OSA Webinar (25 July 2019, 12:00pm-1:00pm EDT)

Optical Communication Technologies for 5G Wireless Access Networks

Xiang Liu

Futurewei Technologies, USA

1

1

Acknowledgements

I wish to thank many colleagues at Futurewei Technologies for collaboration. Among them are:

Frank Effenberger, Huaiyu Zeng, Sharief Megeed, Naresh Chand, Andy Shen, Ning Cheng, Yuanqiu Luo, and Linlin Li.

I also would like to acknowledge valuable discussion with many Huawei colleagues working in both optical and wireless departments. Among them are:

Guangxiang Fang, Ning Deng, Min Zhou, Yin Wang;
Lei Zhou, Huafeng Lin, Minghui Tao, Shengping Li;
Jiang Qi, Liang Song, and Xiao Sun.

The progresses on optical communication assisted radio access networking summarized in this short course implicitly represent the works of many researchers and engineers around the world. Some of their works are cited in the presentation. Particularly, I would like to acknowledge valuable discussion with experts from China Telecom, China Mobile, Ericsson, ETRI, Finisar, Georgia Institute of Technology, New York University, Molex, Nokia, NTT, and Orange Lab.

2

Outline

1) 5G Wireless Trends and Technologies (5 min)
- Cloud-RAN, Massive MIMO, and coordinated multipoint (CoMP)
- Mobile fronthaul, midhaul and backhaul

2) The Optical Interfaces for Wireless (10 min)
- The common public radio interface (CPRI)
- Evolved CPRI (eCPRI) and next-generation fronthaul interface (NGFI)

3) Enabling Optical Communication Technologies (20 min)
- Modulation, detection, and DSP (100G coherent and low-cost IM/DD)
- Reconfigurable optical add/drop multiplexers (ROADM) & OXC
- Low-cost transceiver devices and subsystems

4) 5G-Oriented Optical Networking (20 min)
- 5G-Oriented metro and core networks
- 5G-Oriented optical access network (PON)
- Industry standard development for 5G-oriented optical networking

5) Concluding Remarks (5 min)

3

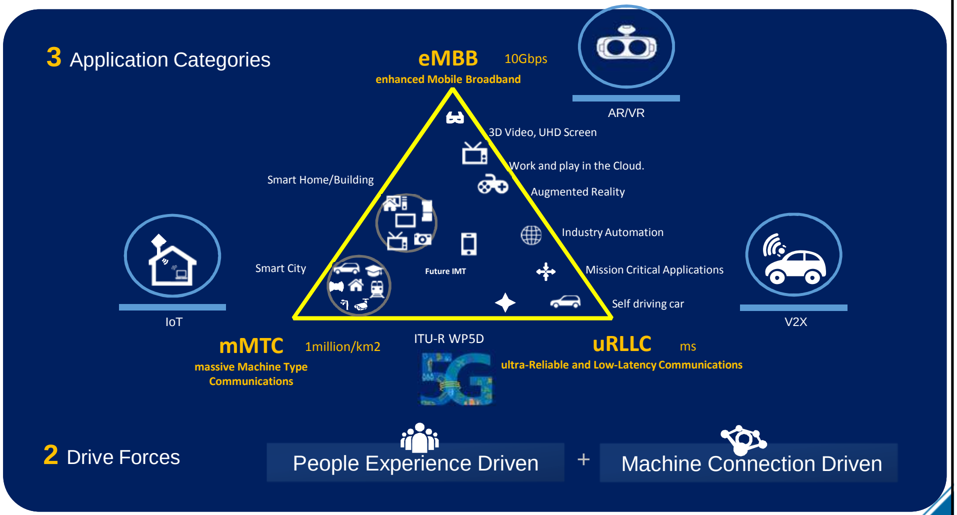
The 5G Vision

"Information a finger away, everything in touch"

References:
ITU IMT-2020's White Paper on "**5G Vision and Requirements**" (May, 2015);
Dr. Chih-Lin I's invited talk at the1st IEEE 5G Summit, May 26, 2015.

4

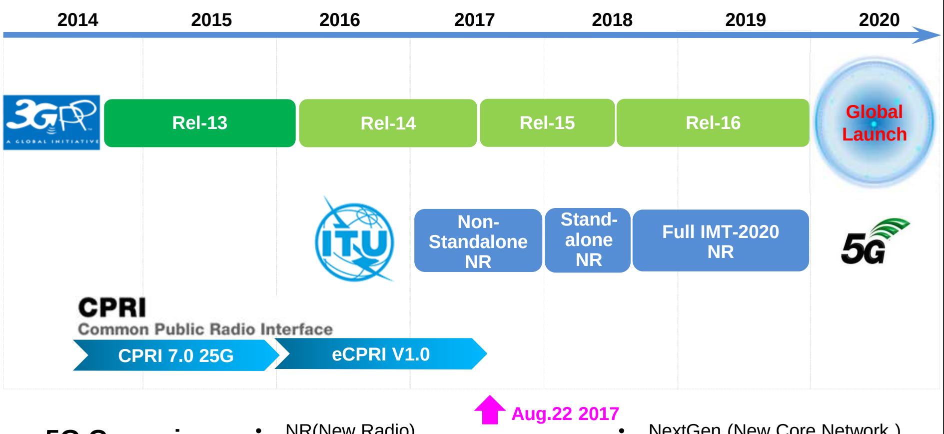
5G: Providing a Super-Connected World



OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 5 Futurewei Technologies

5

Standards Activities: 5G Timeline



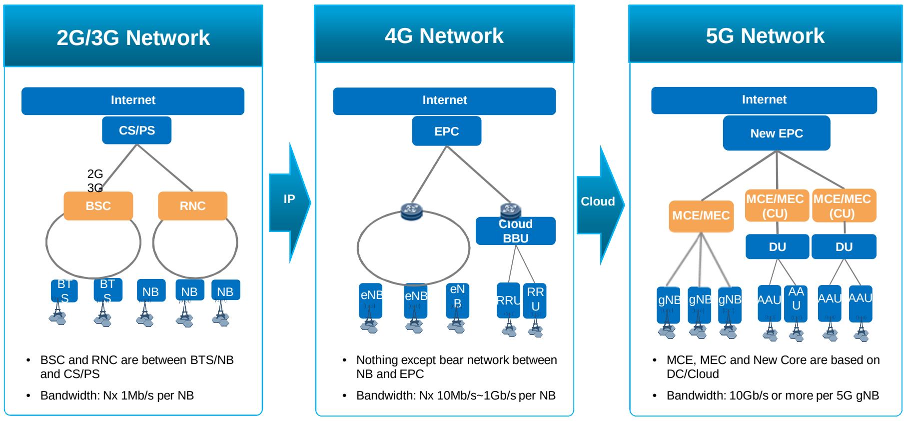
5G Comprises

- NR(New Radio)
- Evolution of LTE Advanced Pro
- NextGen (New Core Network)
- Evolution of EPC

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 6 Futurewei Technologies

6

Network Architecture Evolution towards 5G



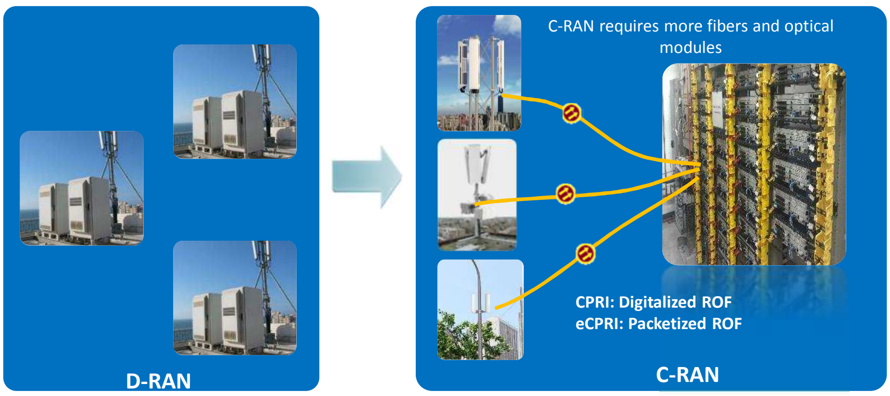
MCE/MEC::5G Architecture Key Components, Support Cache, GW, APP, RAN-Non Real Time and so on

