Emerging 5G Transport Networks

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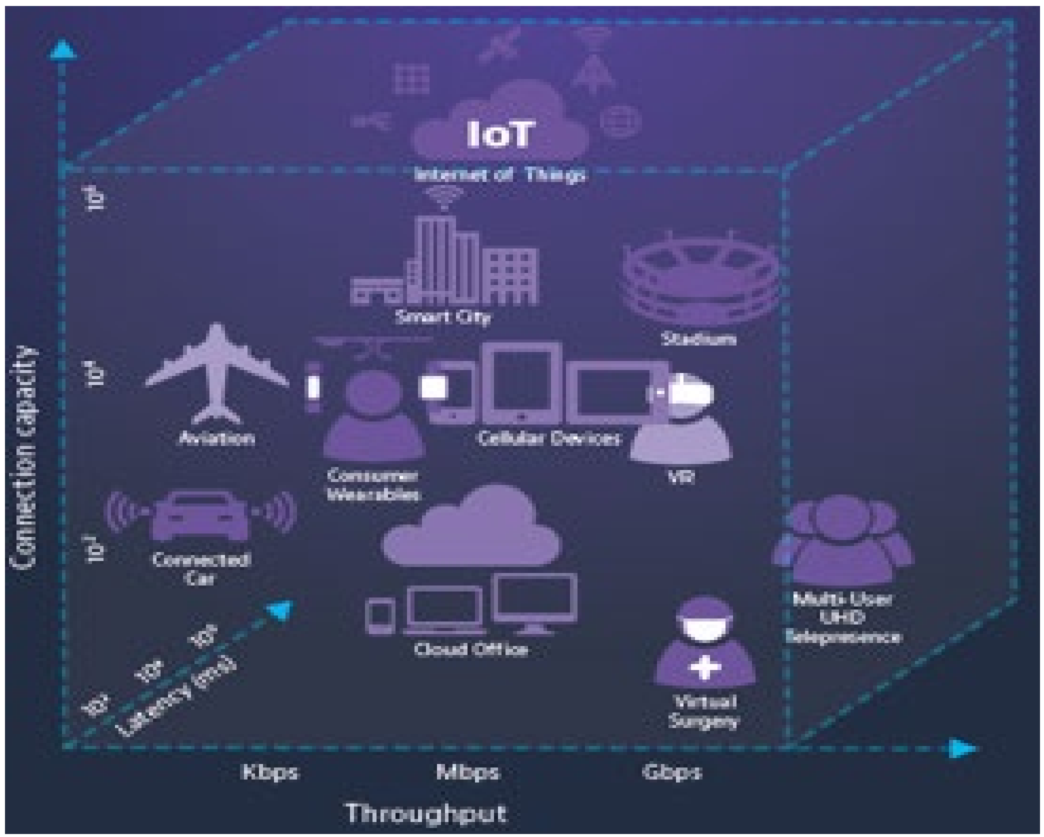
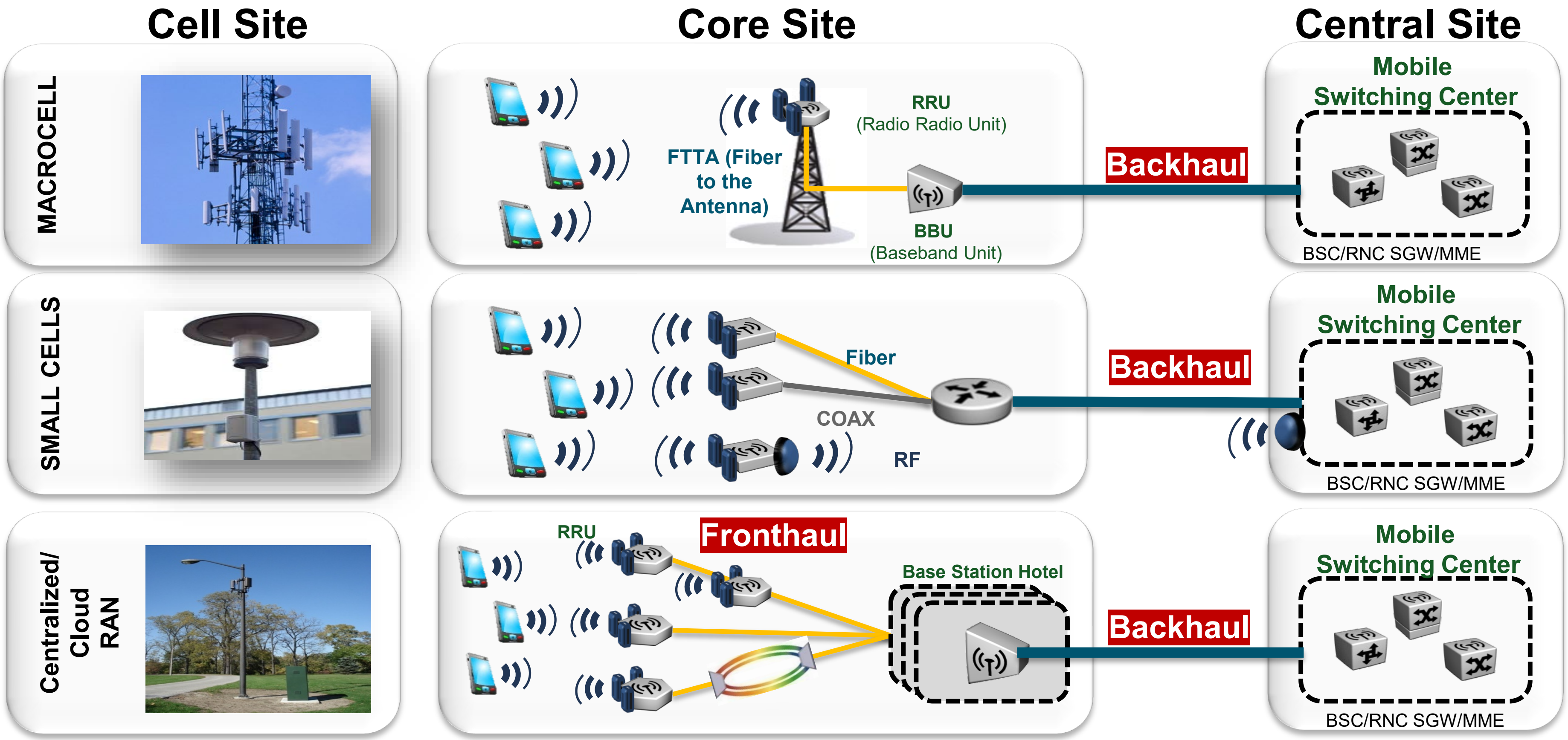
What is 5G?

