P802.3dj ad-hoc meeting on April 25, 2024

Market need and technical feasibility of 1.6T-LR8

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- Qifei Zheng, ZTT

Outline

- **The market need for 1.6T-LR8 application**
- **The technical feasibility for 1.6T-LR8**
- **Summary**

CMCC Building Nationwide Optical Computing Force Network

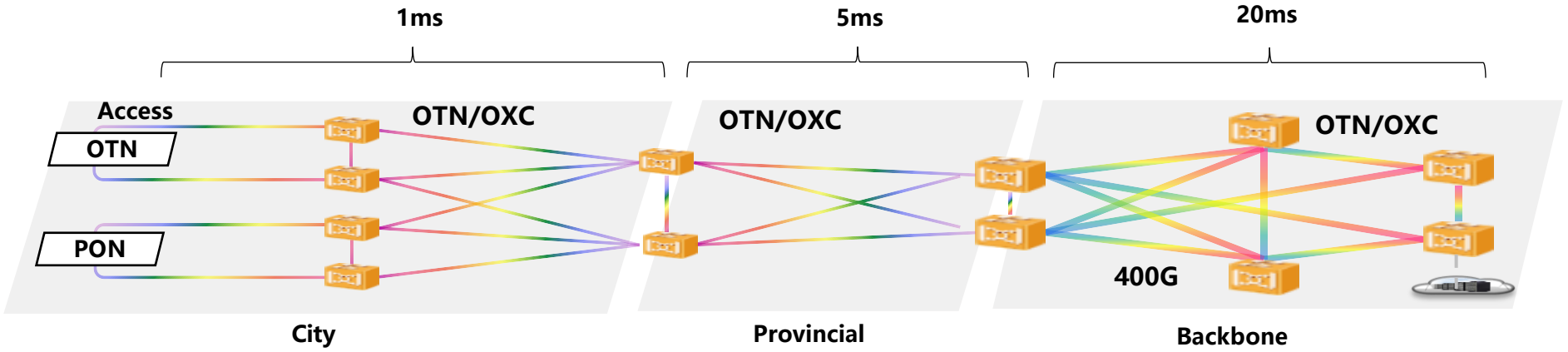
Builds the New Foundation for Computing Era

- Computing Force/Power Network Strategy
- Optical Is the Important Fundamental Base
- "One-Point Access and Ready-to-Use Everywhere",
  Computing Power Like Water and Electricity.

One Network for Nationwide Coverage

- Longest service distance: >5000km (North to South or East to West in China)
- Line Rate: current ~ 400G，future ~ 1.6T and beyond
- Single direction: >100T
- Unified Scheduling System

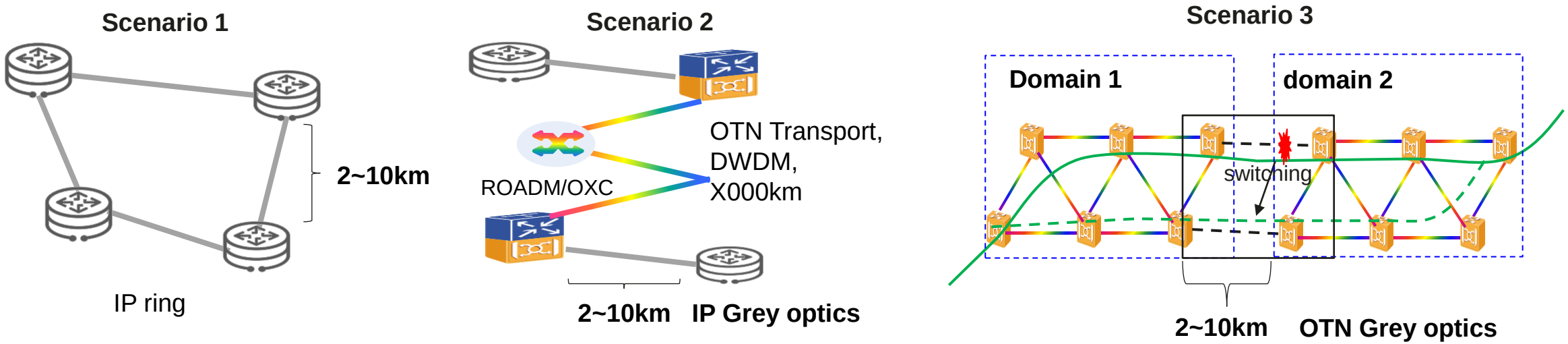
All-Optical Backbone Supports the Computing Force Network Strategy



