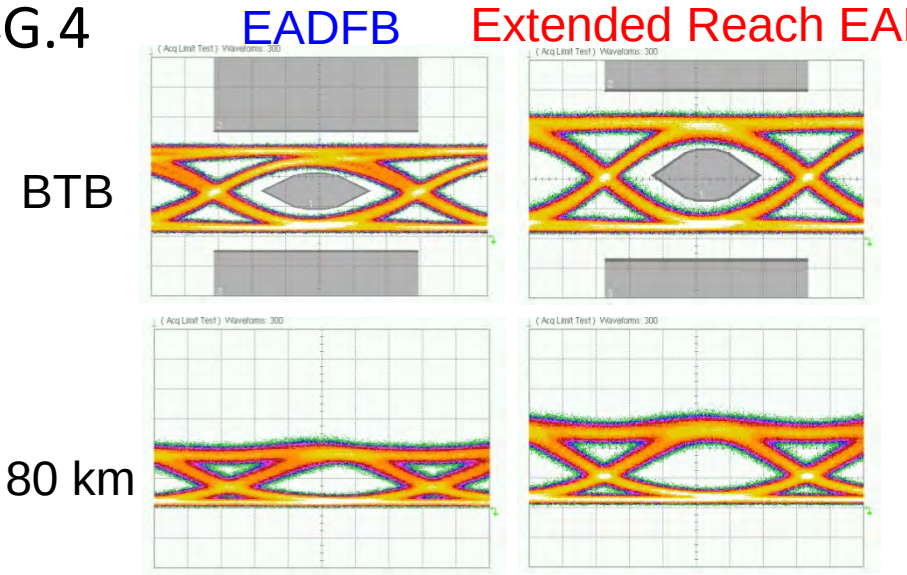


NCG for HG FEC options, Assuming post BER@1E-13 objective.

Emerging latest technology in OFC2017

Hasebe et.al, OFC2017, paper Th4G.4





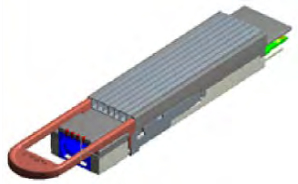
Output power(dBm)	5.7	8.7
Extinction ratio (dB)	8.5	8.9
OMA (dBm)	7.5	10.4
Mask margin	8%	9%

Achievement: 28 Gbit/s, 80-km transmission
Modulated average power P_{avg} = 8.7 dBm

The OIF 400ZR Project

- Implementation agreement (IA) for pluggable digital coherent optical (DCO) modules
  - Passive single channel ZR (80km)
  - Amplified short-reach DWDM applications with distances up to 120 km
- Single-carrier 400 G, coherent detection and advanced DSP / FEC algorithms.
- Operates as a 400 GbE PMD compatible with 400G-AUI.
- Other formats could be considered in the project as well.
- Supporters from more than 34 companies, including end users, system and component suppliers. Unanimous support for start of project

OIF Liaions to IEEE 802.3:
http://www.ieee802.org/3/minutes/nov16/incoming/OIF_to_IEEE_802d3_Nov_2016.pdf



Form Factor

Targeting coherent optics in client pluggable form factors <15W
(see next slide)