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



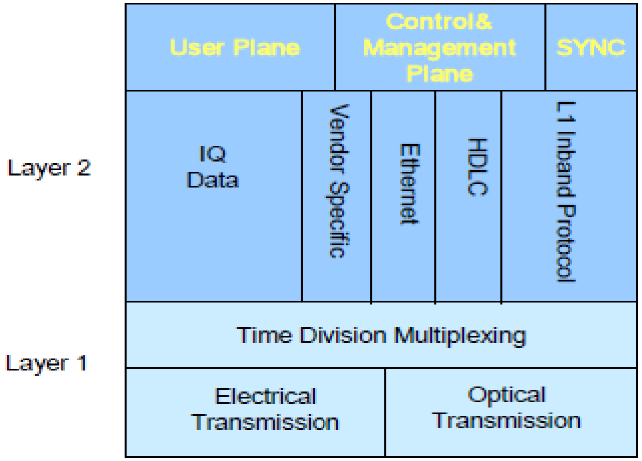
Definition Backhaul, Fronthaul, CRAN



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

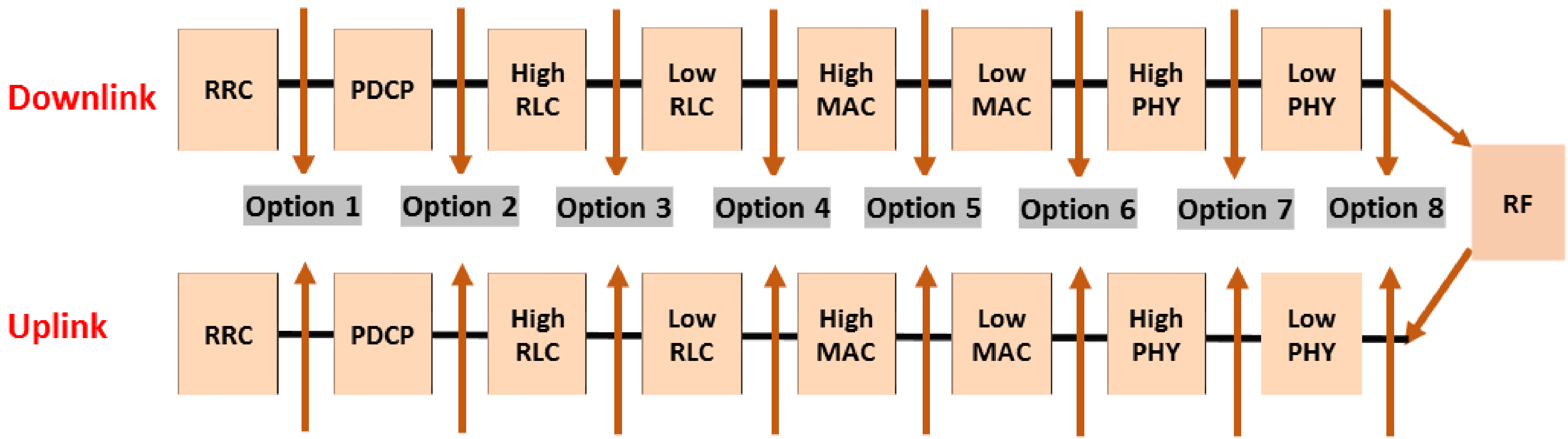
- CPRI Technology can be scaled up to a certain level with WDM and OTN
- Bandwidth requirements increase with number of antennas and signal bandwidth
- CPRI may not meet the requirements of massive MIMO applications

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

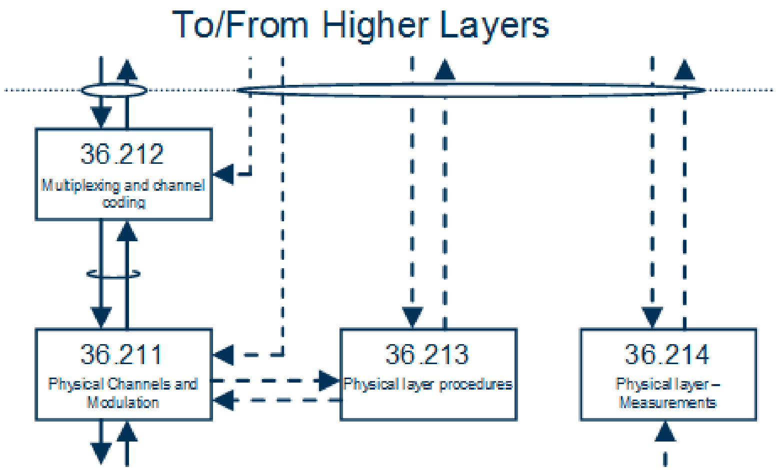
Functional Split Options

- Solving the bandwidth problem of 4G requires redistribution of functions between BBU and RRH
- Backhaul network interfaces with BBU (S1) which holds most functions from RRC to PHY
- RRH hosts the RF functions