MCE: Mobile Cloud Engine; MEC: Mobile Edge Computing

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 7 Futurewei Technologies

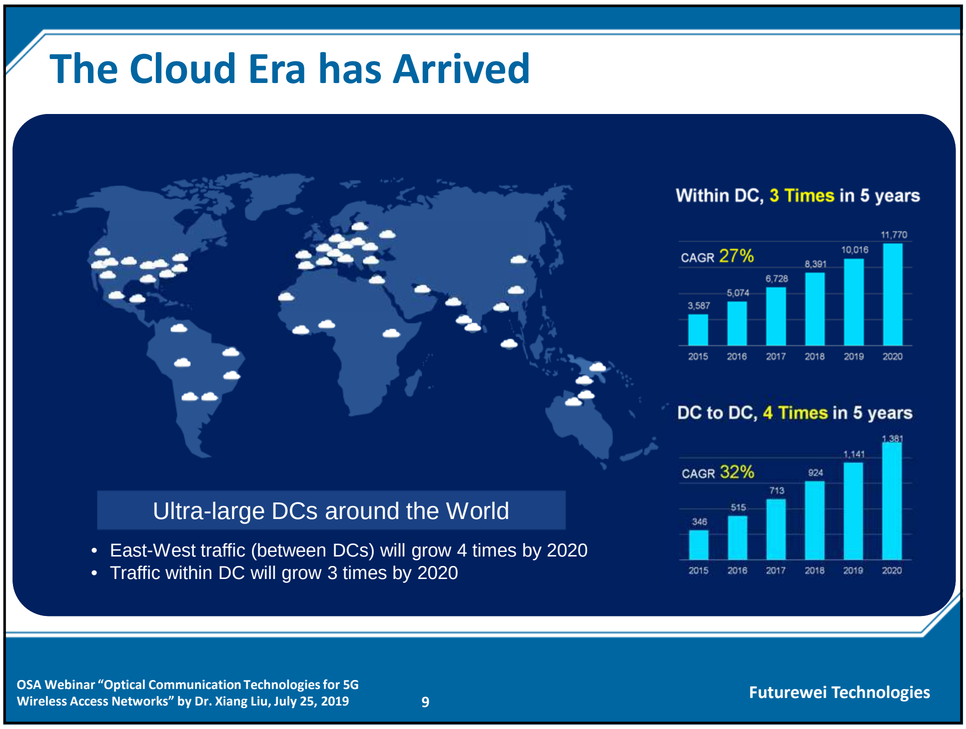
7

5G RAN: D-RAN and C-RAN

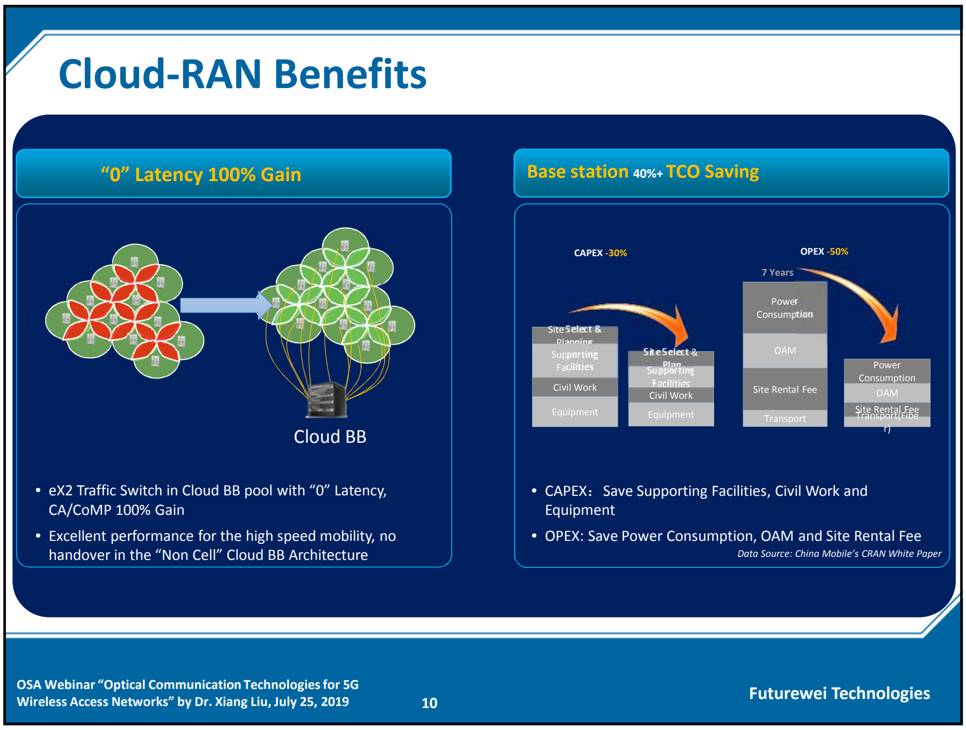


OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 8 Futurewei Technologies

8

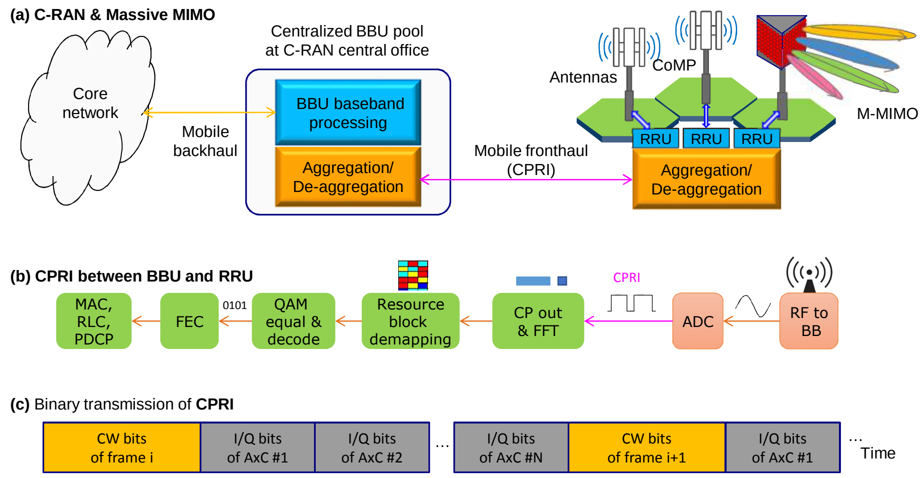

The Cloud Era has Arrived
Within DC, 3 Times in 5 years
CAGR 27%
3,587
5,074
6,728
8,391
10,016
11,770
2015 2016 2017 2018 2019 2020
DC to DC, 4 Times in 5 years
CAGR 32%
346
515
713
924
1,141
1,381
2015 2016 2017 2018 2019 2020
Ultra-large DCs around the World
• East-West traffic (between DCs) will grow 4 times by 2020
• Traffic within DC will grow 3 times by 2020
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
9
Futurewei Technologies

9


Cloud-RAN Benefits
"0" Latency 100% Gain
Cloud BB
• eX2 Traffic Switch in Cloud BB pool with "0" Latency, CA/CoMP 100% Gain
• Excellent performance for the high speed mobility, no handover in the "Non Cell" Cloud BB Architecture
Base station 40%+ TCO Saving
CAPEX -30%
OPEX -50%
7 Years
Site Select & Planning
Supporting Facilities
Civil Work
Equipment
Power Consumption
OAM
Site Rental Fee
Transport
Transport(Fiber)
• CAPEX： Save Supporting Facilities, Civil Work and Equipment
• OPEX: Save Power Consumption, OAM and Site Rental Fee
Data Source: China Mobile's CRAN White Paper
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
10
Futurewei Technologies

10

C-RAN & Massive MIMO



Reference: X. Liu and F. Effenberger, "Emerging Optical Access Network Technologies for 5G Wireless [Invited]," JOCN 8, B70 (2016).

Outline

1) 5G Wireless Trends and Technologies
- Cloud-RAN, Massive MIMO, and coordinated multipoint (CoMP)
- Mobile fronthaul, midhaul and backhaul

2) The Optical Interfaces for Wireless
- The common public radio interface (CPRI)
- Evolved CPRI (eCPRI) and next-generation fronthaul interface (NGFI)

3) Enabling Optical Communication Technologies
- Modulation, detection, and DSP (100G coherent and low-cost IM/DD)
- Reconfigurable optical add/drop multiplexers (ROADM) & OXC
- Low-cost transceiver devices and subsystems

4) 5G-Oriented Optical Networking
- 5G-Oriented metro and core networks
- 5G-Oriented optical access network (PON)
- Industry standard development for 5G-oriented optical networking

5) Concluding Remarks

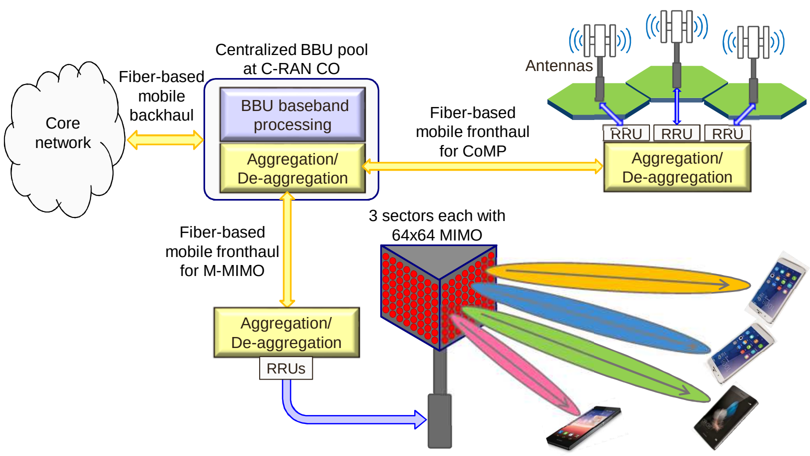
CPRI – Line rate specifications

Reference: http://www.cpri.info/downloads/CPRI_v_7_0_2015-10-09.pdf

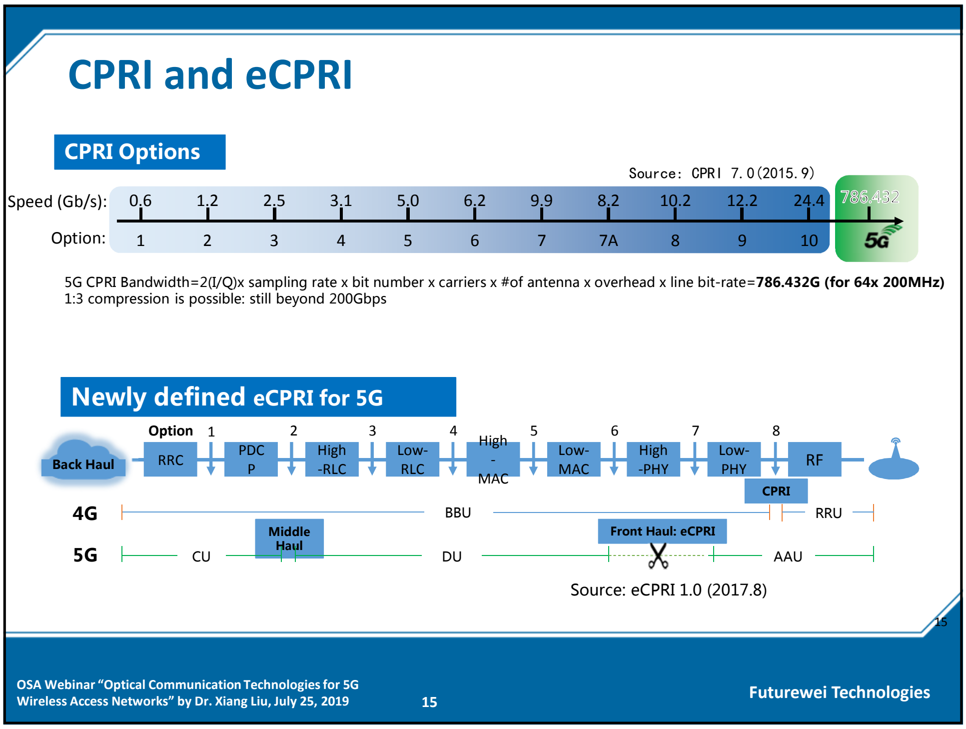
Option	Bit rate (Gb/s)	# of CPRI containers	Typical application example	Wireless rate (Gb/s)
1	0.6144	1	2G/3G RF channel	0.0375
2	1.2288	2	LTE 20-MHz channel	0.075
3	2.4576	4	20-MHz, 2x2 MIMO	0.15
4	3.0720	5		
5	4.9152	8	20-MHz, 4x4 MIMO	0.3
6	6.144	10	5x 20-MHz, 2x2 MIMO	
7	9.8304	16	20-MHz, 8x8 MIMO	0.6
7A	8.11008	16		
8	10.1376	20	5x 20-MHz, 4x4 MIMO	0.75
9	12.16512	24	3x 20-MHz, 8x8 MIMO	0.9
10	24.33024	48	6x 20-MHz, 8x8 MIMO	1.8

Options 1~7 use 8b/10b line coding, while Options 7A~10 use 64b/66b line coding; The bit rate of each CPRI container is 491.52 Mb/s, for transmitting 16 bytes (128 bits) within each 3.84-MHz UMTS chip period.

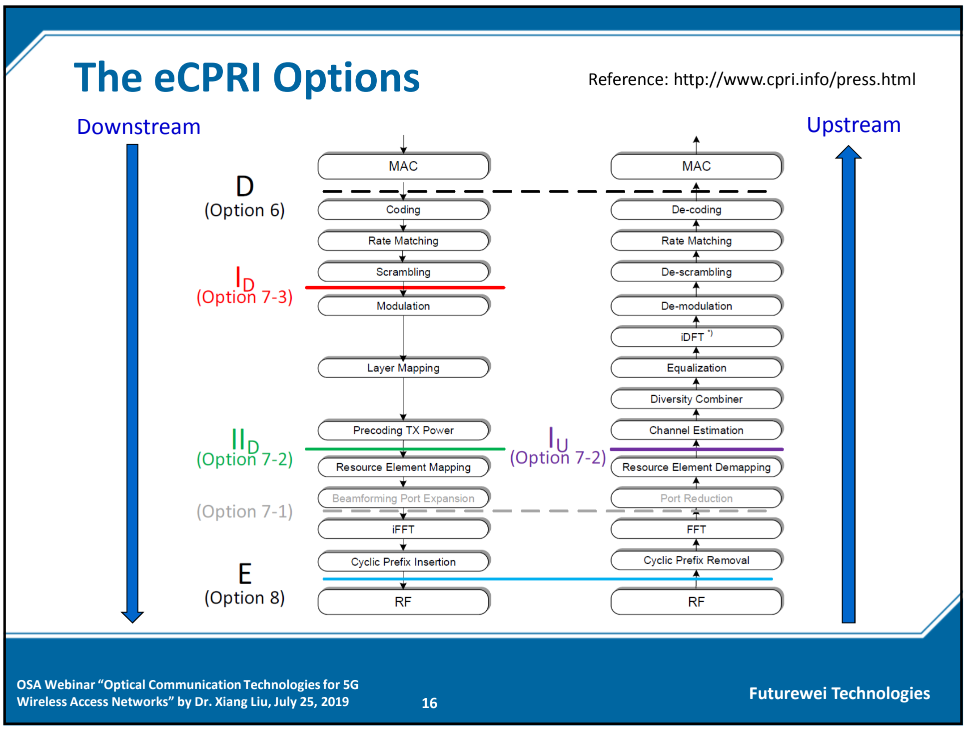
Fronthaul Requirements in 5G Massive MIMO



Typical CPRI data rate for 64x64 MIMO with 200MHz 5G signals:
64*10/8*10Gb/s=800 Gb/s; 3 sectors: **2.4 Tb/s!**


CPRI and eCPRI
CPRI Options
Source: CPRI 7.0(2015.9)
Speed (Gb/s): 0.6 1.2 2.5 3.1 5.0 6.2 9.9 8.2 10.2 12.2 24.4 786.432
Option: 1 2 3 4 5 6 7 7A 8 9 10
5G
5G CPRI Bandwidth=2(I/Q)x sampling rate x bit number x carriers x #of antenna x overhead x line bit-rate=786.432G (for 64x 200MHz)
1:3 compression is possible: still beyond 200Gbps
Newly defined eCPRI for 5G
Option 1 2 3 4 5 6 7 8
Back Haul
RRC
PDCP
High-RLC
Low-RLC
High-MAC
Low-MAC
High-PHY
Low-PHY
RF
CPRI
4G
BBU
RRU
5G
CU
Middle Haul
DU
Front Haul: eCPRI
AAU
Source: eCPRI 1.0 (2017.8)
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
15
Futurewei Technologies

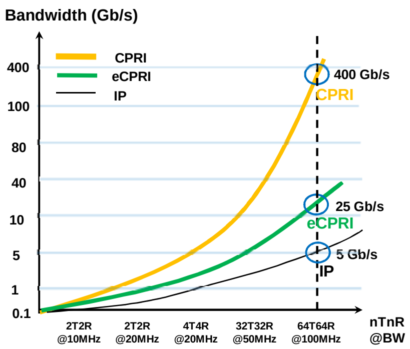
15


The eCPRI Options
Reference: http://www.cpri.info/press.html
Downstream
Upstream
D
(Option 6)
I_D
(Option 7-3)
II_D
(Option 7-2)
I_U
(Option 7-2)
(Option 7-1)
E
(Option 8)
MAC
Coding
Rate Matching
Scrambling
Modulation
Layer Mapping
Precoding TX Power
Resource Element Mapping
Beamforming Port Expansion
iFFT
Cyclic Prefix Insertion
RF
MAC
De-coding
Rate Matching
De-scrambling
De-modulation
iDFT
Equalization
Diversity Combiner
Channel Estimation
Resource Element Demapping
Port Reduction
FFT
Cyclic Prefix Removal
RF
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
16
Futurewei Technologies

