IEEE FNI Webinar –

Evolution of Optical and Transport Technologies for 5G Crosshaul Networks

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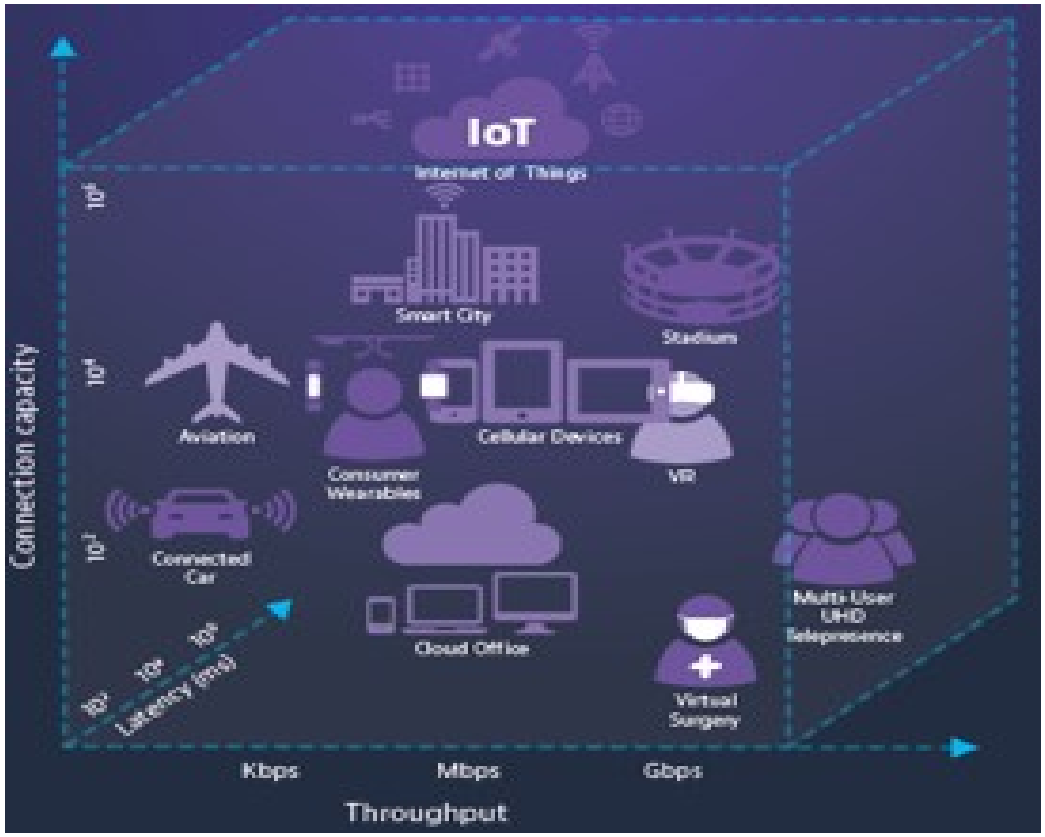
What is 5G?

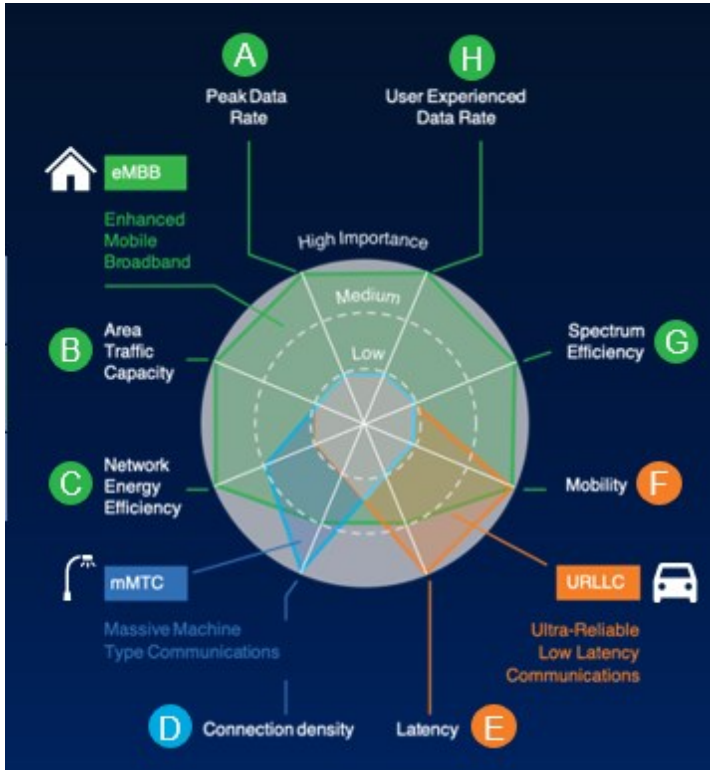
- eMBB: much higher bandwidth
- uRLLC: extremely low latency
- mMTC: very large number of low power end points