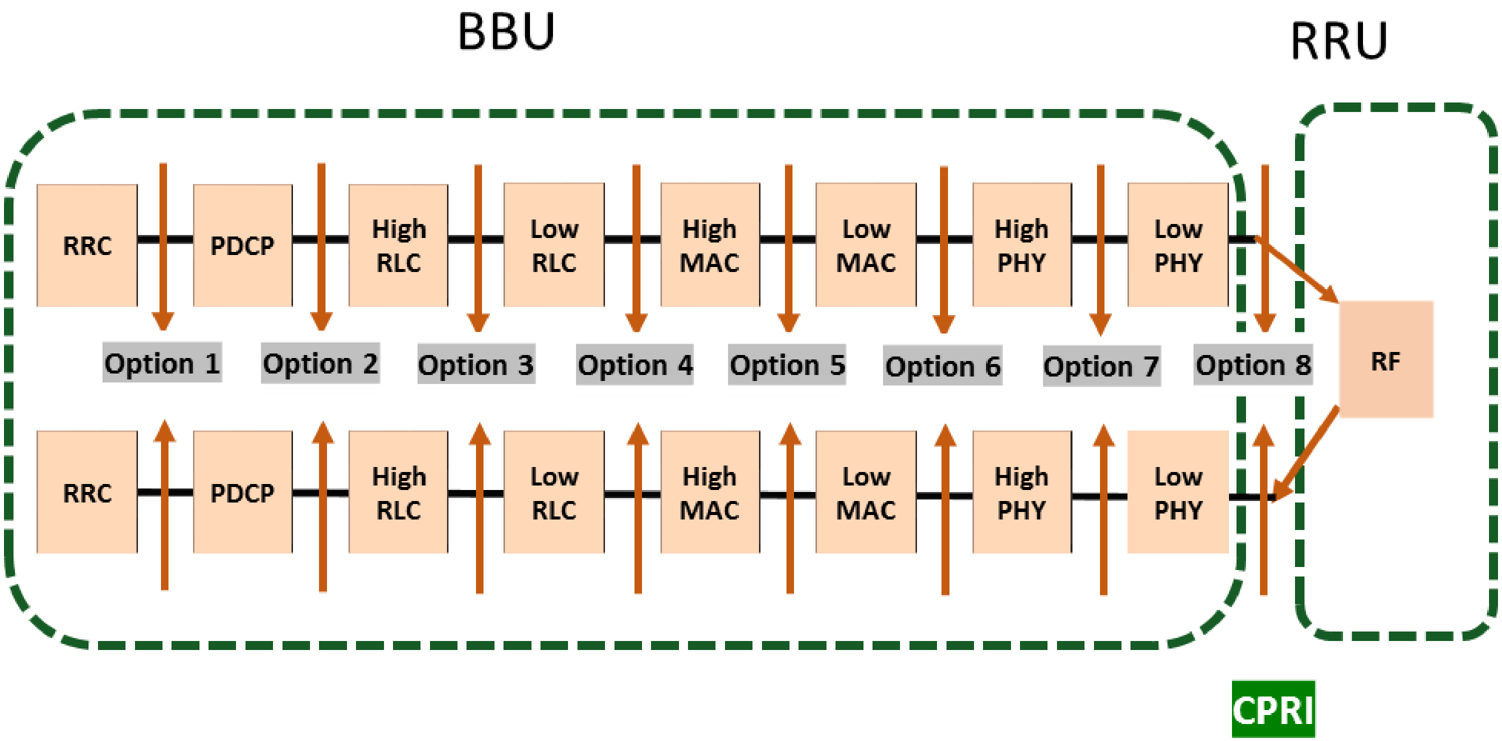
Radio Layer Functions

- RRC (3gpp TS 36.331/38.331)
  - Radio Resource Control
  - Broadcast of general control info, Ue notification on terminating a call
- PDCP (3gpp TS 36.323/38.323)
  - Packet Data Convergence Protocol
  - Data transfer, header compression, ciphering, integrity protection
- RLC (3gpp TS 36.322/38.322)
  - Radio Link Control
  - Data transfer UM, AM, TM
  - ARQ Error Correction
  - Re-segmentation & reassembly
- MAC (3gpp TS 36.321/38.321)
  - Media Access Control
  - Data transfer, radio resource allocation, HARQ, mapping of logical and transport channels
- PHY (3gpp TS 36.2xx/38.2xx)
  - Physical layer