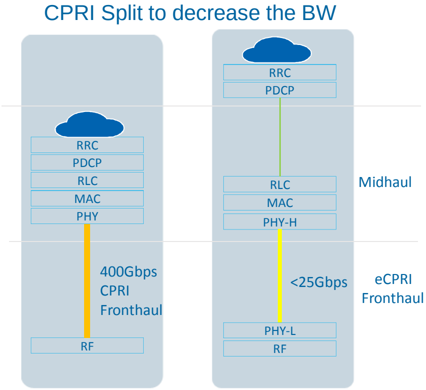
16

eCPRI's Bandwidth Efficiency

5G require more bandwidth in CPRI



CPRI Split to decrease the BW



eCPRI Specification for 5G plan to release in August 2017
http://www.cpri.info/press.html

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 17 Futurewei Technologies

17

Outline

1) 5G Wireless Trends and Technologies
- Cloud-RAN, Massive MIMO, and coordinated multipoint (CoMP)
- Mobile fronthaul, midhaul and backhaul

2) The Optical Interfaces for Wireless
- The common public radio interface (CPRI)
- Evolved CPRI (eCPRI) and next-generation fronthaul interface (NGFI)

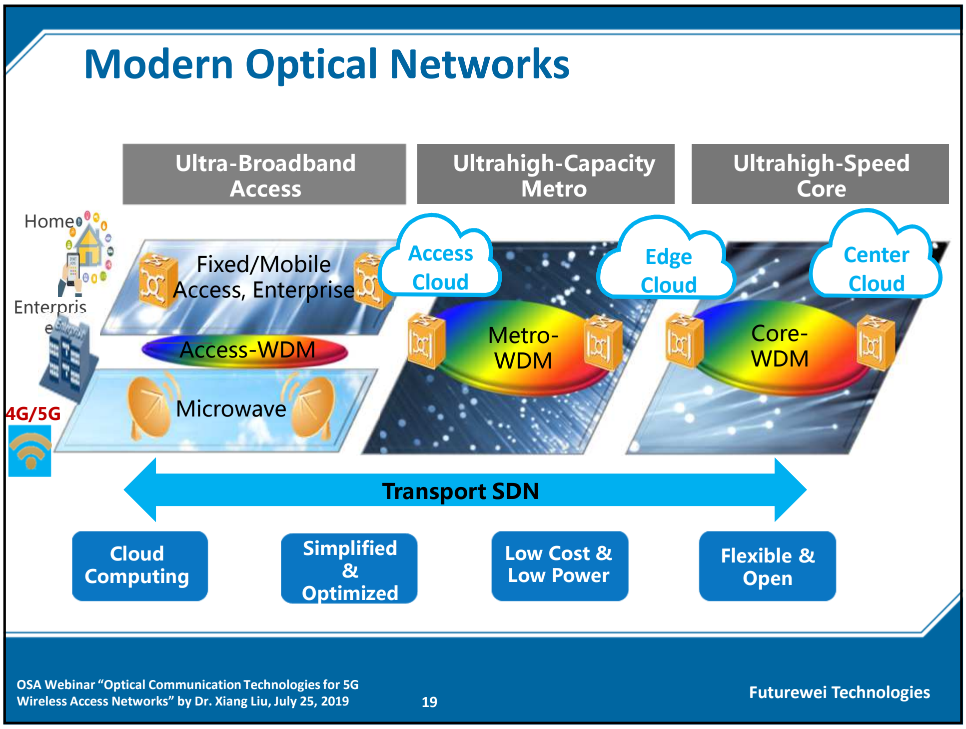
3) Enabling Optical Communication Technologies
- Modulation, detection, and DSP (100G coherent and low-cost IM/DD)
- Reconfigurable optical add/drop multiplexers (ROADM) & OXC
- Low-cost transceiver devices and subsystems

4) 5G-Oriented Optical Networking
- 5G-Oriented metro and core networks
- 5G-Oriented optical access network (PON)
- Industry standard development for 5G-oriented optical networking

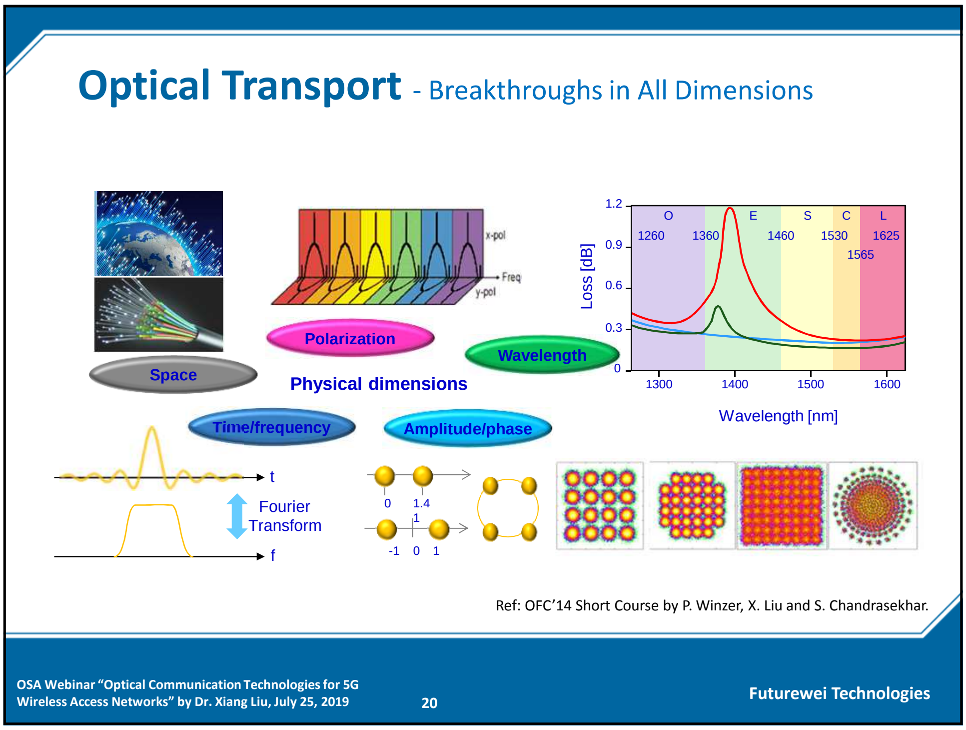
5) Concluding Remarks

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 18 Futurewei Technologies

18


Modern Optical Networks
Ultra-Broadband Access
Ultrahigh-Capacity Metro
Ultrahigh-Speed Core
Home
Enterprise
4G/5G
Fixed/Mobile Access, Enterprise
Access-WDM
Microwave
Access Cloud
Metro-WDM
Edge Cloud
Core-WDM
Center Cloud
Transport SDN
Cloud Computing
Simplified & Optimized
Low Cost & Low Power
Flexible & Open
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
19
Futurewei Technologies

19


Optical Transport - Breakthroughs in All Dimensions
Space
Polarization
Wavelength
Physical dimensions
Time/frequency
Amplitude/phase
Fourier Transform
Loss [dB]
Wavelength [nm]
O E S C L
1260 1360 1460 1530 1565 1625
Ref: OFC'14 Short Course by P. Winzer, X. Liu and S. Chandrasekhar.
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
20
Futurewei Technologies

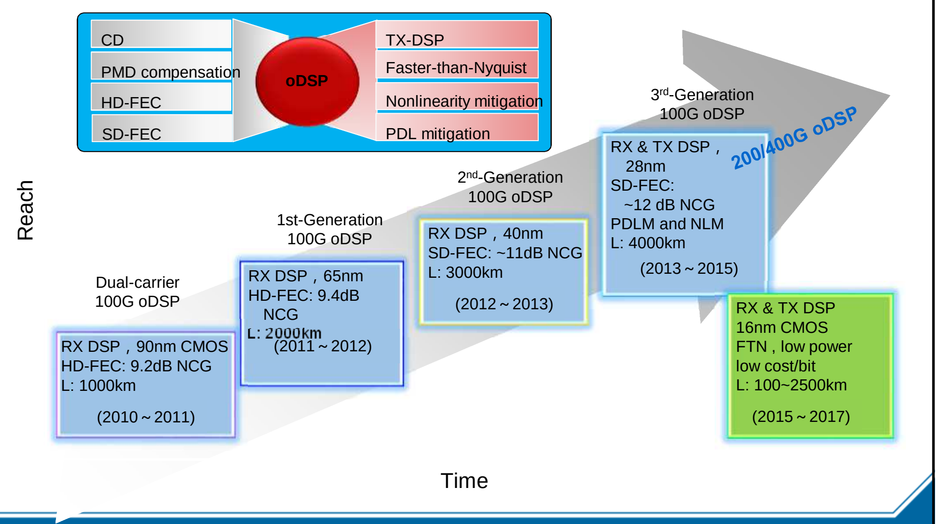
20

Advances in Optical Transport

Year:	1980	1990	2000	2010	2020
Channel rate	**2.5 Gb/s**	**10 Gb/s**	**40 Gb/s**	**100 Gb/s**	**200G/400G/1T+**
Modulation format (typical)	OOK (NRZ)	OOK (RZ)	DPSK -1 0 1; DQPSK	PDM-QPSK X-pol. Y-pol.	PDM-16QAM X-pol. Y-pol.
System features (newly added)	Single-span, Single-channel	Multi-span with EDFAs, WDM	DWDM, Raman, ROADMs	1:N WSS, CDC-ROADMs	Flexible-grid WDM, M:N WSS
System capacity (typical)	**2.5 Gb/s** (single channel)	**400 Gb/s** (40 WDM channel)	**1.6 Tb/s** (40 WDM channel)	**8 Tb/s** (80 DWDM channel)	**20 Tb/s** (50 flex-grid channel)
System reach (typical)	100 km (single span)	1000 km	1000 km @40G 3000 km @10G	2000 km @100G	4000/2500 km @100(200)G
Enabling technologies	Optical modulation and detection	High-speed mod, HD-FEC	Differential phase-shift-keying	Coherent detection with ODSP	SD-FEC, QAM, Superchannel.

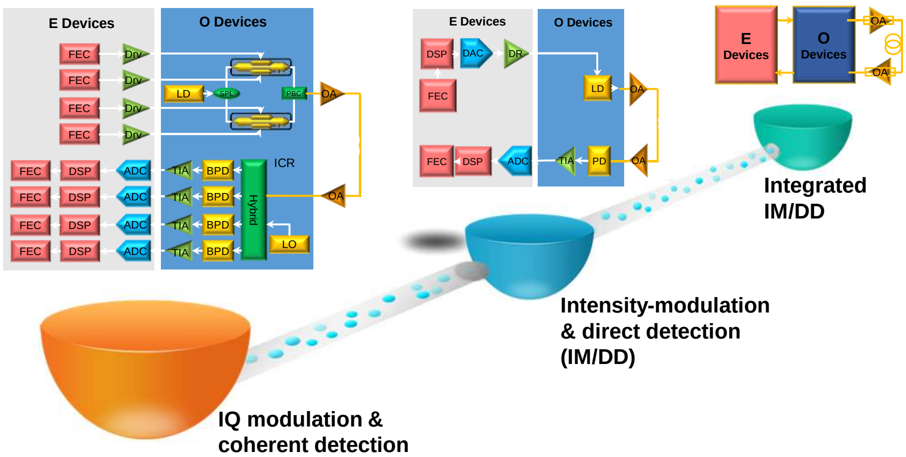
21

Evolution of the oDSP Technology



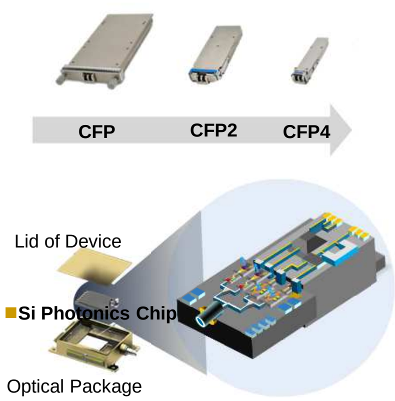
22

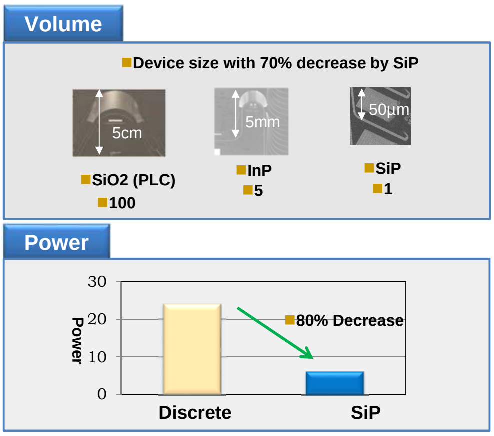
Evolution of Metro WDM Transceivers



Silicon-Photonics

- Addressing the Power/Volume Issues

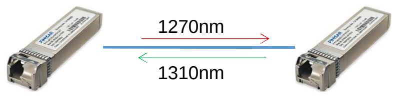




25G Optical Transceivers for Wireless

Grey Optics @ 25Gb/s

- 25GE & 25G eCPRI
- SFP+ preferred (compatibility with 10G)
- BiDi preferred (over SMF)
- 2km and 10km ready, 20km/30km TBD
- Industrial Temperature