Assumes tunable λ not required for this application

Source: Tom Williams, Acacia

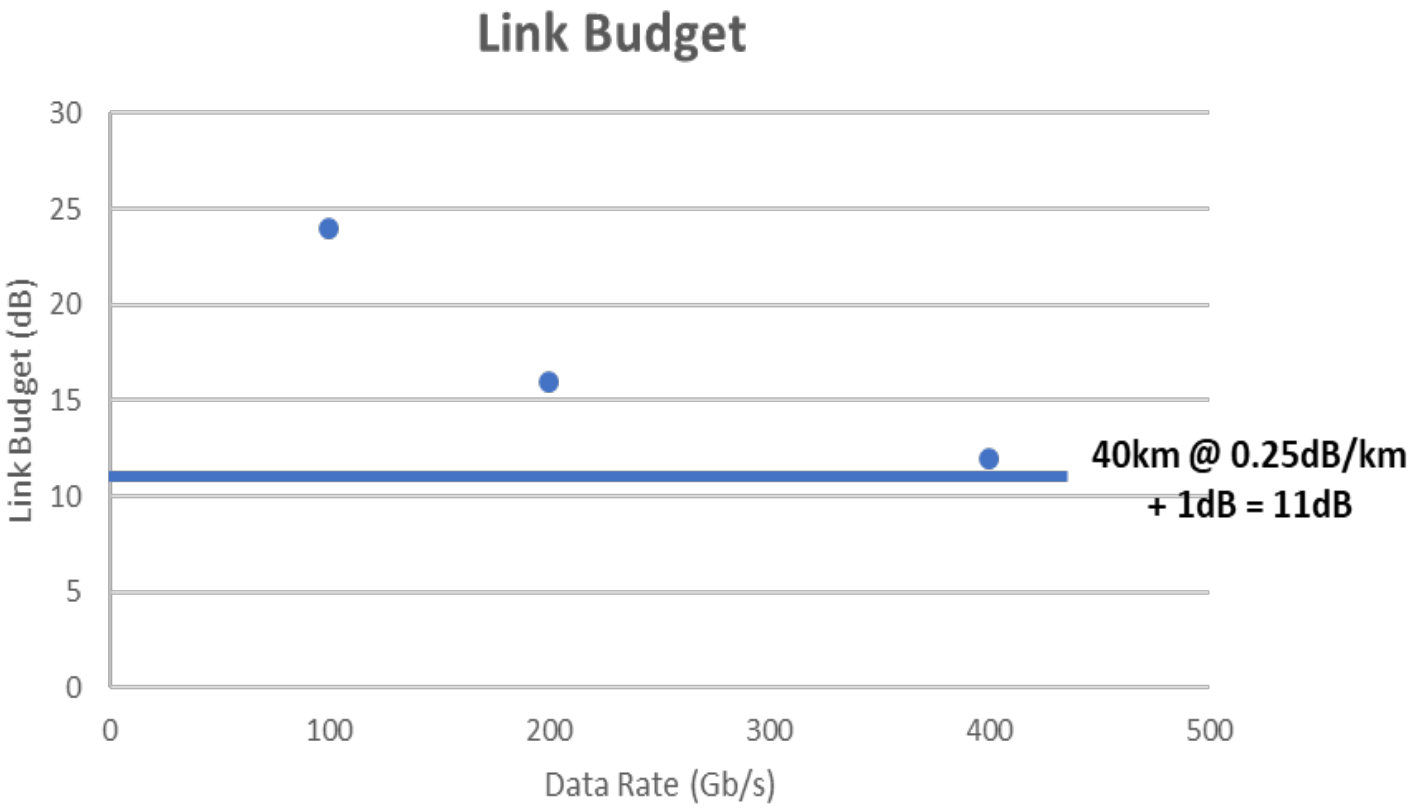
400G Coherent Power Comparison

Component	Requirement influenced by modulation		16QAM	32QAM	64QAM
		from 16QAM to 64QAM			
Baud rate			62.8 Gbaud	50.2 Gbaud	41.9 Gbaud
SERDES incl. FEC	N/A		1.4	1.4	1.4
Ethernet Framer/Mapper	N/A		0.3	0.3	0.3
15% SD-FEC	Coding gain	increasing	0.5 >10dB NCG	0.9 >10.5dB NCG	1.3 >11dB NCG
Digital Modem	Clock rate Complexity	decreasing increasing	2.3	2.0	1.8
ASIC others	N/A		0.3	0.3	0.3
ADC / DAC	Sample rate Resolution	decreasing increasing	1.8	2.1	2.2
Total 7nm ASIC power			6.6	7.0	7.3
Driver	Bandwidth Linearity	decreasing Increasing	1.0	1.2	1.4
Modulator	N/A		0.2	0.2	0.2
Laser	Phase noise Output power	decreasing increasing	2.2	2.3	2.4
TIA	Bandwidth Linearity	decreasing increasing	0.8	0.8	0.8
Total Optics power			4.2	4.5	4.8
Controller, PLLs	N/A		0.8	0.8	0.8
DC/DC	N/A		89% efficiency	89% efficiency	89% efficiency
Total			13.0	13.8	14.5