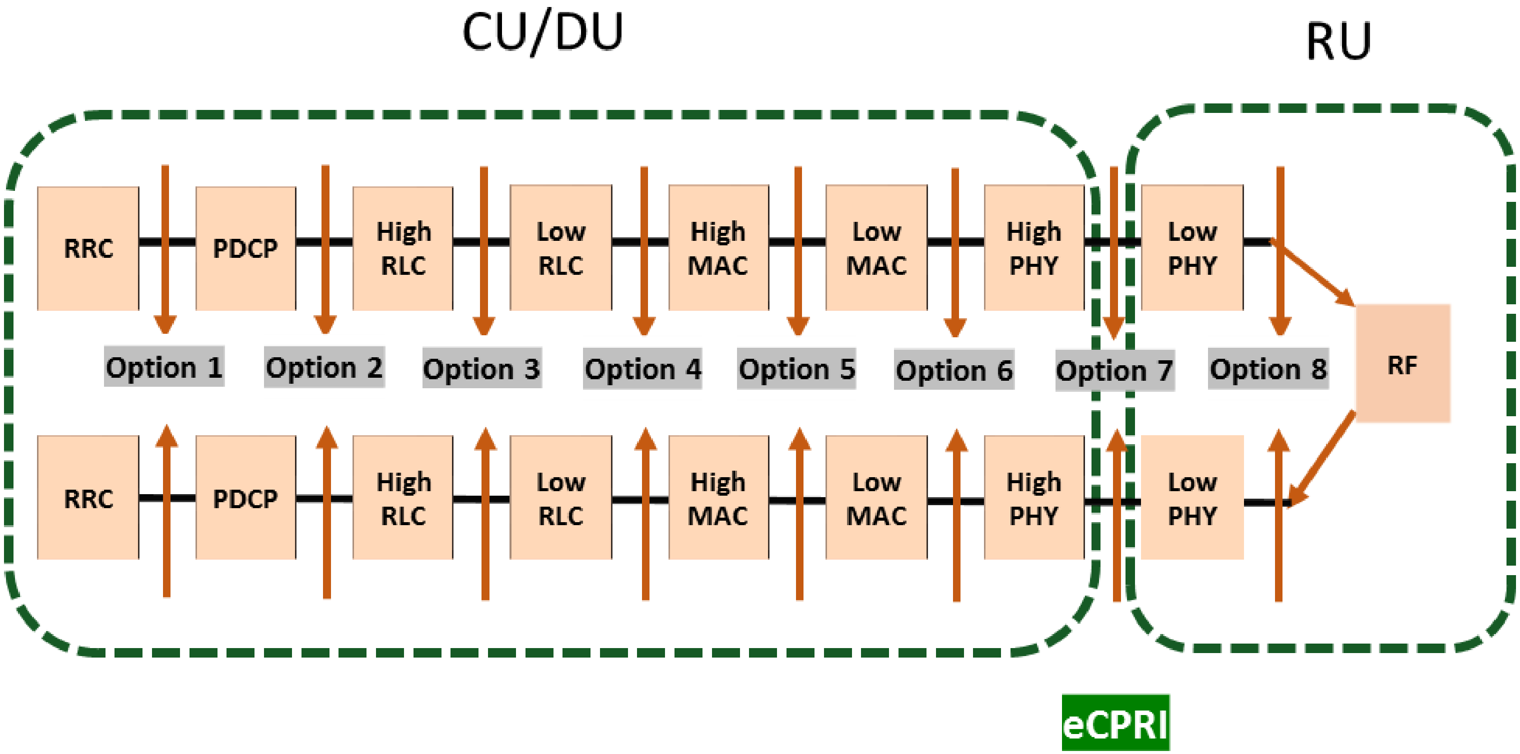
Functional Split 4G

- Current split (8): all intelligence in BBU
- Option 8: primarily CPRI (or OBSAI)
- Optimal for central processing and coordination of radios
- Bandwidth propositional to number of antennas -> high bandwidth
- CPRI has limited latency budget (< 100 us) -> Limited distance