25Gb/s BiDi

CWDM Optics @ 25Gb/s

- O-band @ 1310nm
- Fixed wavelength
- 10km: reuse 100G LR4 technology
- 2km: reuse 100G CWDM4 technology
- 4x25G: 3x5G Cell + 1 for others
- No separate 25G module available
- No outside Mux/DeMux available

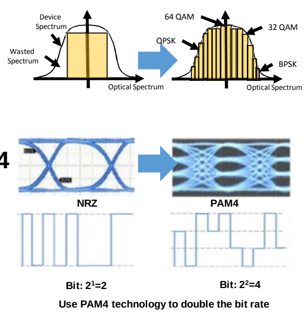
DWDM Optics @ 25Gb/s

- C-band @ 1550nm
- Tunable wavelength preferred
- SFP preferred
- 10km: NRZ
- 20km/20km+: PAM4 or DMT
- BiDi #1: C-band US, L-band DS
- BiDi #2: US & DS in 100GHz Grid

50/100G Optical Transceivers for Wireless

DMT

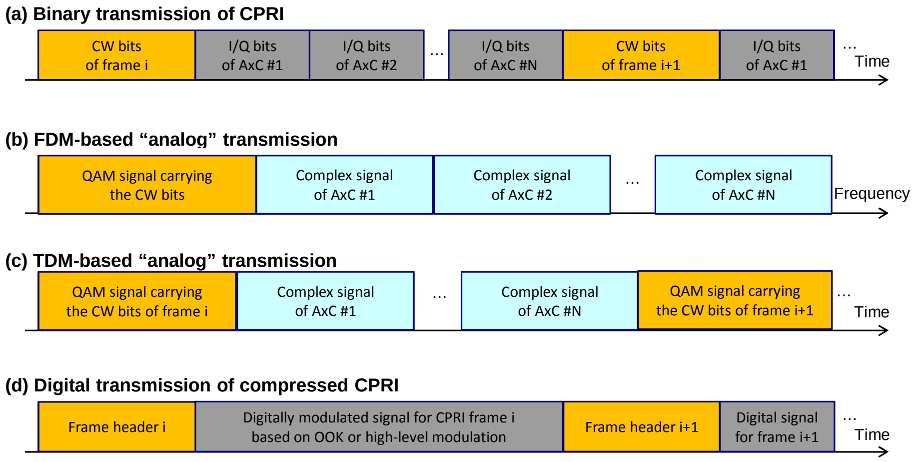
PAM4



	DMT	PAM4
Spectrum efficiency	High	Medium
Multi Path Interference	Medium	Medium
Device cost	Low	Low
Power consumption	Medium	Low
Dispersion tolerance	Medium	High
Standardization	Low	Medium

- 25G: proven performance, commercialized soon
- 50G/100G: still under evaluation, limited reach due to dispersion tolerance

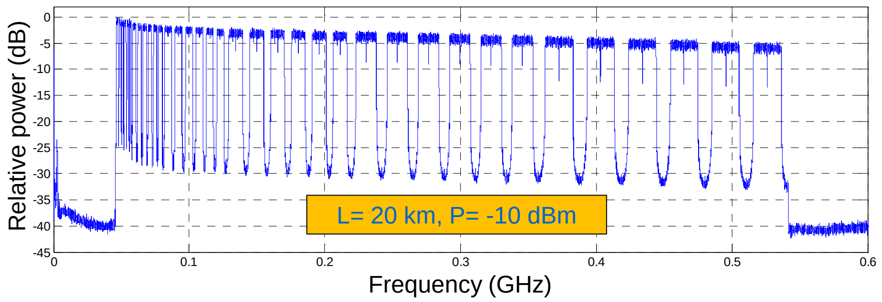
Efficient Mobile Fronthaul (EMF)



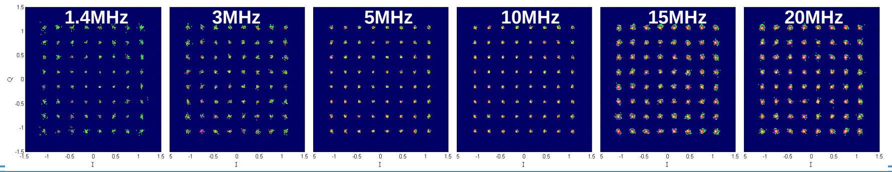
FDM-EMF Results (1)

Reference: X. Liu et al., OFC'15.

Aggregation of **36 E-UTRA** signals: **~20 Gb/s** CPRI-equivalent rate.

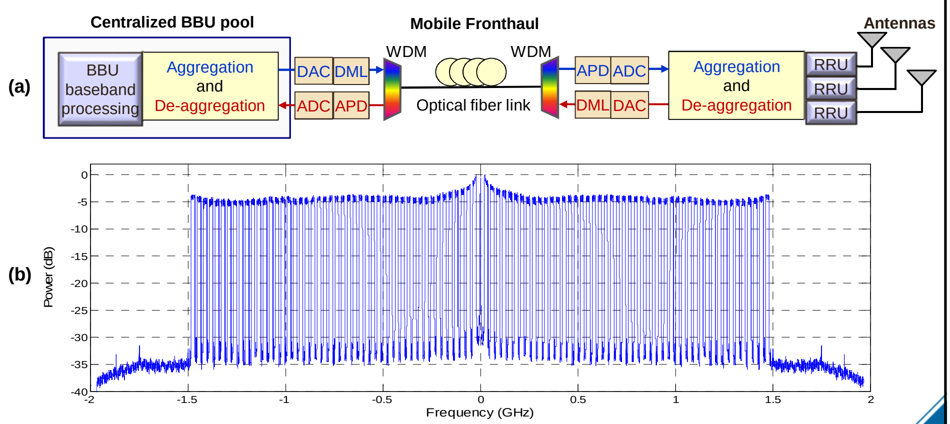


Measured constellations of the 36 E-UTRA signals

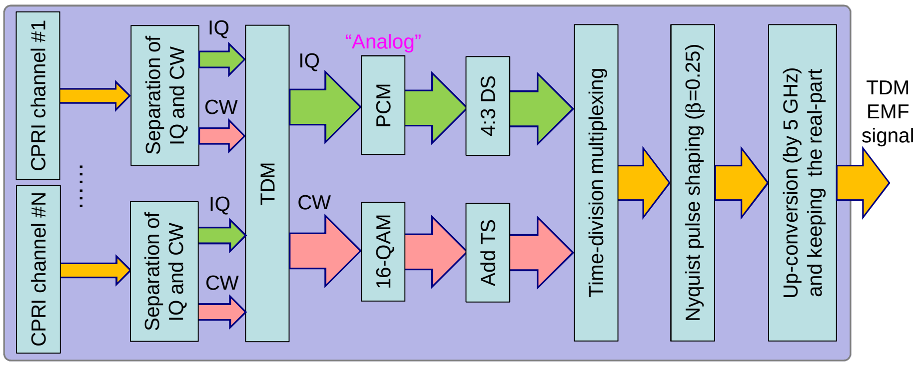


FDM-EMF Results (2)

Aggregation of **48× 20-MHz LTE-A** Channels (8x8 MIMO, 3 sectors, 2 CA):
~59 Gb/s CPRI-Equivalent Data Rate:

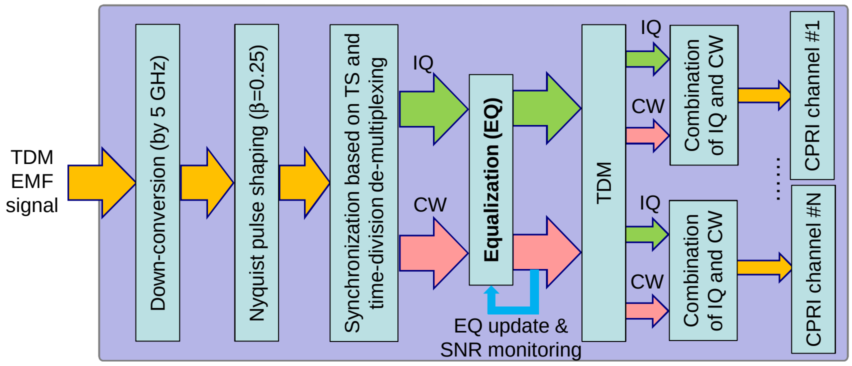


CPRI-Compatible TDMA-EMF Transmitter



PCM: pulse-code modulation;
QAM: quadrature-amplitude modulation;
TS: training symbols (header) for synchronization and for channel equalization.

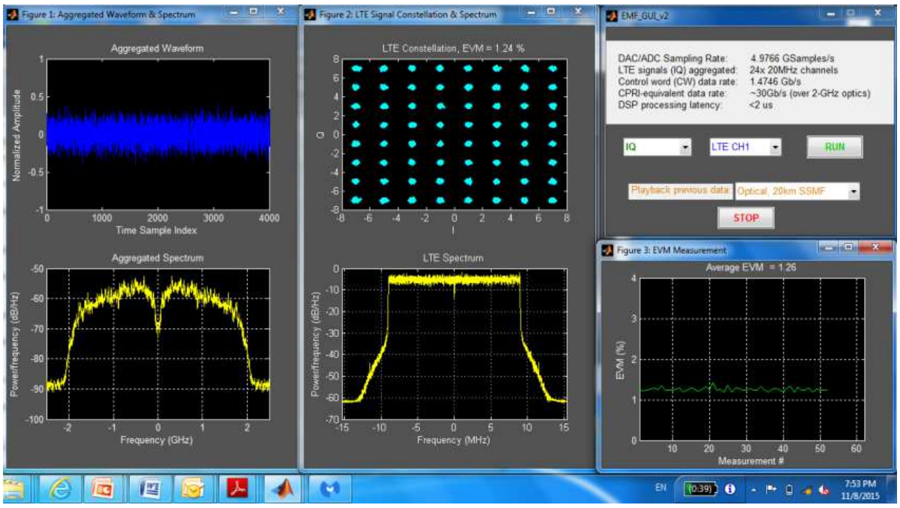
CPRI-Compatible TDMA-EMF Receiver



OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 31 Futurewei Technologies

31

EMF Real-Time Demo – 64-QAM

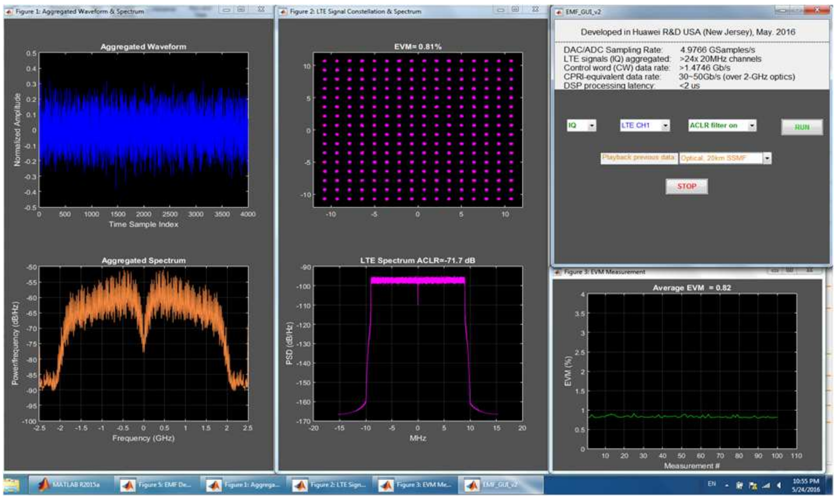


➢The measured EVM was 1.24%, as shown in the picture above

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 32 Futurewei Technologies

32

EMF Real-Time Demo – 256-QAM



➢The measured EVM was <1%, as shown in the picture above

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 33 Futurewei Technologies

33

5G-EMF Integration Test

➢ 5G signals (generated by the BBU server) were transmitted over the EMF system with 10-km fiber reach to the RRU. The measured EVM was 1.54%, as shown in the picture above.