- Assumptions
  - 400GE Client Interface
  - 15% SD-FEC
  - 2400ps/nm
  - 24dB link budget

Source: Tom Williams, Acacia

Coherent Technology – Reach / Rate

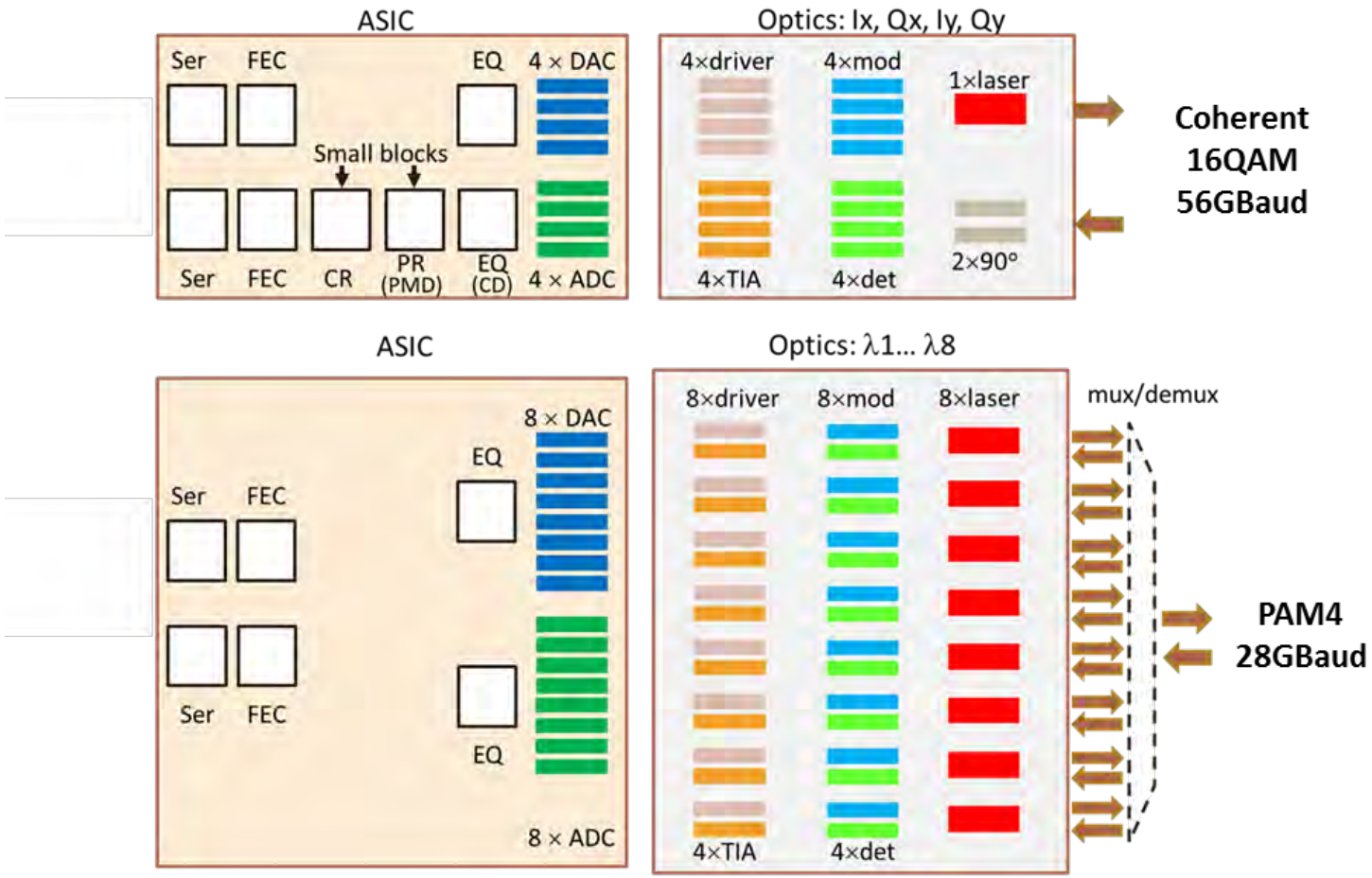


Assumptions

- No transmit SOA/EDFA
- Modulation Format
  - 100G – QPSK @ ~30Gbaud
  - 200G – 16QAM @ ~30Gbaud
  - 400G – 16QAM @ ~60Gbaud
- Tx and Rx power levels achievable with high yield and multiple optical technologies
- Higher link budgets can be supported by hardware variants

Source: Tom Williams, Acacia

Complexity of Coherent Optics



- **Fewer optical components**
  - **Improves manufacturability and reliability**
- **Does not require APD technology**

Cost Implications of Coherent Technology need to be studied

Source: Tom Williams, Acacia

Potential Synergy with IEEE P802.3ca 100G-EPON

- Device
  - Tx: EML, DML
    - Wavelength plan (?)
      - 100GBASE-ER4: 1295nm, 1300nm, 1305nm, 1310nm
      - 100G-EPON: US/DS “blue-shift” / “red-shift”
  - Rx: APD, PIN
    - O-Band wavelength range
  - Opt Amp: SOA
    - Pre-amp (Rx) vs. Booster (Tx)
    - Sat power
- Packaging
  - Opt filters
  - O/E Au-box, miniaturization, integration
  - RF structures/materials
  - Temp control