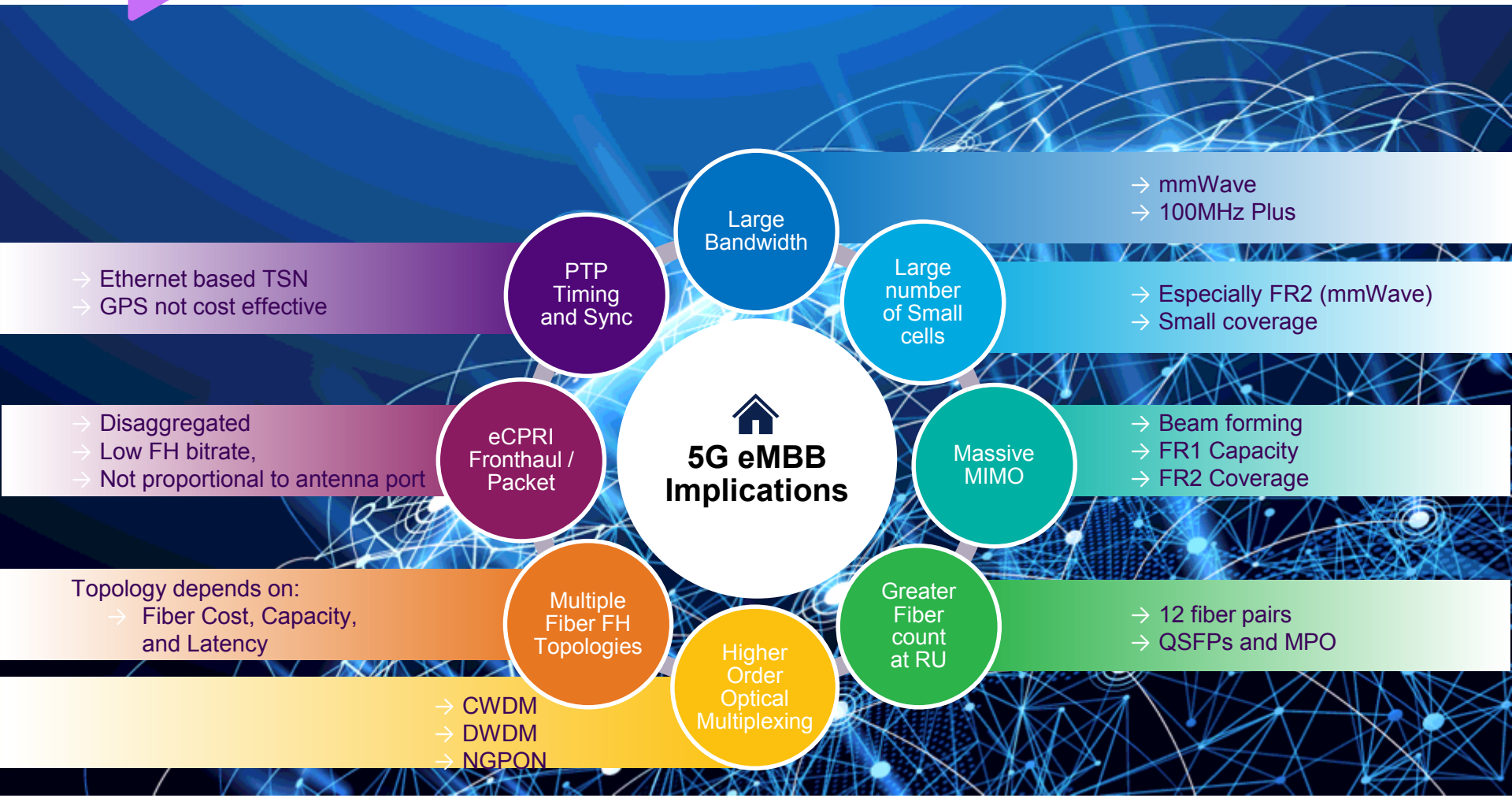
Drivers
eMBB, URLLC and mMTC

	Latency	Mobility	Spectrum Efficiency	User Experience Data Rate	Peak Data Rate	Area Traffic Capacity	Network Energy Efficiency	Connection Density
eMBB	Med	High	High	High	High	High	High	Med
URLLC	High	High	Low	Low	Low	Low	Low	Low
mMTC	Low	Low	Low	Low	Low	Low	Med	High

5G Use Cases:
eMBB, URLLC and mMTC impose a diversified set of requirements on the network