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 34 Futurewei Technologies

34

Outline

1) 5G Wireless Trends and Technologies
- Cloud-RAN, Massive MIMO, and coordinated multipoint (CoMP)
- Mobile fronthaul, midhaul and backhaul

2) The Optical Interfaces for Wireless
- The common public radio interface (CPRI)
- Evolved CPRI (eCPRI) and next-generation fronthaul interface (NGFI)

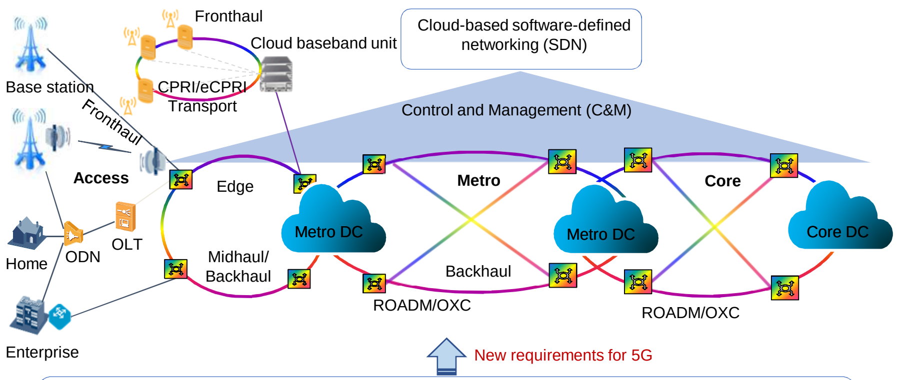
3) Enabling Optical Communication Technologies
- Modulation, detection, and DSP (100G coherent and low-cost IM/DD)
- Reconfigurable optical add/drop multiplexers (ROADM) & OXC
- Low-cost transceiver devices and subsystems

4) 5G-Oriented Optical Networking
- 5G-Oriented metro and core networks
- 5G-Oriented optical access network (PON)
- Industry standard development for 5G-oriented optical networking

5) Concluding Remarks

35

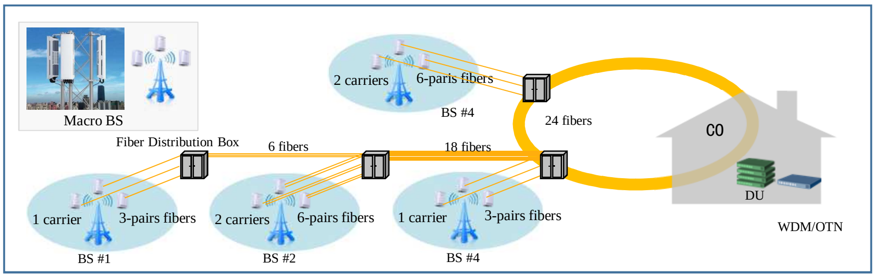
5G-Oriented Optical Networking



High Bandwidth | Low Latency | Accurate Synchronization | Network Slicing

36

5G Fronthaul: Massive Fiber Requirement



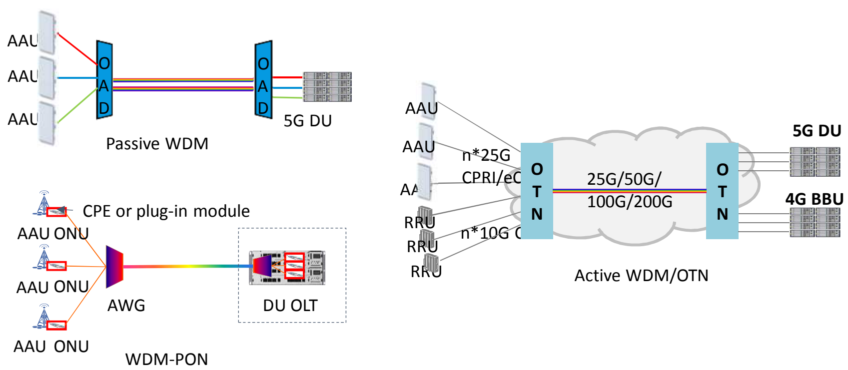
- Early stage of 5G（3.5GHz only）：
  - -5G-only： 3 x Cells，6 fibers(duplex)/3 fibers (BiDi)
  - -3G/4G/5G co-site：accumulated

A Solution：WDM

- More carriers, more BSs, more fibers

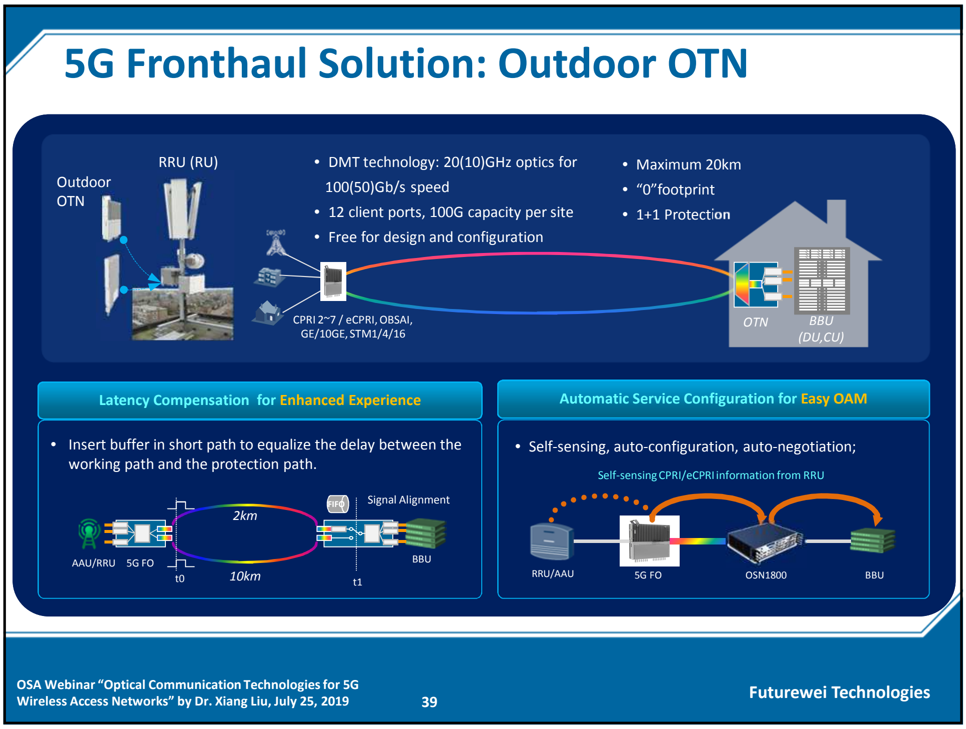
Reference: Junjie Li of China Telecom, ACP’17 Invited Talk “Photonics for 5G”

5G Fronthaul: WDM Solutions

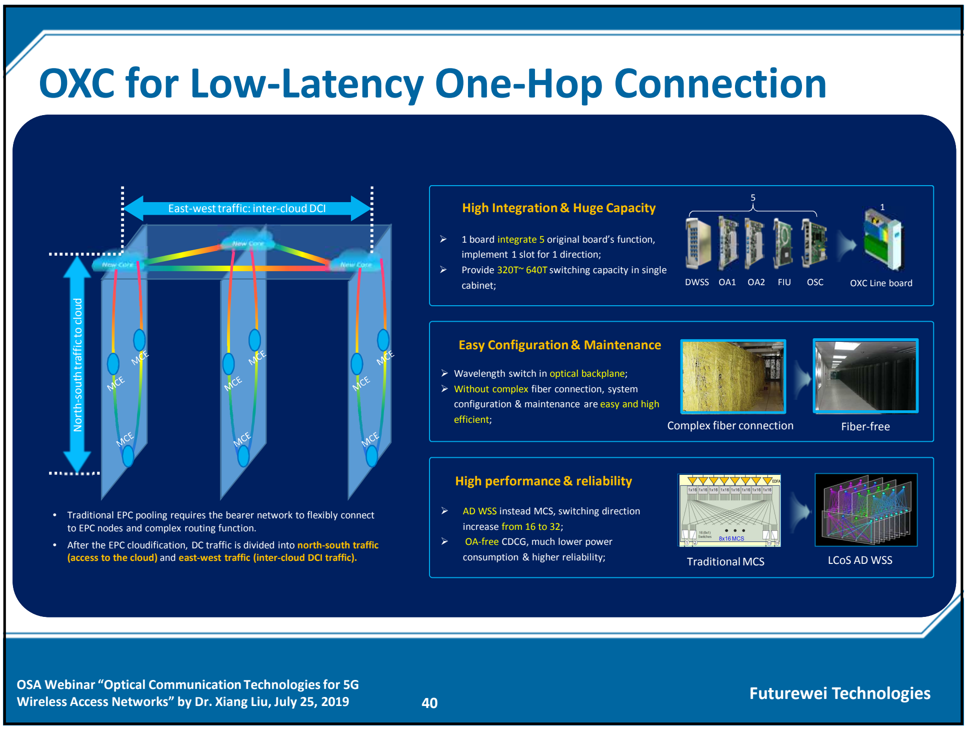


Reference: Junjie Li of China Telecom, ACP’17 Invited Talk “Photonics for 5G”

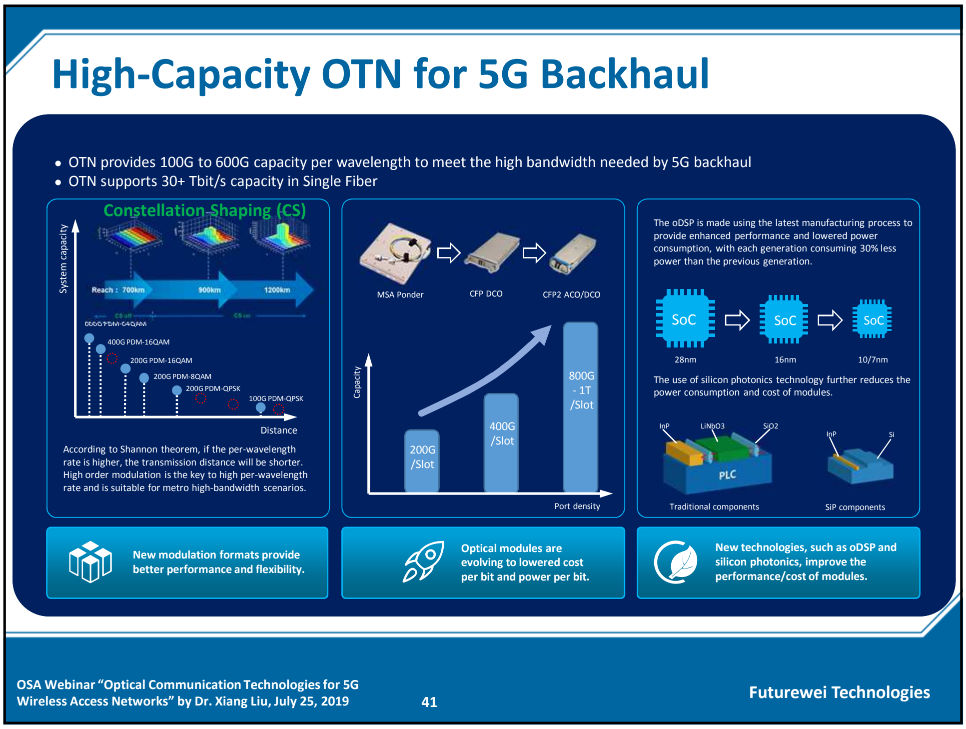
38


5G Fronthaul Solution: Outdoor OTN
Outdoor OTN
RRU (RU)
DMT technology: 20(10)GHz optics for 100(50)Gb/s speed
12 client ports, 100G capacity per site
Free for design and configuration
Maximum 20km
"0"footprint
1+1 Protection
CPRI 2~7 / eCPRI, OBSAI, GE/10GE, STM1/4/16
OTN
BBU (DU,CU)
Latency Compensation for Enhanced Experience
Insert buffer in short path to equalize the delay between the working path and the protection path.
2km
Signal Alignment
AAU/RRU
5G FO
t0
10km
t1
BBU
Automatic Service Configuration for Easy OAM
Self-sensing, auto-configuration, auto-negotiation;
Self-sensing CPRI/eCPRI information from RRU
RRU/AAU
5G FO
OSN1800
BBU
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
39
Futurewei Technologies