- Ultra-low latency
- Ultra-high bandwidth
- Ultra-high reliability

LR optical modules are widely required in CMCC future Computing Force Network

- At present, the LR(10km) optical modules are extensively used in CMCC network.
- In addition, 5km reach can cover many useful applications such as CMCC's C-RAN fronthaul links
- The bandwidth growth rate of CMCC backbone network will stay around over 30%
- There will be a large demands for 1.6T optics in order to meet the traffic growth



Percentages of real-world 5G C-RAN fronthaul links that are under 5 km and 10 km

Distance	5 km	10 km
CMCC, Province A	95%	100%
CMCC, Province B	100%	100%
CMCC, Province C	88%	99%
CMCC, Province D	80%	100%

Comparison between 1.6T LR8 and 1.6T LR2/LR1

- Our analysis indicates that the 1.6T LR8 IMDD for 10km SMF is more cost-effective and power consumption saving than the coherent 1.6T LR2 or LR1 approach.

	1.6T LR8	1.6T LR2	1.6T LR1
Signaling	PAM4 113.3GBd (IM-DD 8 lanes)	DP-16QAM 123.7GBd (Coh-Lite 2 lanes)	DP-16QAM ~250GBd (Coh-Lite 1 lane)
DSP	3/5nm CMOS	3/5nm CMOS	2nm CMOS
Key opto-components	8x (EML+Ge/Si RX)	2xIC-TROSA (SiP or InP)	1xIC-TROSA (TFLN or InP)
TX/RX RF pairs	8	8(higher swing)	4(higher swing)
Wavelength	LWDM or NWDM	O Band	O Band
Power	~21W[1]	~40W[2]	~35W[3]
Form Factor	QSFP-DD	OSFP?	QSFP-DD?

[1]: estimated value from page 8 of chang_3df_01a_2211
[2]: estimated value of 2x800G ZR from page 7 of oif2024.090.00
[3]: estimated value of 1.6T ZR from page 7 of oif2024.090.00

1.6TBASE-LR8 haven’t been discussed yet

- Could be a valuable addition of the IEEE P802.3dj family
- Or start a new standard project in the future

Summary IEEE P802.3dj Progress @ End of Mar 2024 Plenary – PMDs (& AUIs)

Ethernet Rate	Assumed Signaling Rate	AUI	Backplane	Cu Cable	SMF 500m	SMF 2km	SMF 10km	SMF 20km	SMF 40km
200 Gb/s	200 Gb/s	200GAUI-1 C2C C2M	200GBASE-KR1	200GBASE-CR1	200GBASE-DR1	200GBASE-FR1			
400 Gb/s	200 Gb/s	400GAUI-2 C2C C2M	400GBASE-KR2	400GBASE-CR2	400GBASE-DR2	400GBASE-DR2-2			
800 Gb/s	200 Gb/s	800GAUI-4 C2C C2M	800GBASE-KR4	800GBASE-CR4	1.800GBASE-DR4 2.800GBASE-FR4-500	1. 800GBASE-DR4-2 2. 800GBASE-FR4	800GBASE-LR4		
	800 Gb/s						800GBASE-LR	800GBASE-ER1-20	800GBASE-ER1
1.6 Tb/s	100 Gb/s	1.6TAUI-16 C2C C2M							
	200 Gb/s	1.6TAUI-8 C2C C2M	1.6TBASE-KR8	1.6TBASE-CR8	1.6TBASE-DR8	1.6TBASE-DR8-2			

1.6TBASE-LR8 is missing

Adopted baselines Proposed Baselines

OTN (FlexO) Short-Reach Interfaces standard status in ITU-T Q6/15

- ITU-T is working on 100/400G OTN interfaces (100G per lane), and 800G/1.6T are potential future standards
- Transceiver components could be leveraged across different speeds, driving up volume and reducing cost
- During the standardization work in ITU-T, IEEE definitions have been widely referenced

Interface		Signal rate and modulation	Standard (FR)	Standard (LR)	Status
100G	Ethernet	1*53.125 GBd PAM4	IEEE 802.3cu 100GBASE-FR1	IEEE 802.3cu 100GBASE-LR1	Published in 2021
	OTN	1*55.904GBd* PAM4	ITU-T G.959.1 8R1-4D1F	ITU-T G.959.1 8I1-4D1F	Amendment work started from 2022.9, finished in 2023.11
400G	Ethernet	4*53.125 GBd PAM4	IEEE 802.3cu 400GBASE-FR4/LR4-6	IEEE 802.3cu 400GBASE-LR4-6	Published in 2021
	OTN	4*55.904GBd* PAM4	ITU-T G.695		Amendment work started from 2023.11
800G	Ethernet	4*113.4375 GBd PAM4	IEEE 802.3dj 800GBASE-FR4	IEEE 802.3dj 800GBASE-LR4	Draft D1.0 in 2024.04
	OTN				
1.6T	Ethernet	8*113.4375 GBd PAM4	IEEE 802.3dj 1.6TBASE-DR8-2		
	OTN				

*: Compared to Ethernet, the rate of OTN is increased by ~5% for more overhead

Released | Adopted baselines | Under discussion | Potential future standard

Technical feasibility of 1.6T-LR8 based on IMDD solution

- 200G per lane optical technology is becoming mature and can be leveraged to define 1.6T with 8 wavelength objective for LR application.