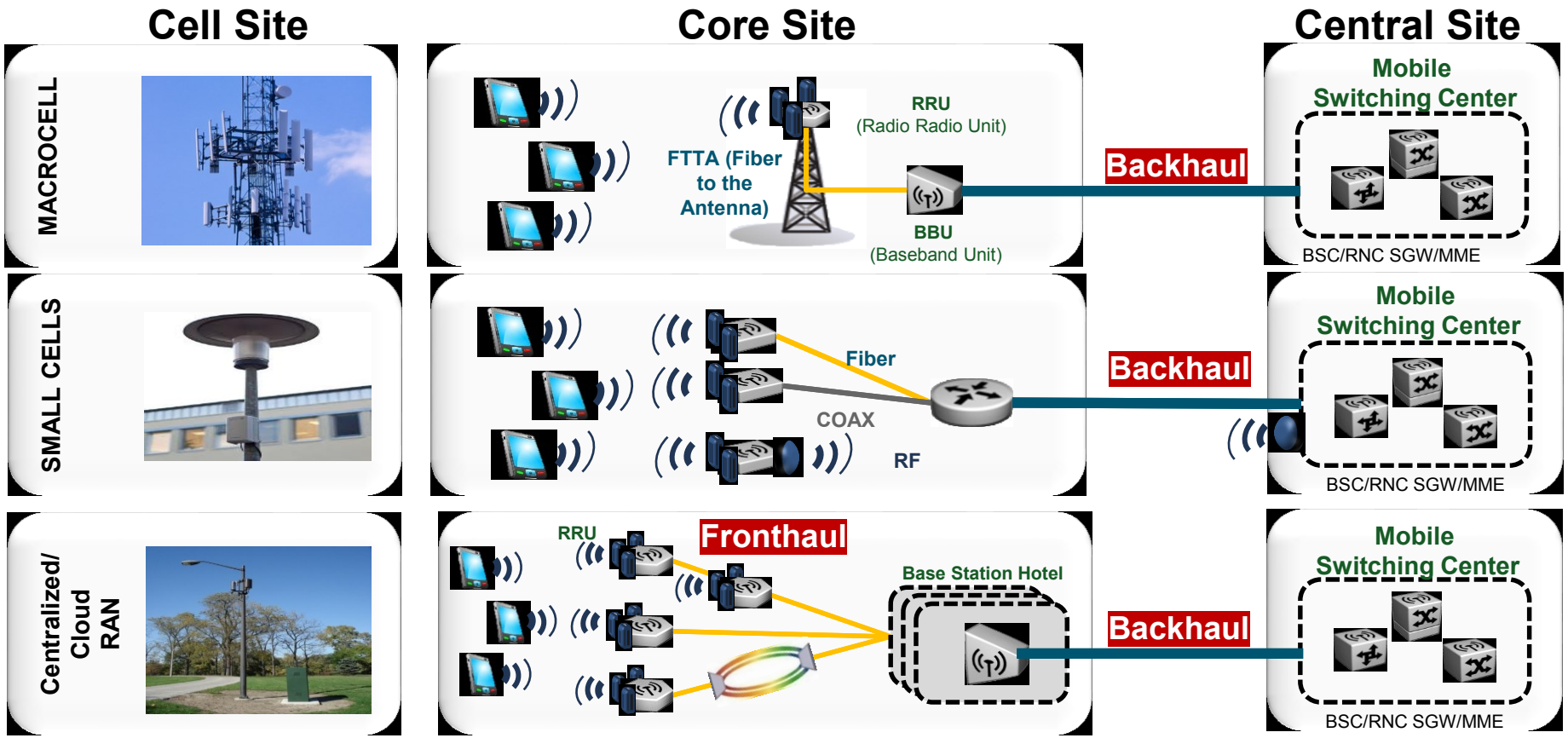


5G is More Than a RAT Evolution



Before 5G

Definition Backhaul, Fronthaul, CRAN

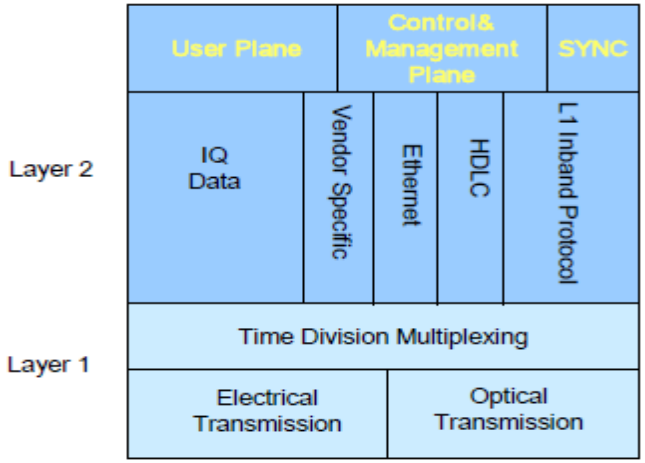


Before 5G

CPRI Specification

- 4G Fronthaul Uses Common Public Radio Interface (CPRI)
- CPRI protocol defines the layer 1 and elements of layer 2
  - Sync
  - Alarms
  - Encoding