39

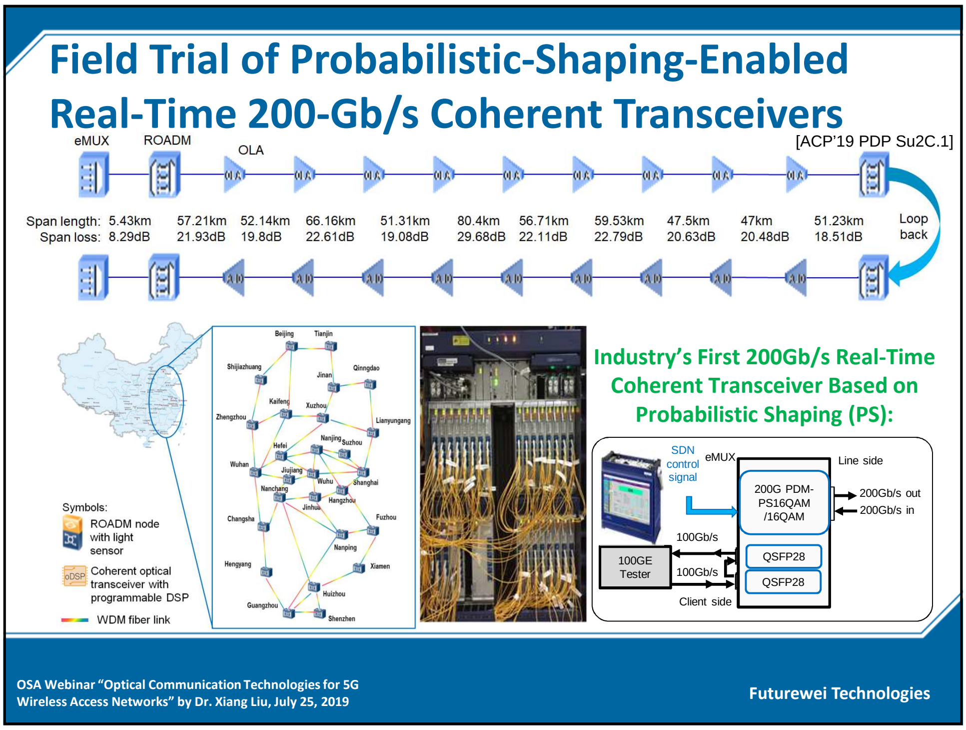

OXC for Low-Latency One-Hop Connection
East-west traffic: inter-cloud DCI
North-south traffic to cloud
MCE
Traditional EPC pooling requires the bearer network to flexibly connect to EPC nodes and complex routing function.
After the EPC cloudification, DC traffic is divided into north-south traffic (access to the cloud) and east-west traffic (inter-cloud DCI traffic).
High Integration & Huge Capacity
1 board integrate 5 original board's function, implement 1 slot for 1 direction;
Provide 320T~640T switching capacity in single cabinet;
DWSS OA1 OA2 FIU OSC
OXC Line board
Easy Configuration & Maintenance
Wavelength switch in optical backplane;
Without complex fiber connection, system configuration & maintenance are easy and high efficient;
Complex fiber connection
Fiber-free
High performance & reliability
AD WSS instead MCS, switching direction increase from 16 to 32;
OA-free CDCG, much lower power consumption & higher reliability;
Traditional MCS
LCoS AD WSS
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
40
Futurewei Technologies

40



High-Capacity OTN for 5G Backhaul
• OTN provides 100G to 600G capacity per wavelength to meet the high bandwidth needed by 5G backhaul
• OTN supports 30+ Tbit/s capacity in Single Fiber
Constellation Shaping (CS)
System capacity
Reach : 700km
900km
1200km
400G PDM-16QAM
200G PDM-16QAM
200G PDM-8QAM
200G PDM-QPSK
100G PDM-QPSK
Distance
According to Shannon theorem, if the per-wavelength rate is higher, the transmission distance will be shorter. High order modulation is the key to high per-wavelength rate and is suitable for metro high-bandwidth scenarios.
MSA Ponder
CFP DCO
CFP2 ACO/DCO
Capacity
200G /Slot
400G /Slot
800G - 1T /Slot
Port density
The oDSP is made using the latest manufacturing process to provide enhanced performance and lowered power consumption, with each generation consuming 30% less power than the previous generation.
SoC
SoC
SoC
28nm
16nm
10/7nm
The use of silicon photonics technology further reduces the power consumption and cost of modules.
InP
LiNbO3
SiO2
PLC
InP
Si
Traditional components
SiP components
New modulation formats provide better performance and flexibility.
Optical modules are evolving to lowered cost per bit and power per bit.
New technologies, such as oDSP and silicon photonics, improve the performance/cost of modules.
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
41
Futurewei Technologies

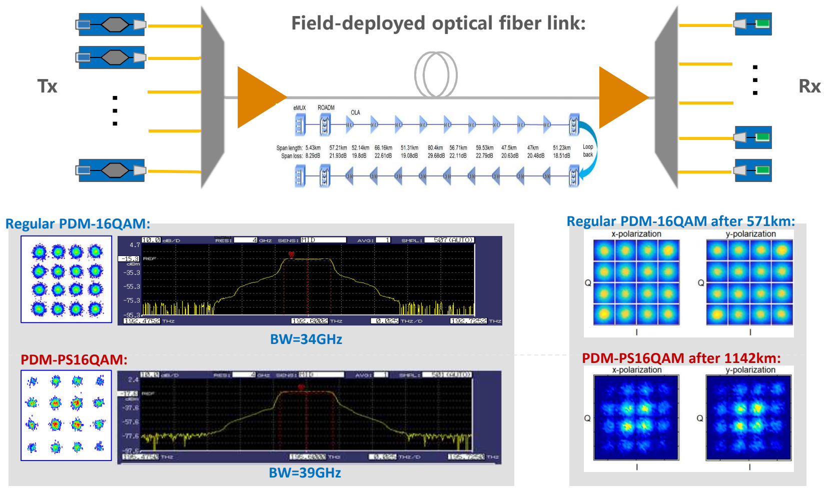
41



Field Trial of Probabilistic-Shaping-Enabled Real-Time 200-Gb/s Coherent Transceivers
[ACP'19 PDP Su2C.1]
eMUX
ROADM
OLA
Span length: 5.43km 57.21km 52.14km 66.16km 51.31km 80.4km 56.71km 59.53km 47.5km 47km 51.23km
Span loss: 8.29dB 21.93dB 19.8dB 22.61dB 19.08dB 29.68dB 22.11dB 22.79dB 20.63dB 20.48dB 18.51dB
Loop back
Symbols:
ROADM node with light sensor
Coherent optical transceiver with programmable DSP
WDM fiber link
Industry's First 200Gb/s Real-Time Coherent Transceiver Based on Probabilistic Shaping (PS):
SDN control signal
eMUX
Line side
200G PDM-PS16QAM /16QAM
200Gb/s out
200Gb/s in
100Gb/s
100GE Tester
100Gb/s
QSFP28
QSFP28
Client side
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
Futurewei Technologies

42

Constellation and Spectrum of 200G PCS



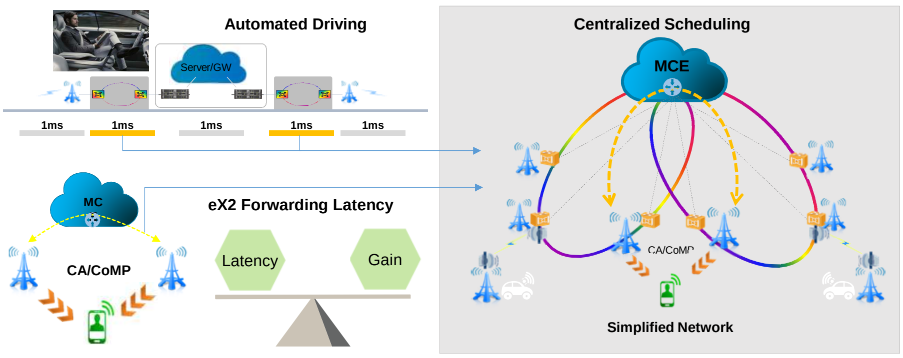
[ACP'19 PDP Su2C.1]

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019

Futurewei Technologies

43

Centralized Scheduling for Low Latency



Guarantee Latency
150km, < 2ms

NE Latency: OTN 30us, MW 50us, DC SW/Router 30us, Fiber 5us/km
In instance, 5G traffic transport via one hops MW, 4 hops OTN, 150km fiber, the latency is below
[(50+30x4+30)+150x5] x 2 = 1900us = 1.9ms
Meet the Auto Driving and eX2 performance requirement

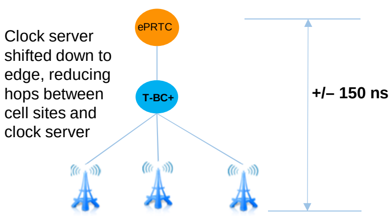
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 44

Futurewei Technologies

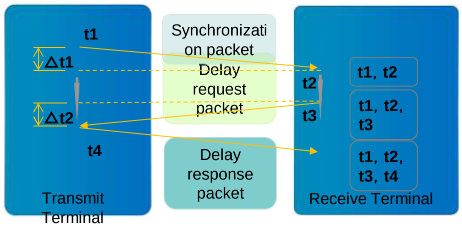
44

Accurate Synchronization

5G Era: ns level clock precision



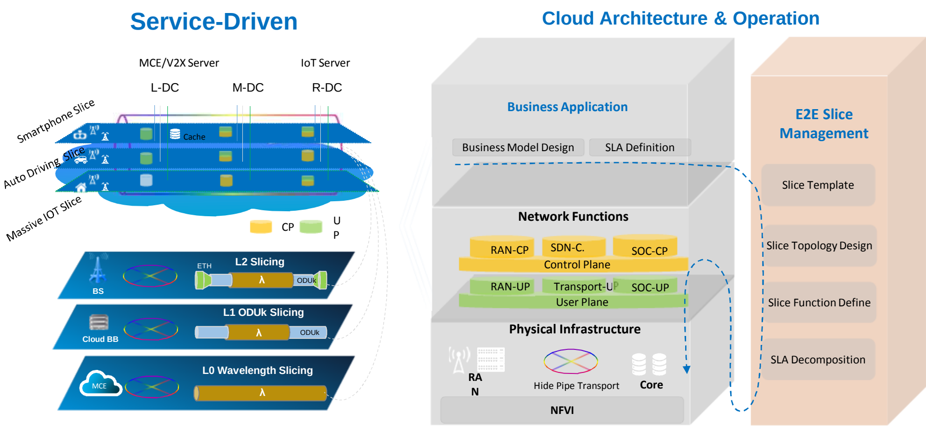
1588 Single-Fiber Bidirectional



Scenario	Services	Timing Requirement	Impacts
5G High frequency(above-6G)	*Basic 5G service*	< ±500ns	Handover failure (high frequency)
5G Low frequency(sub-6G)	Coordinated features	< ±150ns	Zero gain

- IEEE 1588 Master and Slave Clock Synch. Computing **Dynamic**
  ▵t1=t2 - t1=Delay1 - Offset　　　Delay = (▵t2 + ▵t1)/2
  ▵t2=t4 - t3=Delay2 + Offset　　　**Offset = (▵t2 - ▵t1)/2**
- Usually, Synch. signal transmit and receive terminal is transmit via two different fiber, **compensation** is needed for differential delay, which need **OTDR** during the deployment, If the uplink and downlink routing change, the Sync. Precision may lost.
- OTN supports **IEEE 1588 Single-Fiber Bidirectional**, which could simplified the Offset calculation **guarantee ns level clock precision**

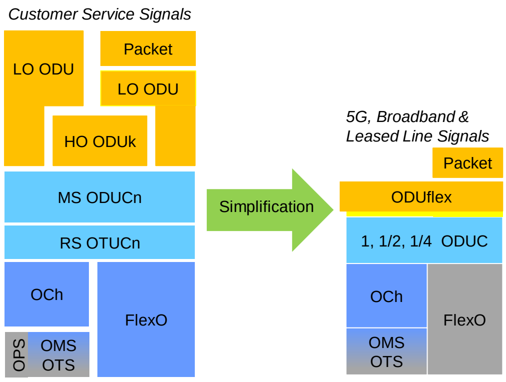
Service-Driven Optimization via Network Slicing



- E2E Slice Management provides intelligent slicing control for 5G applications
- Optimized OTN provides flexible slicing at L0/L1/L2

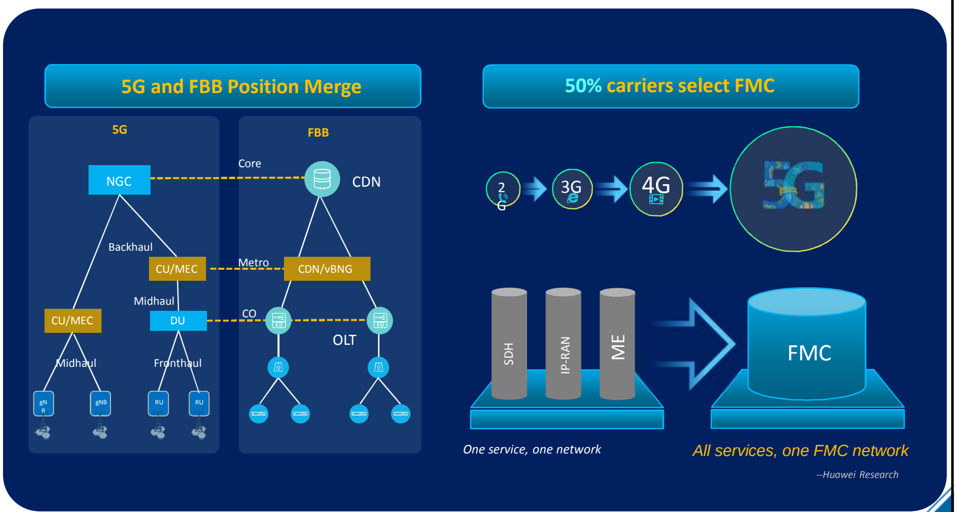
Simplification of OTN Architecture for 5G