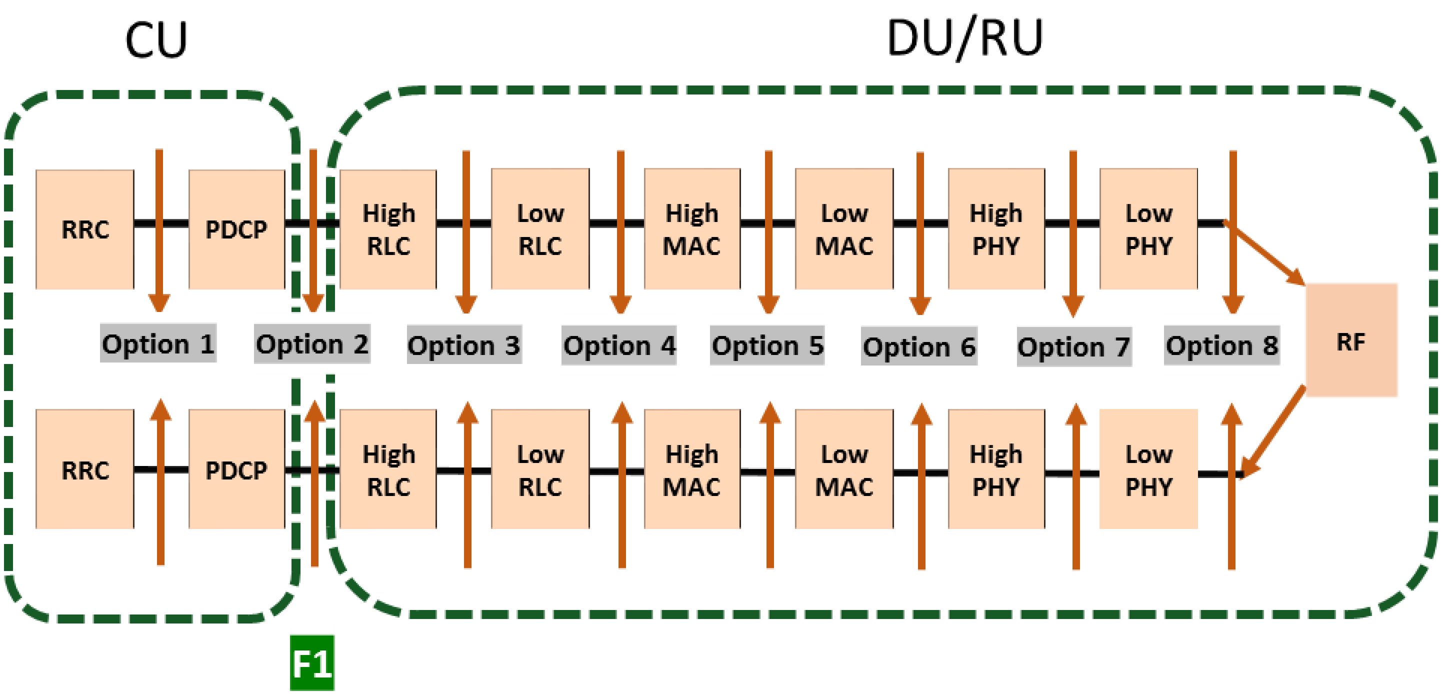
Lower Layer Split

- Low Phy moves to RU -> saving bandwidth
  - Not proportional to antenna #
- Optimized for central processing and coordination of radios -> mobility
- Moving Low Phy to RRU makes the interface more complicated (control data exchange with DU) -> adds processing power, heat, and costs to RRU



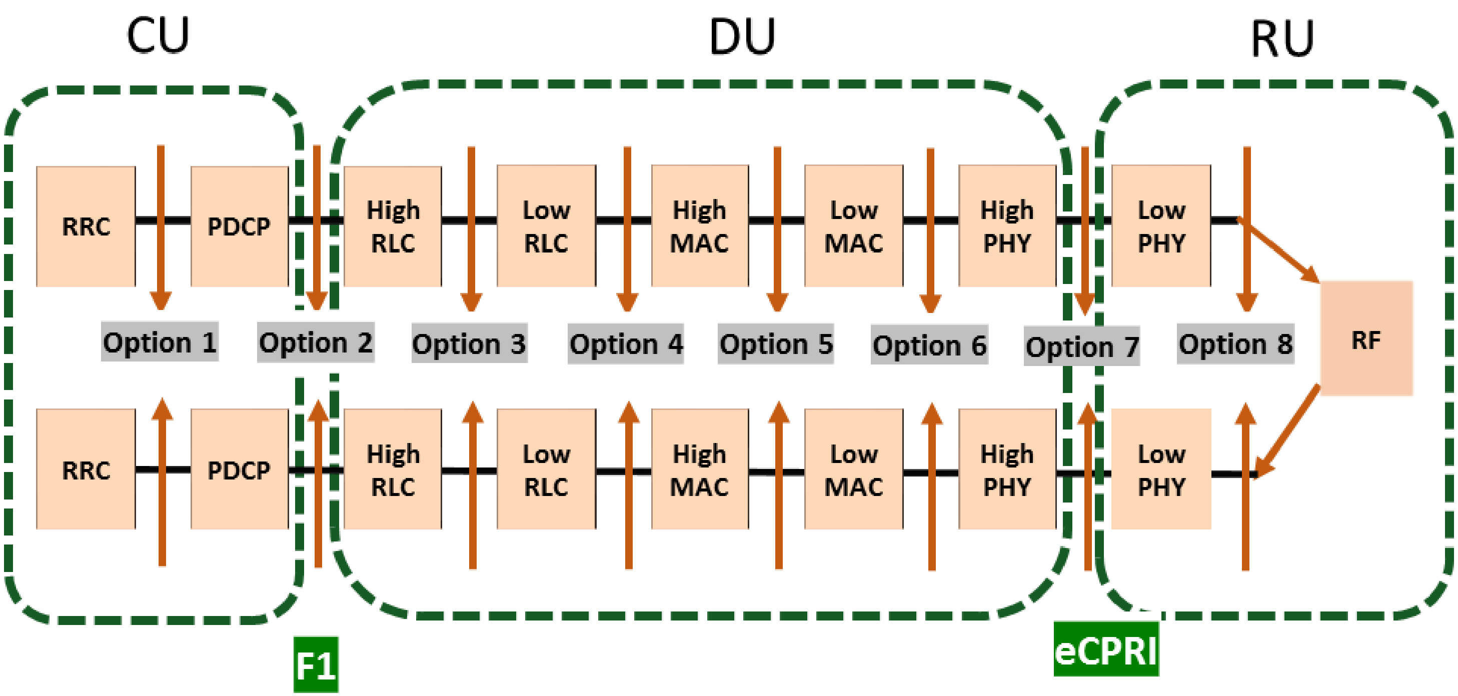
Higher Layer Split

- Large portion of BBU moves to RU -> saving lots of bandwidth
- Optimized for high bandwidth application that don't need mobility -> Fixed wireless access
- Delay budget much larger (than lower layer split): 4-10 ms
  -> much larger distance possible