Option	Rates (Mbps)
1	614.4
2	1228.8
3	2457.6
4	3072.0
5	4915.2
6	6144.0
7A	8110.1
7	9830.4
8	10137.0
9	12165.1
10	24330.2



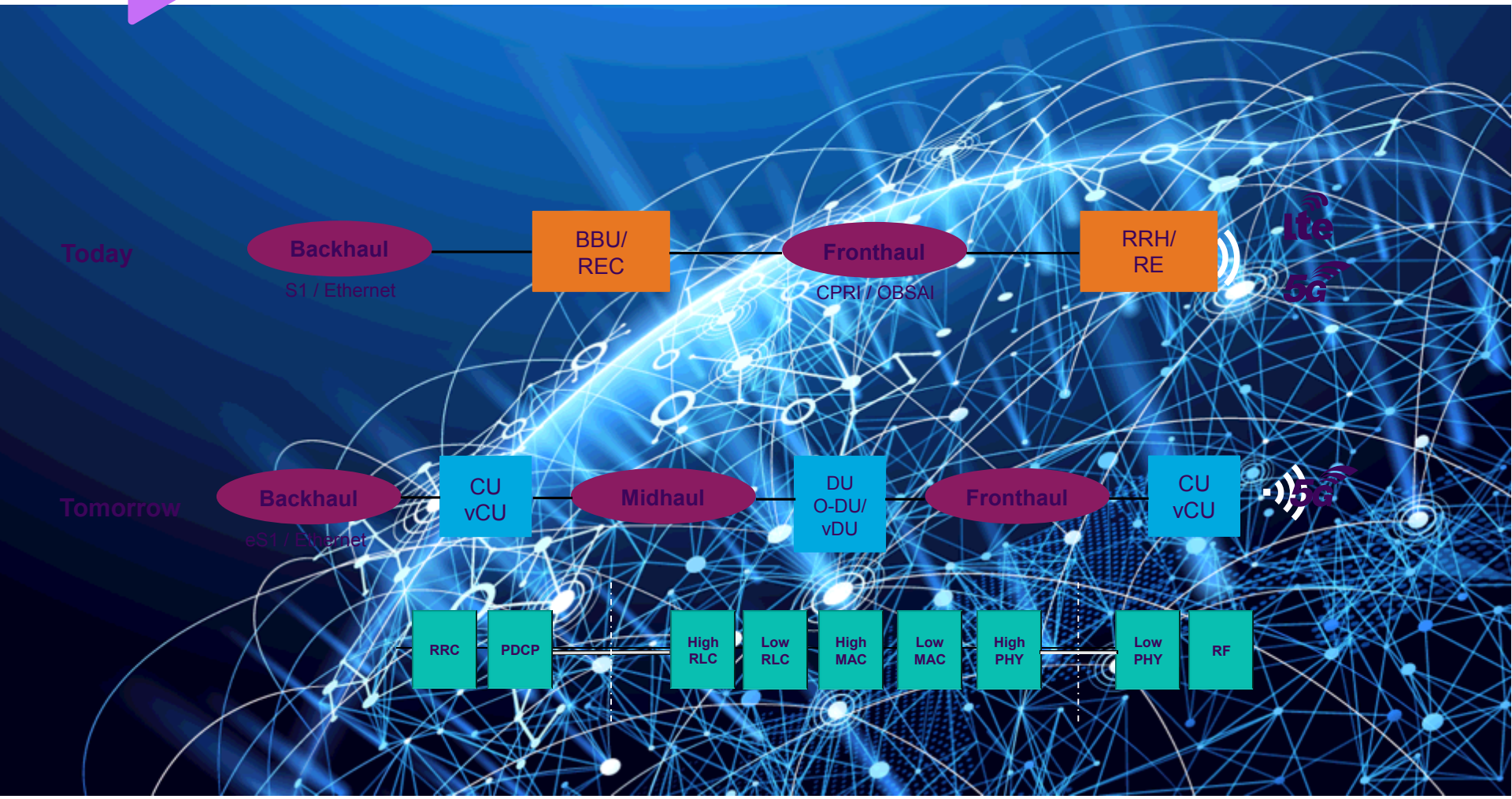
4G Fronthaul Challenge

- CPRI Technology can be scaled up to a certain level with WDM and OTN
- Bandwidth requirements increase with number of antennas and signal bandwidth
- CPRI may not meet the requirements of massive MIMO applications