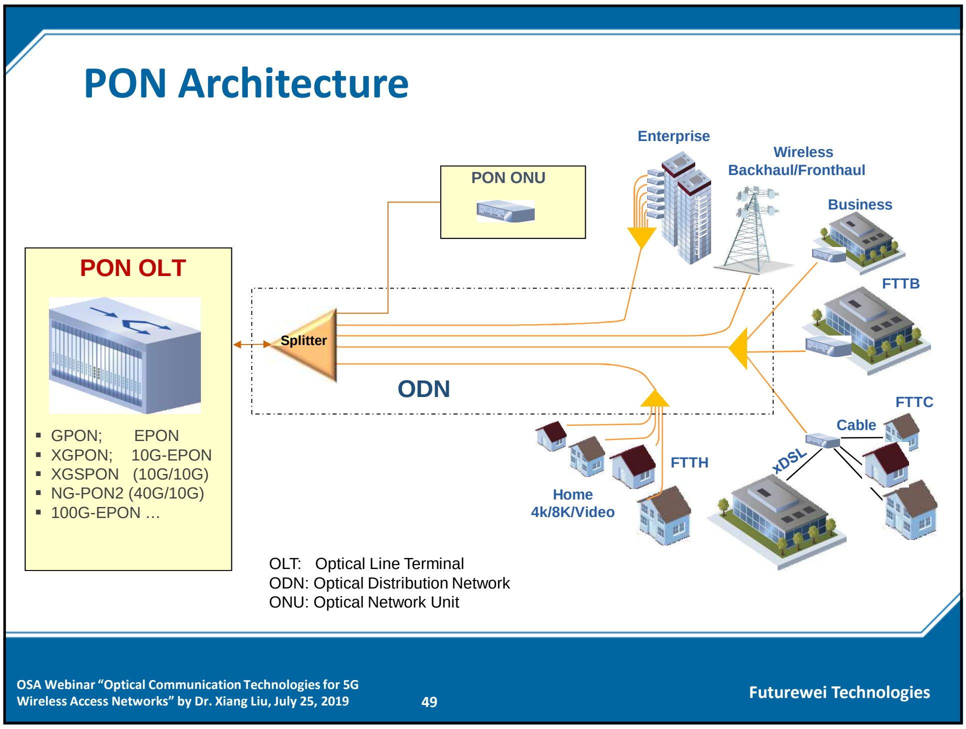
- OTN is currently designed to support multiple businesses and to carry multi-service client signals.
- To more efficiently carry the upcoming 5G client signals, the "full-stack" OTN can be simplified as well as enhanced to focus on 5G services, as shown below.



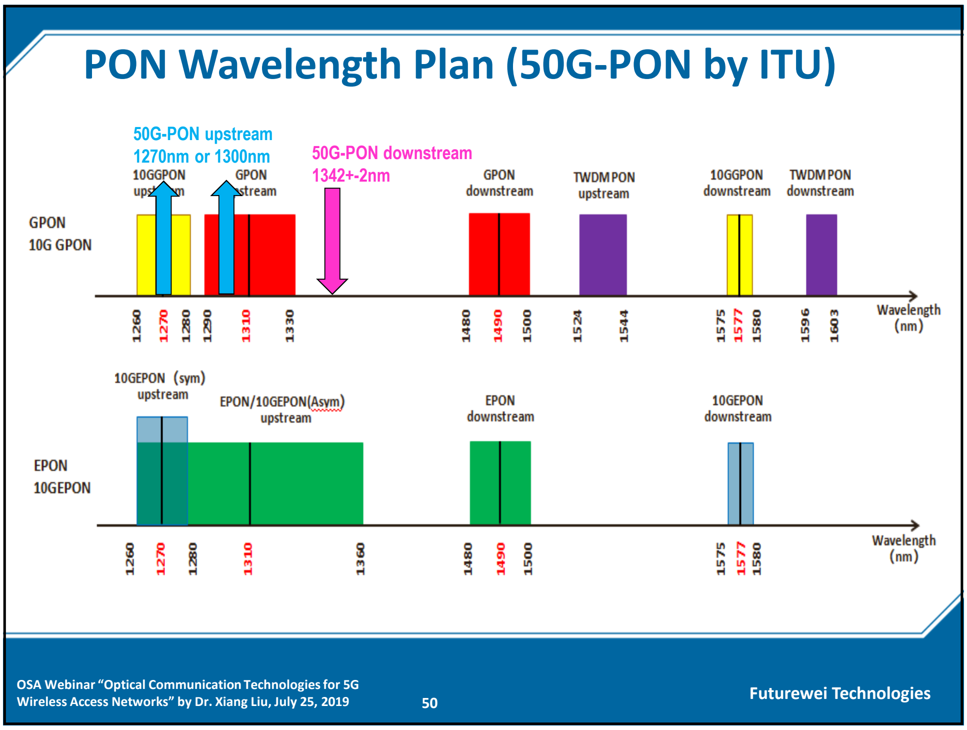
Further reading: M. Vissers, "Introduction to Mobile-optimized Multi-service Metro OTN (M-OTN)," Invited talk in ECOC Workshop WS15 - Technology Trends for Optical Networks Towards 2020 and Beyond, Rome, Italy (2018).

Towards Fixed-Mobile Convergence (FMC)



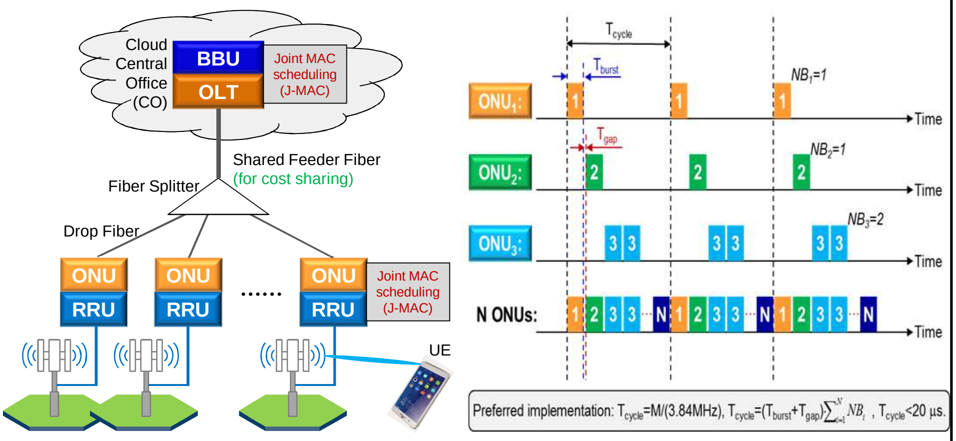

PON Architecture
Enterprise
Wireless
Backhaul/Fronthaul
Business
PON ONU
PON OLT
Splitter
FTTB
ODN
FTTC
Cable
xDSL
FTTH
Home
4k/8K/Video
▪ GPON; EPON
▪ XGPON; 10G-EPON
▪ XGSPON (10G/10G)
▪ NG-PON2 (40G/10G)
▪ 100G-EPON …
OLT: Optical Line Terminal
ODN: Optical Distribution Network
ONU: Optical Network Unit
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
49
Futurewei Technologies

49


PON Wavelength Plan (50G-PON by ITU)
50G-PON upstream
1270nm or 1300nm
50G-PON downstream
1342+-2nm
10GGPON upstream
GPON upstream
GPON downstream
TWDM PON upstream
10GGPON downstream
TWDM PON downstream
GPON
10G GPON
1260
1270
1280
1290
1310
1330
1480
1490
1500
1524
1544
1575
1577
1580
1596
1603
Wavelength (nm)
10GEPON (sym) upstream
EPON/10GEPON(Asym) upstream
EPON downstream
10GEPON downstream
EPON
10GEPON
1260
1270
1280
1310
1360
1480
1490
1500
1575
1577
1580
Wavelength (nm)
OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019
50
Futurewei Technologies

50

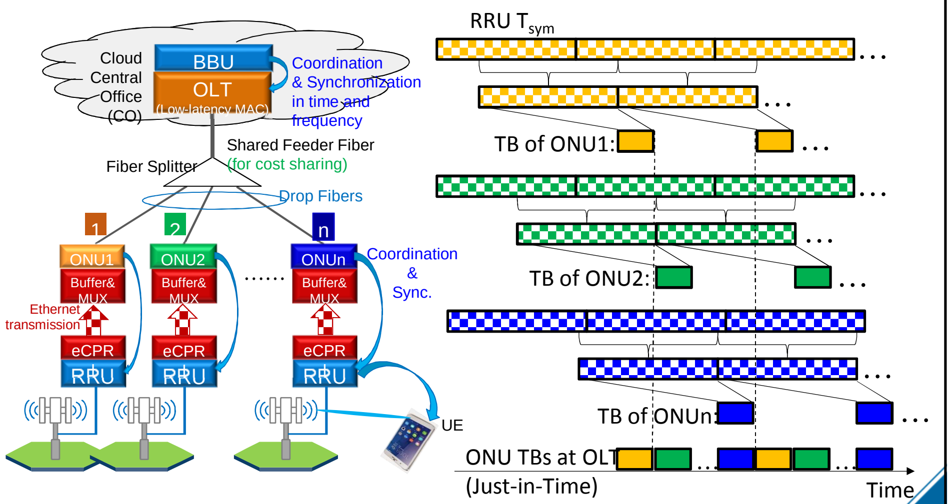
CPRI-PON



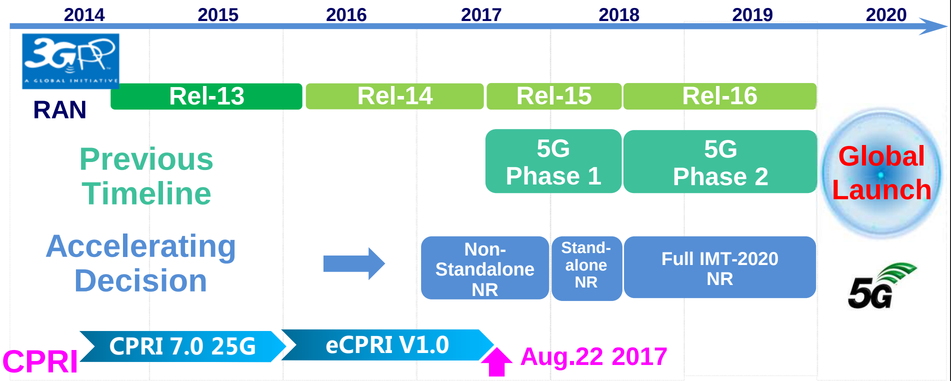
References:
J. Kani, S. Kuwano, and J. Terada, "Options for future mobile backhaul and fronthaul," Optical Fiber Technology 26, pp. 42–49 (2015).
X. Liu and F. Effenberger, "Emerging Optical Access Network Technologies for 5G Wireless [Invited]," JOCN 8, B70 (2016).

eCPRI-PON

Low latency achieved by Just-in-Time Buffering & Coordination between eCPRI and ONU



Standards Activities: 5G Timeline



5G Comprises

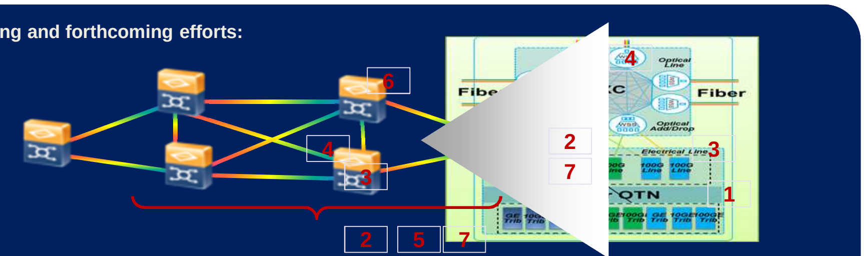
- NR(New Radio)
- Evolution of LTE Advanced Pro
- NextGen (New Core Network)
- Evolution of EPC

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 53 Futurewei Technologies

53

Standards Efforts Towards Agile&Open WDM

Existing and forthcoming efforts:



1	OTN L1 logical 100G&beyond	Q11 / SG15
2	OTN OAM, protection	Q11, Q9 / SG15
3	DWDM 100G interworking	Q6 / SG15
4	ROADM, optical monitoring	Q7, Q6 / SG15
5	L0 networking control	CCAMP, TEAS, …
6	L0 networking (WTN) model	Q12, Q14 / SG15
7	L0 OAM, interface, prot., etc.	Q11, Q9, … / SG15

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019 54 Futurewei Technologies

54

Outline

1) 5G Wireless Trends and Technologies
- Cloud-RAN, Massive MIMO, and coordinated multipoint (CoMP)
- Mobile fronthaul, midhaul and backhaul

2) The Optical Interfaces for Wireless
- The common public radio interface (CPRI)
- Evolved CPRI (eCPRI) and next-generation fronthaul interface (NGFI)

3) Enabling Optical Communication Technologies
- Modulation, detection, and DSP (100G coherent and low-cost IM/DD)
- Reconfigurable optical add/drop multiplexers (ROADM) & OXC
- Low-cost transceiver devices and subsystems

4) 5G-Oriented Optical Networking
- 5G-Oriented metro and core networks
- 5G-Oriented optical access network (PON)
- Industry standard development for 5G-oriented optical networking

5) Concluding Remarks

55

Most recent update from MWC 2019

Feb. 25-28, 2019, Barcelona, Spain

- Organized by GSMA (Global System for Mobile Communications Association)
- Over 100,000 attendees, with exhibition starting at 7:30am each day.
- 5G networks and 5G-ready consumer devices are highlighted.