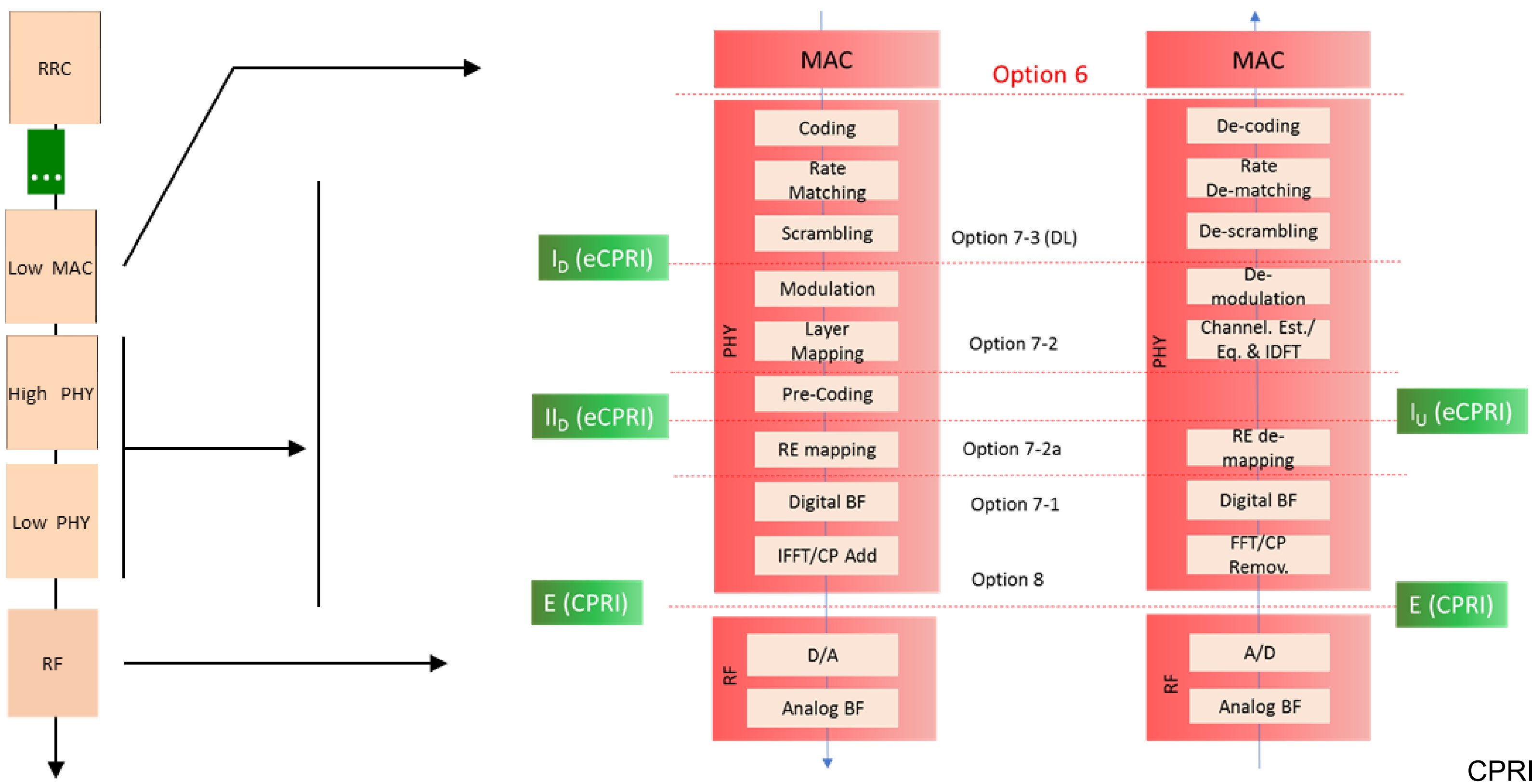
Double Split

- Centralized unit can be virtualized over time in larger data center farther away from cell sites
- Optimized for mobility and ultra low latency applications
- CU located in data center, and run on NFV infrastructure
    - Reduces cost, improves scalability



PHY Split

- Low Phy: different options possible
- Option 7-3 has the lowest BW requirements
- Option 7-1: simple DU design
- eCPRI recommends two options for downlink and one for uplink