Antenna	10 MHz	20 MHz	100 MHz
1	0.49 Gbps	0.98 Gbps	4.9 Gbps
2	0.98 Gbps	1.96 Gbps	9.8 Gbps
4	1.96 Gbps	3.92 Gbps	19.6 Gbps
64	31.36 Gbps	62.72 Gbps	313.6 Gbps

Source: China Mobile

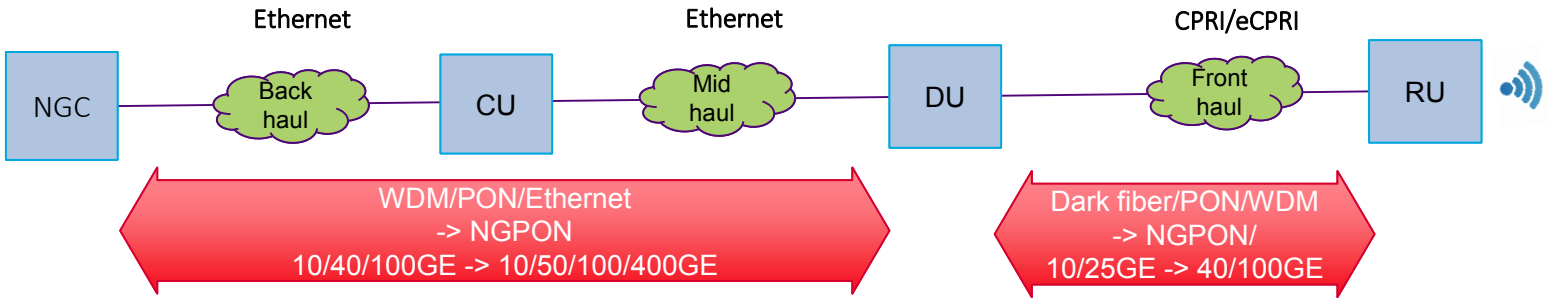
Evolving xHaul Networks



Optical Technologies in xhaul

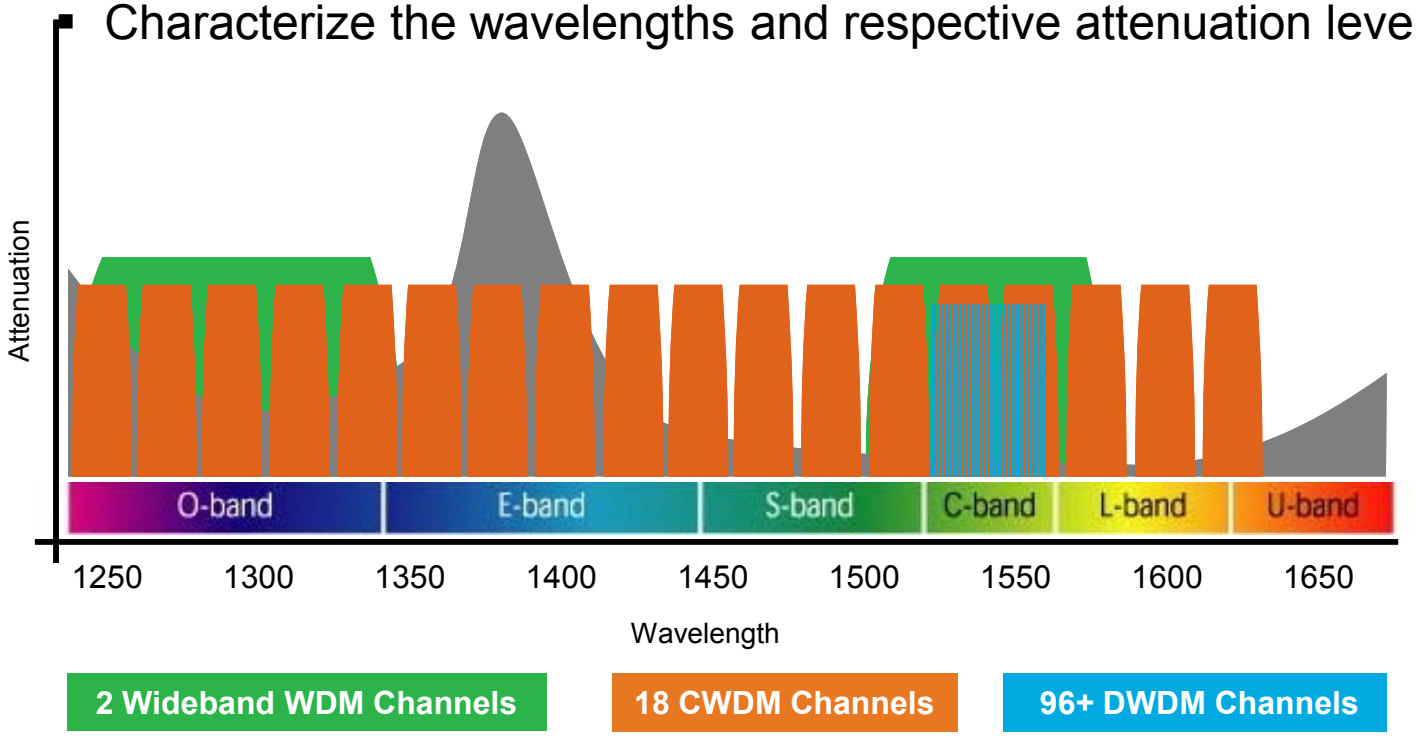
xHAUL Optical Network Technologies

- Backhaul and Midhaul
  - Bandwidth -> Big Pipes
  - WDM, PON -> DWDM/NG-PON
- Fronthaul:
  - Latency/jitter -> Delay sensitive
  - Initial deployments: Dark fiber and WDM
  - Future: DWDM/NG-PON



WDM Technologies

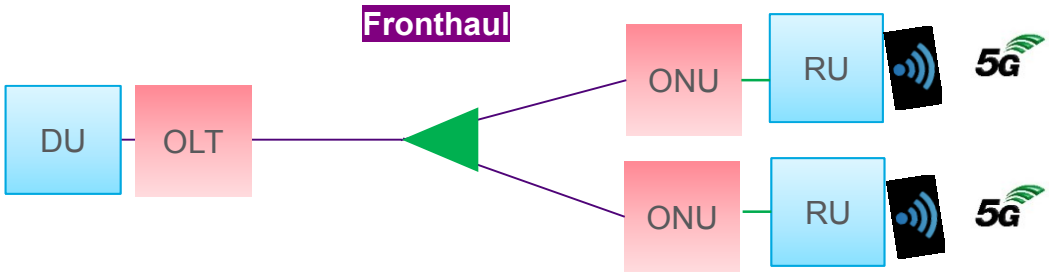
- Wideband WDM channels spaced ~100 nm apart
- CWDM channels are spaced 20 nm apart