56

5G Status at MWC 2019 (1)

Actual 5G-ready handsets are finally here

Despite all the hype about how 5G is going to change mobile communication as we know it, much of that discussion has been largely academic up until now. That's because aside from a handful of 5G hotspots for use in limited areas, before last week, there weren't any actual 5G-ready phones on the market.

But with the announcement of the Galaxy S10 5G, LG V50 5G, and Huawei Mate X (yes, Huawei's bendy phone is also 5G-ready), and several 5G prototypes from the likes of OnePlus, Oppo, ZTE, and others, there's finally some actual 5G hardware to talk about. However, with none of those devices expected to become available before sometime this spring at the earliest, it seems we're still in for a little wait until we can test out true 5G devices for real.

https://gizmodo.com/the-five-biggest-takeaways-from-the-most-important-mwc-1832971313

Best-in-Show Award at MWC 2019:

Huawei's 5G-Ready Mate-X Foldable Phone

https://bgr.com/2019/02/28/mate-x-vs-galaxy-fold-huawei-beats-samsung-to-best-in-show-mwc-award/

5G + 8K Live Broadcast at MWC 2019

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019

Futurewei Technologies

59

5G Status at MWC 2019 (2)

Waiting on 5G networks to catch up

For a trade show that had 5G plastered on practically every other sign, … there wasn't a lot of concrete info or updates on when 5G networks would be available.

As OnePlus founder Pete Lau pointed out during a panel co-hosted by Qualcomm, the 5G revolution is one that will take places over three phases, with the phase 1 being an improvement of data speeds over the next three to five years. Only once the 5G networks are up and running can we begin to build out full ecosystems of 5G devices and AI-powered software in phase 2, before finally making everything interconnected in phase 3 of the 5G era.

https://gizmodo.com/the-five-biggest-takeaways-from-the-most-important-mwc-1832971313

OSA Webinar "Optical Communication Technologies for 5G Wireless Access Networks" by Dr. Xiang Liu, July 25, 2019

Futurewei Technologies

60

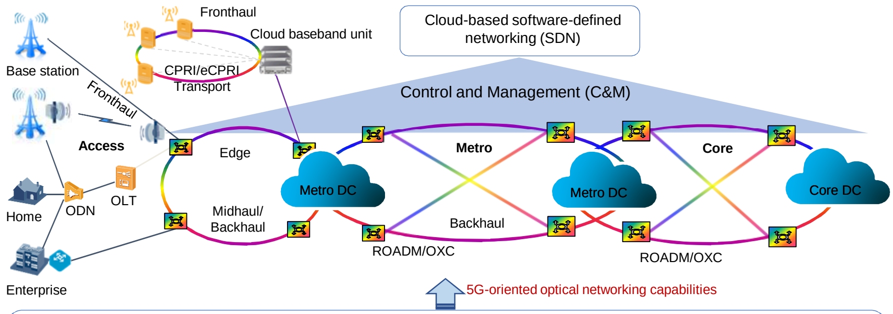
China gives green light for local 5G rollout

Published by CNBC on Thu, Jun 6 2019 1:34 AM EDT
https://www.cnbc.com/2019/06/06/china-5g-rollout-gives-licenes-to-major-carriers.html

Key points:

- China gives licenses to major state-owned mobile carriers for the commercial rollout of 5G.
- China Telecom, China Mobile, China Unicom and China Radio and Television are the companies that have obtained the license.
- While China was initially considering a 5G rollout in 2020, analysts say the timeline appears accelerated with services likely to be launched later this year.
- The GSMA, a trade body that represents mobile networks globally, said in a recent report that it expects a wide scale rollout of 5G in 2020.
- China will, according to the association, account for the largest number of 5G connections in 2025, greater than North America and Europe combined.
- The GSMA expects China to reach 460 million 5G connections by the end of that year.

More to Expect on Optical Networking for 5G …



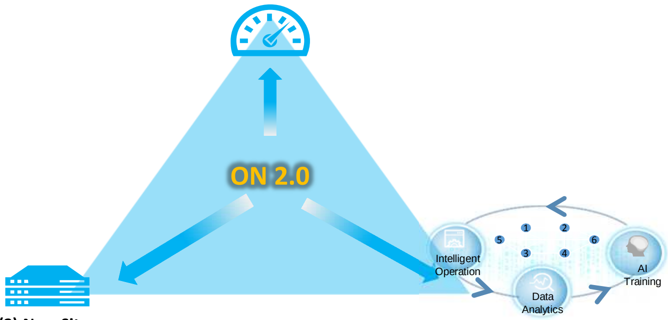
High Bandwidth	Low Latency & High Sync.	Network Slicing	Experience & TCO
• 100G/200G/400G/600G… • Tb/s Superchannel • Constellation shaping • Silicon photonics • Large-scale photonic integration	• Guaranteed low and fixed latency for L1 processing • One-hop from edge to core via L0 pass-through to reduce latency. • Accurate synchronization	• End-to-end slicing management provides intelligent 5G slicing • Simplified optical transport network to provide L0/L1/L2 slicing	• AI-enabled SDN for improved user experience • Intent-driven networking with "automatic" C&M • Significantly lower OPEX & CAPEX

Huawei's Optical Networking 2.0 (ON2.0)

https://www.huawei.com/en/press-events/news/2019/5/huawei-on2-all-optical-networks-operators

(1) New Speeds

200G/400G/600G/>1T; Super-C band: 50% increase in bandwidth over the traditional C-band



(2) New Sites

Dramatic simplification of the optical nodes via OXC etc.

(3) New Smart O&M

AI-based Optical Intelligence for fault identification and predication, improving O&M efficiency and marking a critical step towards zero-touch optical networks

More to Expect on Optical Networking for 5G …

ON2020

IEEE Industry Connections Activity **ON2020**

A Global Effort on Long-term Perspectives for Innovative Optical Networking Solutions

- Six technical topics:
  1. Traffic evolution in optical networks
  2. Optics integration onto switch engines
  3. Optics integration onto coherent engines
  4. Transmission Systems
  5. Transport Network Protocols
  6. Network Autonomy and Control

https://standards.ieee.org/industry-connections/optical-networks-2020.html

Facing the challenges & opportunities brought by 5G, DCI, 4K/8K Video, and AR/VR, our optical networking community shall work together to innovate and contribute to our society in the Cloud & 5G Era towards 2020 and beyond!

ON2020

NGOF

Thank You All!

Review Questions

Q1: 5G requires:

1. Higher capacity
2. Lower Latency
3. More connectivity
4. Lower energy consumption per bit
5. All of the above

Q2: What are the emerging techniques for low-cost optical transceivers for 5G applications?

1. Bi-directional transceivers
2. Low-cost O-band transceivers
3. Low-cost WDM transceivers
4. DSP-enabled bandwidth-efficient transceivers
5. All of the above

Q3: What are the desired features of 5G-oriented core/metro optical networks?

1. High bandwidth (e.g., via 400G/s and beyond)
2. Low latency (e.g., via ROADM/OXC)
3. Accurate synchronization (e.g., via 1588)
4. Ability to perform network slicing functions (e.g., via SDN and mobile-optimized OTN)
5. All of the above

Q4: What are the desired features of 5G-oriented optical access networks?

1. High bandwidth (such as 50G-PON)
2. Low latency (via improved MAC)
3. Accurate synchronization
4. Ability to interwork with eCPRI
5. All of the above

Summary

Now we have covered the key materials of this Webinar:

This course aims to provide an up-to-date overview of the emerging optical communication technologies for next-generation wireless networks such as 5G. It is intended to help the attendees to broaden their knowledge on the emerging applications of optical networks in future wireless networks, deepen their understanding of the state-of-the-art optical communication technologies, and explore new R&D opportunities in the field of converged fixed-mobile networks.

Hope we have together achieved our Learning Objectives:

- ✓ Describe 5G wireless trends and technologies such as massive MIMO & CoMP
- ✓ Identify promising applications of optical communication technologies in 5G
- ✓ Get an insight into recent advances on CPRI and eCPRI for C-RAN.
- ✓ Describe emerging optical communication technologies such as 100+Gb/s coherent, low-cost IM/DD transmission, and associated DSP techniques for high-throughput and low-latency wireless fronthaul & backhaul
- ✓ Discuss emerging network architectures and design tradeoffs among various optical transport and access systems for better converged fiber/wireless networks

For more questions, you are welcome to contact me at: xiang.liu@futurewei.com

Thank You All!

Useful References (1)

Classic Book Series

- I.Kaminow and T.Li, Optical Fiber Telecommunications IV, Academic Press (2002).
- I.Kaminow, T.Li, A.E.Willner, Optical Fiber Telecommunications V, Elsevier (2007).
- I.Kaminow, T.Li, A.E.Willner, Optical Fiber Telecommunications VI, Elsevier (2013).
- A.E.Willner, Optical Fiber Telecommunications VII, Elsevier (2019).

Relevent OFC Short Courses

- SC105: Modulation Formats and Receiver Concepts for Optical Transmission Systems, by Peter Winzer and S. Chandrasekhar
- SC114: Passive Optical Networks (PONs) Technologies, by Frank J. Effenberger
- SC203: 100 Gb/s and Beyond Transmission Systems, Design and Design Trade-offs, by Martin Birk and Benny Mikkelsen
- SC217: Optical Fiber Based Solutions for Next Generation Mobile Networks, by Dalma Novak
- SC444: Optical Communication Technologies for 5G Wireless, by Xiang Liu
  https://www.ofcconference.org/en-us/home/program-speakers/short-courses/sc444/

IEEE Communications Socity Training Course

- Optical Communication Technologies for 5G Wireless, by Xiang Liu
  https://www.comsoc.org/education-training/training-courses/online-courses/2019-05-optical-communication-technologies-5g

Useful References (2)

Publications

- F. Boccardi, R. W. Heath, A. Lozano, T. L. Marzetta and P. Popovski, "Five disruptive technology directions for 5G," in IEEE Communications Magazine, vol. 52, no. 2, pp. 74-80, February 2014.
- E. Larsson, O. Edfors, F. Tufvesson, and T. Marzetta, “Massive MIMO for next generation wireless systems,” IEEE Communications Magazine, vol.52, no.2, pp.186-195, February 2014.
- A. Pizzinat, P. Chanclou, T. Diallo, and F. Saliou, “Things you should know about fronthaul,” ECOC’14, invited paper Tu.4.2.1 (2014).
- X. Liu, H. Zeng, N. Chand and F. Effenberger, “Efficient mobile fronthaul via DSP-based channel aggregation,” in Journal of Lightwave Technology, vol. 34, no. 6, pp. 1556-1564, March 15 2016.
- N. Shibata, T. Tashiro, S. Kuwano, N. Yuki, Y. Fukada, J. Terada, and A. Otaka, "Performance evaluation of mobile front-haul employing Ethernet- based TDM-PON with IQ data compression [Invited]," in IEEE/OSA Journal of Optical Communications and Networking, vol. 7, no. 11, pp. B16-B22, November 1 2015.
- X. Liu and F. Effenberger, "Emerging optical access network technologies for 5G wireless [invited]," in IEEE/OSA Journal of Optical Communications and Networking, vol. 8, no. 12, pp. B70-B79, December 2016.
- H. Zeng, X. Liu, S. Megeed, A. Shen and F. Effenberger, "Digital signal processing for high-speed fiber-wireless convergence [invited]," in IEEE/OSA Journal of Optical Communications and Networking, vol. 11, no. 1, pp. A11-A19, Jan. 2019.
- Xiang Liu, Ning Deng, Min Zhou, Yin Wang, Minghui Tao, Lei Zhou, Shengping Li, Huaiyu Zeng, Sharief Megeed, Andy Shen, and Frank Effenberger, "Enabling Technologies for 5G-Oriented Optical Networks," 2019 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, USA, Invited paper Tu2B.4.

Thank you all for your attention!