- Chromatic dispersion (CD) and four wave-mixing (FWM) need to be mitigated for the 8-λ LR PHY

- It is feasible* to support 1.6T-LR8 with the following advances:
  - Advanced DSP (FFE+MLSE) for better channel equalization
  - The development of new channel CD model to reduce the CD penalty
  - FWM reduction via fiber cable segmentation etc.

  (*: Both 400-GHz and 800GHz channel spacing are feasible)

1.6T-LR8 channel plan examples

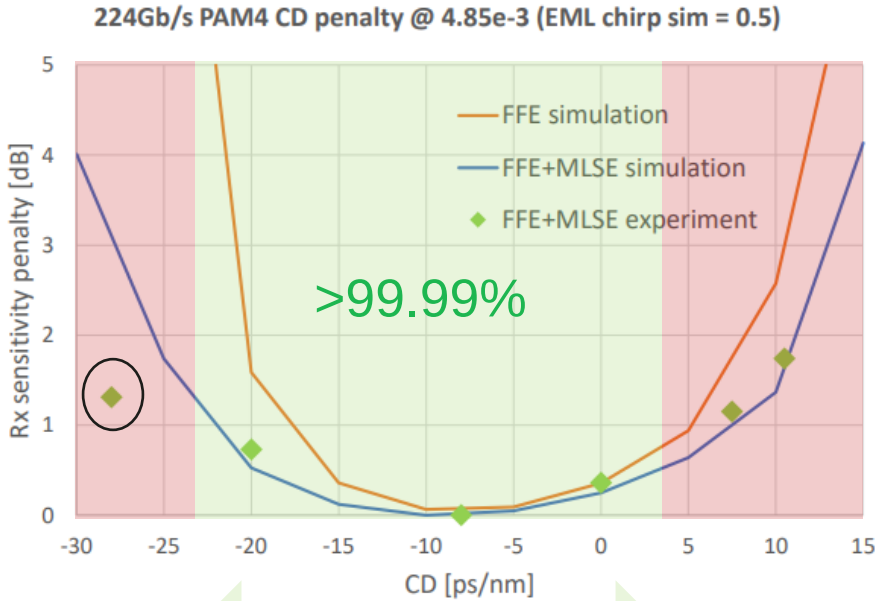
☐ 400GHz channel spacing

- The wavelength range is similar to 800G-LR4 and the CD penalties can be well tolerated
- The 400GHz-spacing was adopted in the existing 400G-ER4-30 MSA spec

☐ 800GHz channel spacing (based on LAN-WDM wavelengths)

- About doubled wavelength range as compared to 800G-LR4, leading to larger CD range.
- The CD penalties can be further mitigated by FFE+MLSE (as shown in the figure below).
- The CD penalties in 1.6T-LR8 could be mitigated to be within 2.5dB via the combined use of FFE+MLSE and a tighter CD model as shown in the tale below (for further information, please refer to [1]).

Improvement by MLSE (kuschnerov_3df_02_221012)



CD limited defined in rodes_3dj_01_2403

Channel	Penalty at BER=4.5E-3 [1]
L0	2.4 dB
L1	2.3 dB
L2	2.2 dB
L3	1.5 dB
L4	0.3 dB
L5	0 dB
L6	-0.2 dB
L7	-0.3 dB

[1] X. Liu and Q. Fan, "Inter-Channel FWM Mitigation Techniques for 800G-LR4, 1.6T-LR8, 400G-ER4 and 5G Fronthaul Applications Based on O-Band WDM," in Journal of Lightwave Technology, vol. 42, no. 3, pp. 1085-1094, Feb.1, 2024.

- **Summary**

  - There is a clear market need for 1.6T-LR8

  - 1.6T-LR8 optics will be also widely required in the future optical computing force network.

  - 200G-per-lane optical technology is becoming mature and can be leveraged to define 1.6T with 8 wavelengths for LR applications.

  - 1.6T-LR8 is technically feasible, thanks to advances in advanced MLSE and optimal transmitter design etc.

Thank you!