- DWDM channels are spaced ~0.4 to 0.8 nm apart
- DWDM enables a much higher density, therefore a better usage of the fiber
- Characterize the wavelengths and respective attenuation level



2 Wideband WDM Channels **18 CWDM Channels** **96+ DWDM Channels**

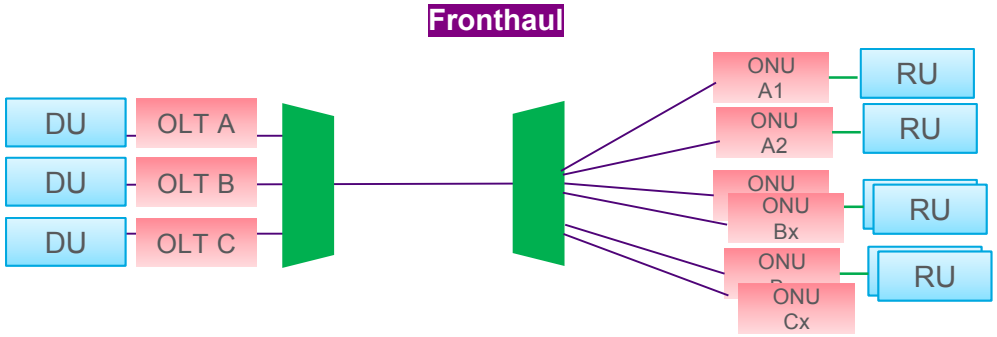
TDM PON in fronthaul (latency sensitive) networks

- TDM PON: challenge: upstream latency in several ms range!
- Need to reduce upstream latency:
  - Differentiated services: prioritize fronthaul traffic above all others
  - Dynamic Bandwidth Allocation (DBA): considers dynamic upstream traffic and buffer status
  - Cooperative DBA: OLT and DU/CU coordinate to determine the optimal upstream bandwidth