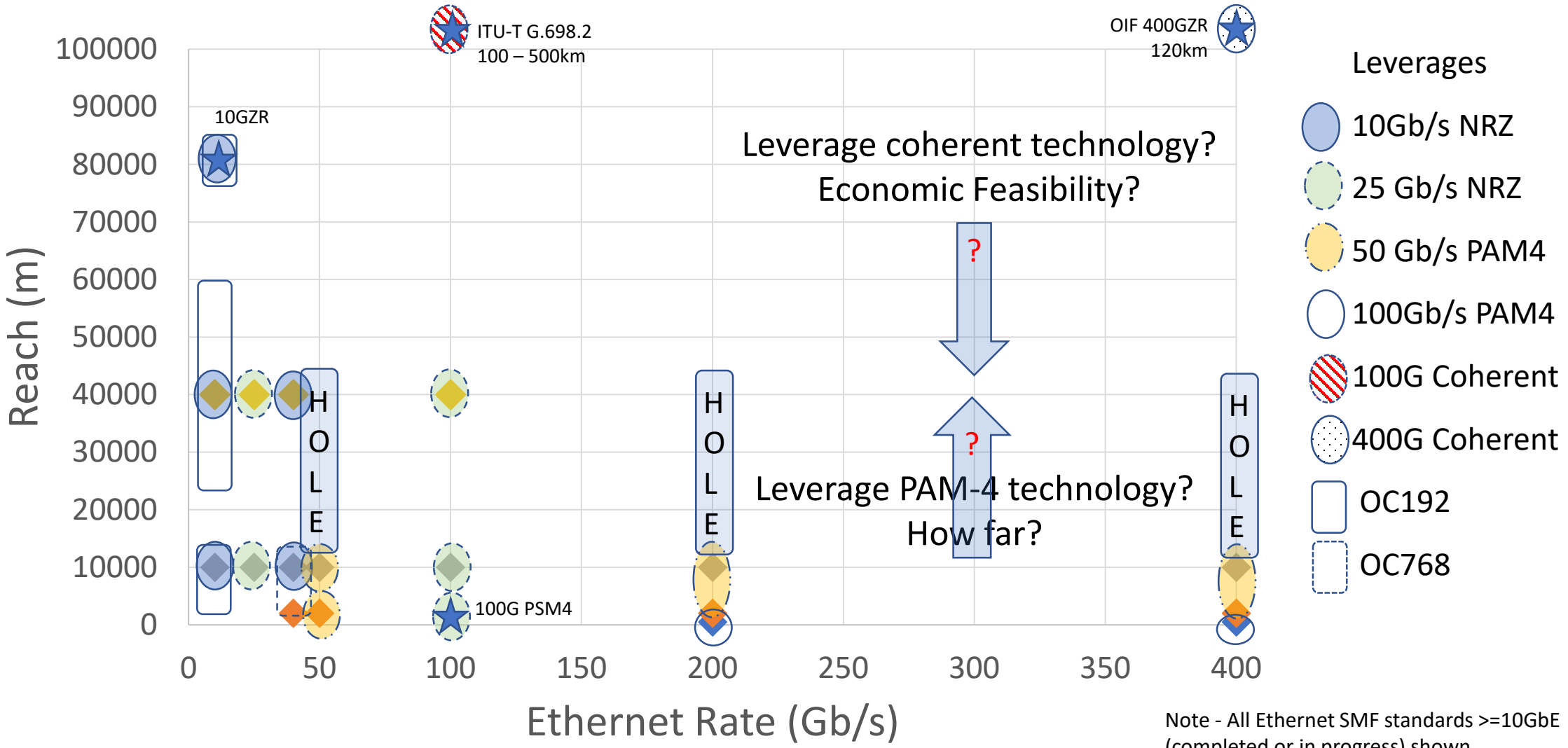
Source: Ken Jackson, Sumitomo Electric Group

“Beyond 10km” Technically Feasible

- Bandwidth growth continues unabated
  - IEEE 802.3 BWA: 2020 Capacity Requirements - 10 Terabit
  - Mobile Networks in China illustrate the impact of consumer video
  - Future bandwidth growth drivers emerging - Automotive
- Growing evidence of proof of different ways to tackle “Beyond 10km” optics for 50GbE, 200GbE, 400GbE
- Industry efforts to leverage.
- This is achievable

Why Now?

Industry P2P Optical Standards and Solutions



Note - All Ethernet SMF standards >=10GbE (completed or in progress) shown.

Why Now?

- Applications for “Beyond 10km”
  - Everywhere
  - Not same volumes as Data Center – but relevant to overall EcoSystem
- Traffic is growing everywhere
  - More users
  - More ways to access the internet faster
  - Higher bandwidth content
  - New applications enabled
  - And it goes on
- There are no Ethernet solutions for Beyond 10km for 50GbE, 200GbE, and 400GbE
- Time is not on our side…

Supporters

Straw Polls

Call-For-Interest

- Should a Study Group be formed to consider “Beyond 10km” PHYs for 50GbE, 200GbE, and 400GbE PHYs?

Y: N: A:

Room Count:

Participation

- I would participate in the “Beyond 10km Optics” Study Group in IEEE 802.3.

  Tally:

- My company would support participation in the “Beyond 10km Optics” Study Group in IEEE 802.3

  Tally:

Future Work

- Ask 802.3 on Thursday
  - Form “Beyond 10km” PHYs SG
- If approved, on Friday
  - Request 802 EC form “Beyond 10km Optics” SG
  - First Beyond 10km Optics SG meeting, week of Sept 2017 IEEE 802.3 Interim
  - Teleconference Calls to be scheduled