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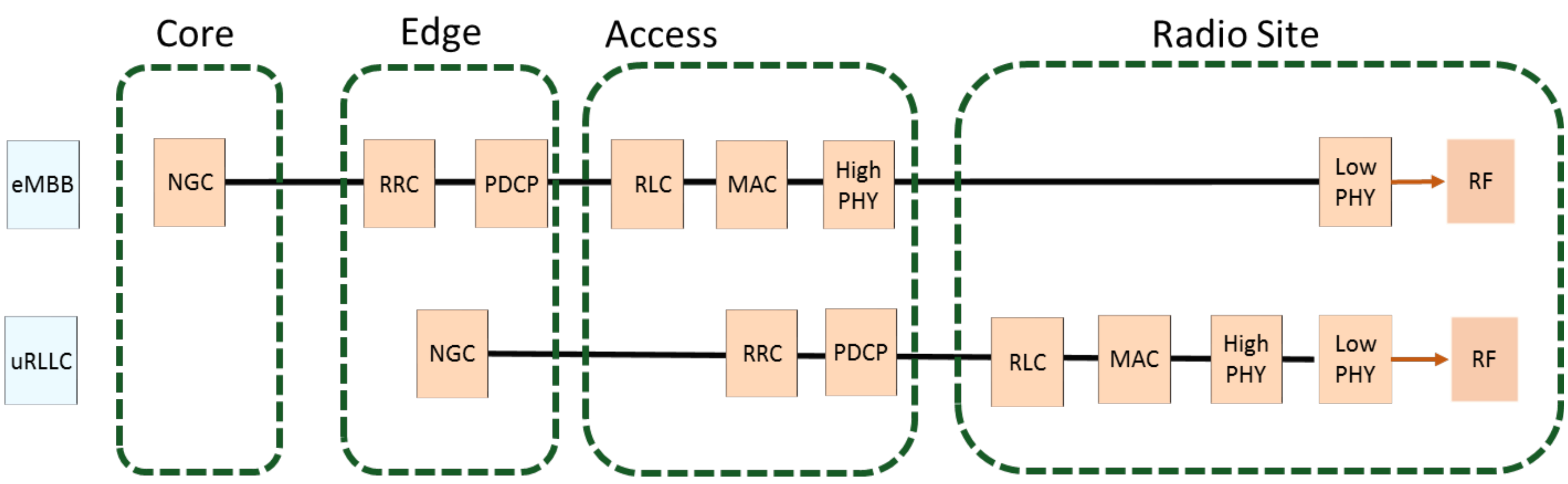
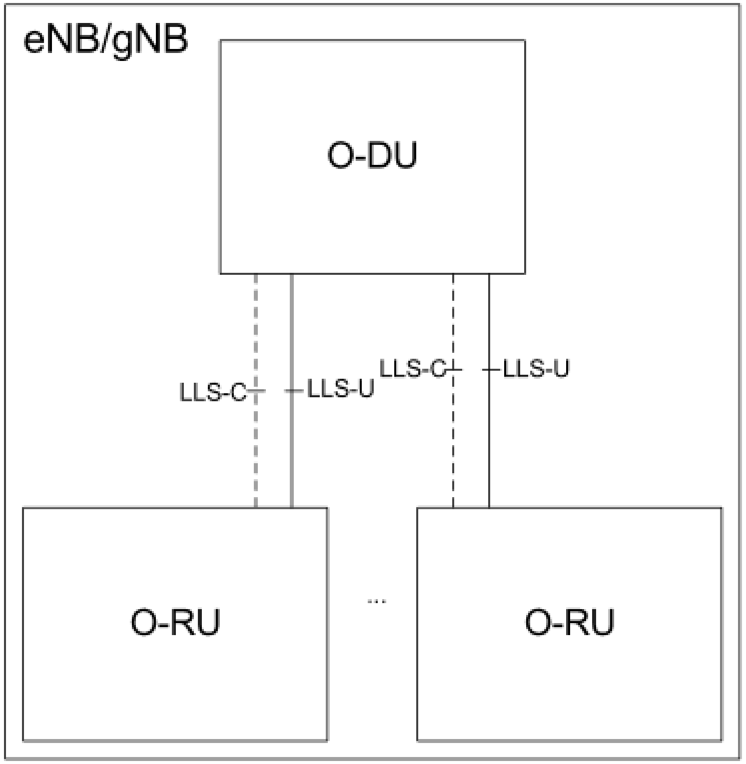
Network Slicing

- Different applications require different splits and geographic locations
- Network slicing allows using the same physical infrastructure for multiple applications