(T)WDM PON in fronthaul (latency sensitive) networks

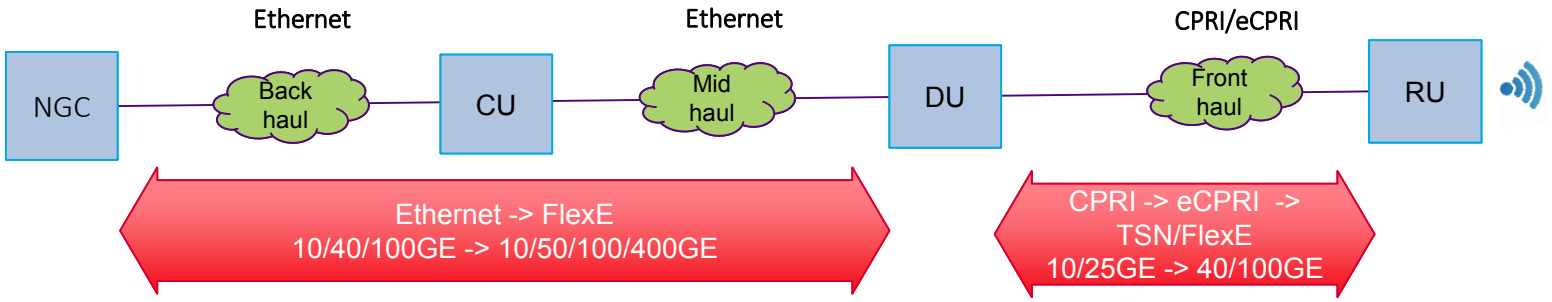
- WDM PON
  - Path loss: fiber + mux/demux + connectors
  - Link distance: mostly below 10 km
  - Delay: fiber transmission + WDM processing
  - Separate links for data, management, and synchronization (SyncE/PTP)
  - Bidirectional optics preferred for saving fiber and operational/fiber management costs.



Transport Technologies

xHAUL Transport Network Technologies

- Backhaul and Midhaul
  - Bandwidth -> Big Pipes
  - Switched Ethernet/FlexE
  - Future: FlexE
- Fronthaul:
  - Latency/jitter -> Delay sensitive
  - CPRI -> eCPRI
  - Future: TSN and FlexE



eCPRI Physical layer

- eCPRI does not mandate any physical layer
- Ethernet PHY and OTN can be valid options
- Most volumes are expected to be Ethernet
- eCPRI physical line rates from 10G to 100G
- 25/40GE starting to show up in vendor and SP designs

Table 3: Common Ethernet interface types for the given use cases

Use case	Standard / Interface Type	#Lanes	Signal Rate per Lane
Optical	10GBASE-SR/LR/ER ([5], clause 52)	1	10G
	10GBASE-LRM ([5], clause 68)	1	10G
	25GBASE-SR ([6])	1	25G
	40GBASE-SR4 LR4/ER4 ([5], clauses 86/87)	4	10G
	100GBASE-SR10 ([5], clause 86)	10	10G
	100GBASE-SR4/LR4/ER4 ([5], clauses 95/88)	4	25G

CPRI.info

eCPRI Transport Requirements

- Latency and Packet Loss Ratio
- Different SLA's for user plane and C&M
- Different classes for User Plane (normal and slow) and C&M (fast and normal)

Table 1 Split E and splits I_D, II_D, I_U requirements

CoS Name	Example use	One way maximum packet delay	One-way Packet Loss Ratio
High	User Plane	100 µs	10^{-7}
Medium	User Plane (slow), C&M Plane (fast)	1 ms	10^{-7}
Low	C&M Plane	100 ms	10^{-6}

CPRI.info

IEEE 802.1cm: Timing Sensitive Networks

- IEEE 802.1cm describes fronthaul and synchronization requirements
- Verification of latency and frame loss ratio essential for fronthaul traffic
- It defines features and options for two classes of fronthaul traffic
  - Class 1: CPRI (Split option 8) IEEE 802.1cm

Flow	Latency	Frame Loss Ratio
IQ	100 µs	10^{-7}
C&M	No requirement	10^{-6}

  - Class 2: eCPRI (Split option 7)
    - Requirements for split options E, I_D, II_D, and I_U (eCPRI Transport Networks)

CoS Name	Flow	Latency	Frame Loss Ratio
High	User Plane (fast)	Table below	10^{-7}
Medium	User Plane (slow) and, C&M Plane (fast)	1 ms	10^{-7}
Low	C&M	100 ms	10^{-6}

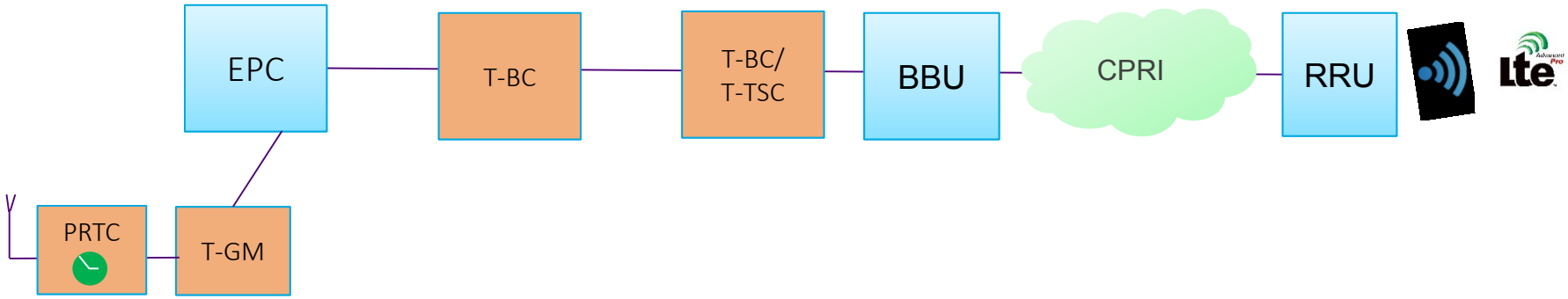
Flow	Latency	Use case
High25	25 µs	Ultra-low latency
High100	100 µs	E-UTRA and NR
High200	200 µs	For installation up to 40 km
High500	500 µs	Large latency installations

4G Network based synchronization

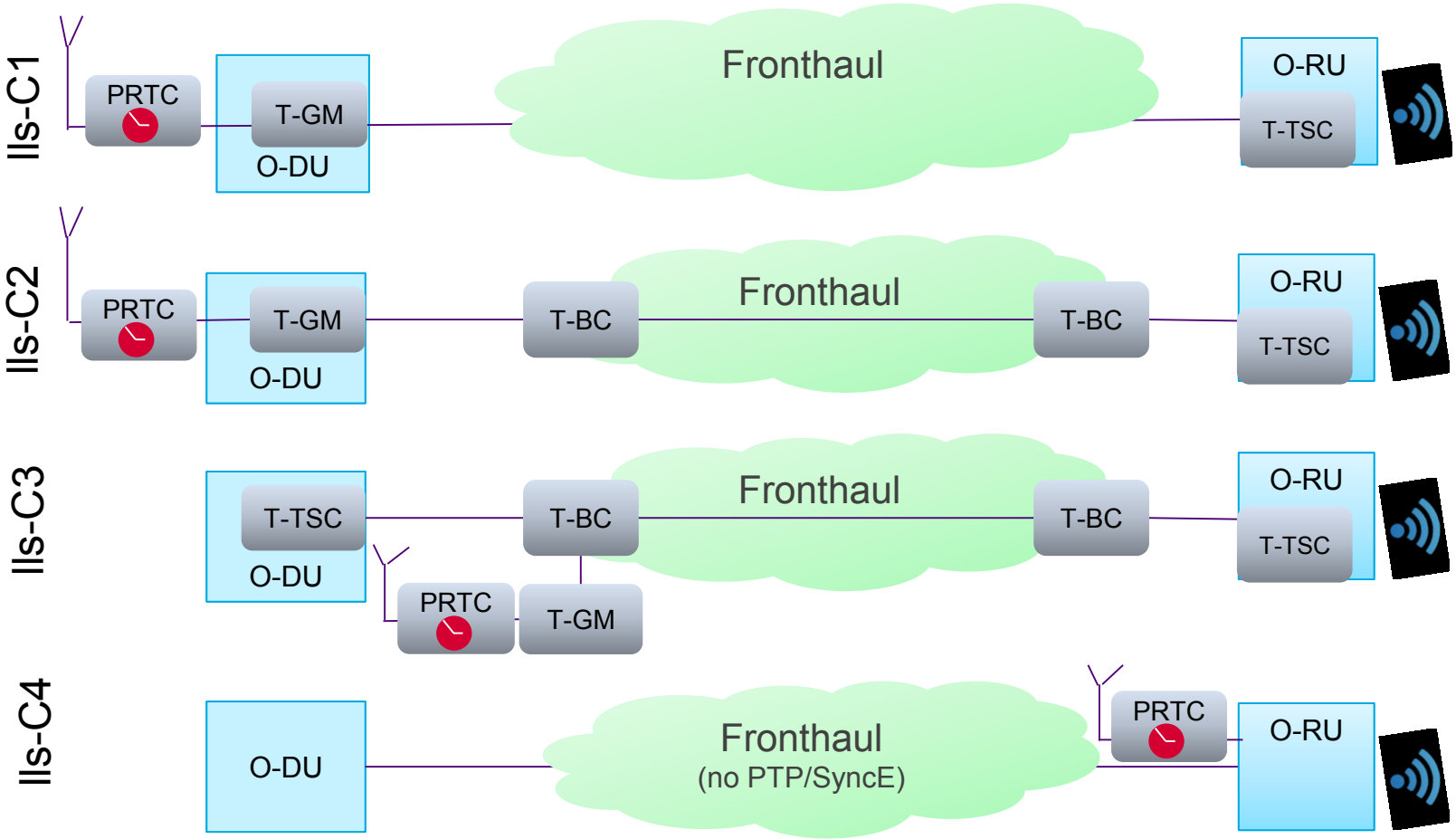
- PTP/SyncE require special switch/router function

-> Boundary Clock (T-BC) function ensures proper synchronization

- For the end-to-end network synchronization
  - All T-BC must:
    - Work properly (connect to Grandmaster (T-GM)
    - Deliver minimum delay (time error)



5G Fronthaul Synchronization Architectures



Thank You