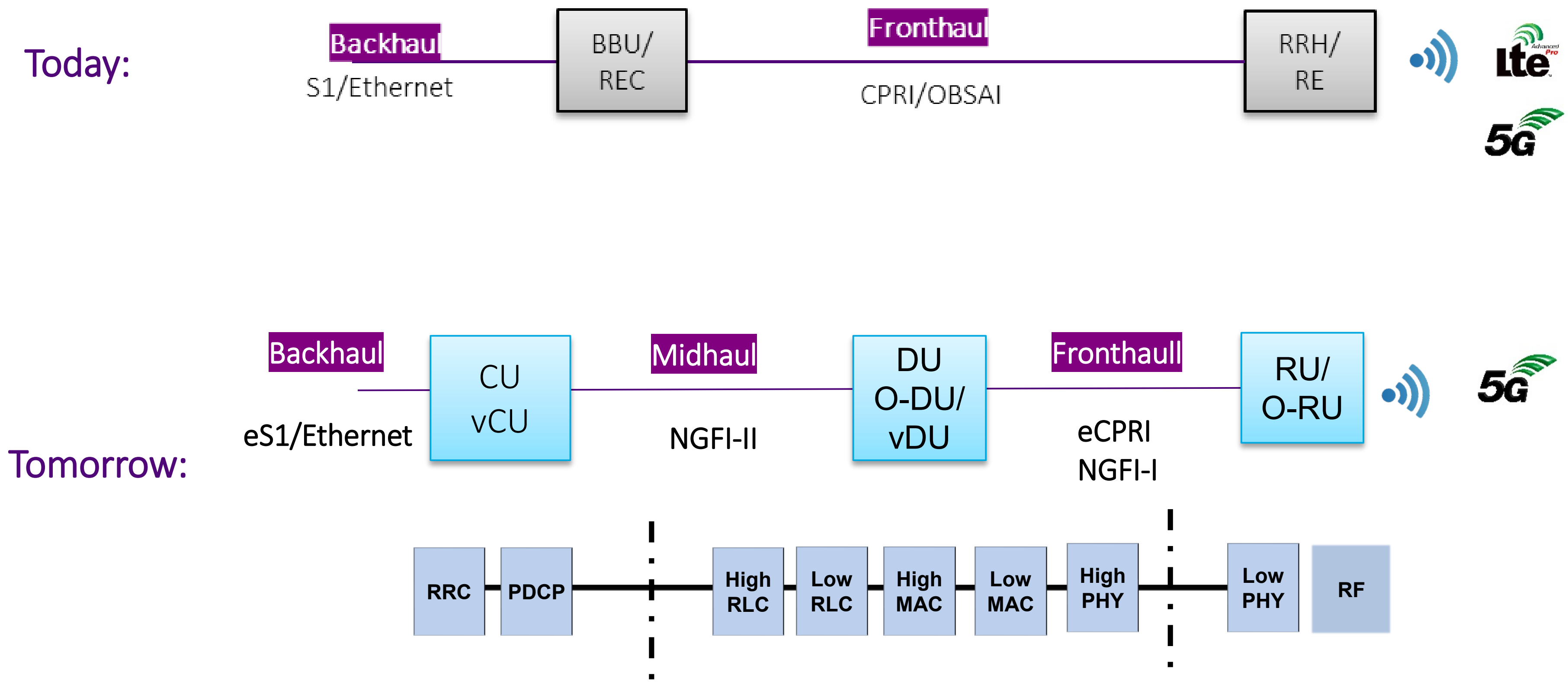


ORAN

- Enables interoperability between DU and RU from different vendors
- Major operators and vendors (and Viavi) sponsoring
- First products to hit market 2H CY2019 (Nokia and possibly others)
- Based on eCPRI (but can also work with RoE)



Evolving xhaul Networks



NGFI: IEEE 1914.1

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
- Most of the volumes are expected to be 10G initially,
- 25/40GE starting to show up in vendor and SP designs
- 100GE (LR) expensive for a radio interface at this time
- Transport SLA's are stringent, for example delay < 100 us

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

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eCPRI Message Types

- eCPRI provides for different message formats
- IQ data format depends on split option:
  - Split E: Time Domain IQ
  - Split I_U, I_D: Frequency Domain IQ
- Split E is simple, but requires much higher BW
- Split I_U, I_D requires much less BW, but are more complex
- Most messages are vendor specific
- Xran/ORAN aims for interoperability

Ethertype ($AEFE_{16}$)

Table 4: eCPRI Message Types

Message Type #	Name	Section
0	IQ Data	3.2.4.1
1	Bit Sequence	3.2.4.2
2	Real-Time Control Data	3.2.4.3
3	Generic Data Transfer	3.2.4.4
4	Remote Memory Access	3.2.4.5
5	One-way Delay Measurement	3.2.4.6
6	Remote Reset	3.2.4.7
7	Event Indication	3.2.4.8
8 - 63	Reserved	3.2.4.9
64 - 255	Vendor Specific	3.2.4.10

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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}

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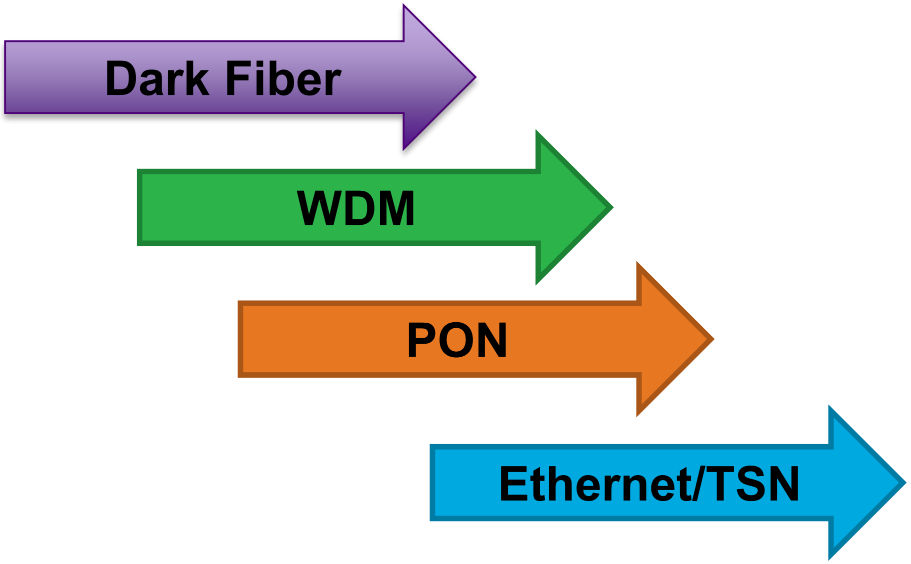
Fronthaul Transport Networks

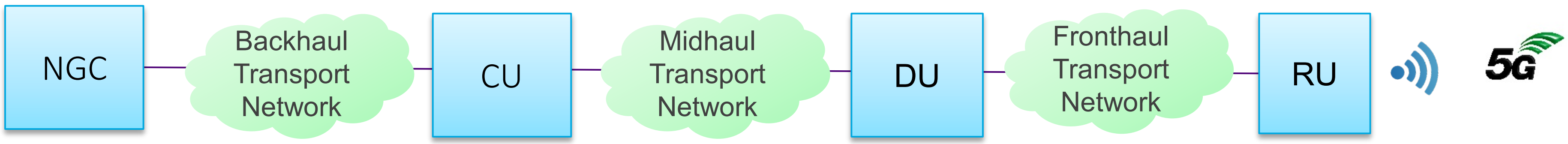
- Fronthaul networks initially deploy dark fiber
- Leading operators will deploy WDM in higher volume
- PON technologies may deliver better efficiency, but require adjustment
- SPN/FlexE/TSN will be the next step



xhaul Transport Networks

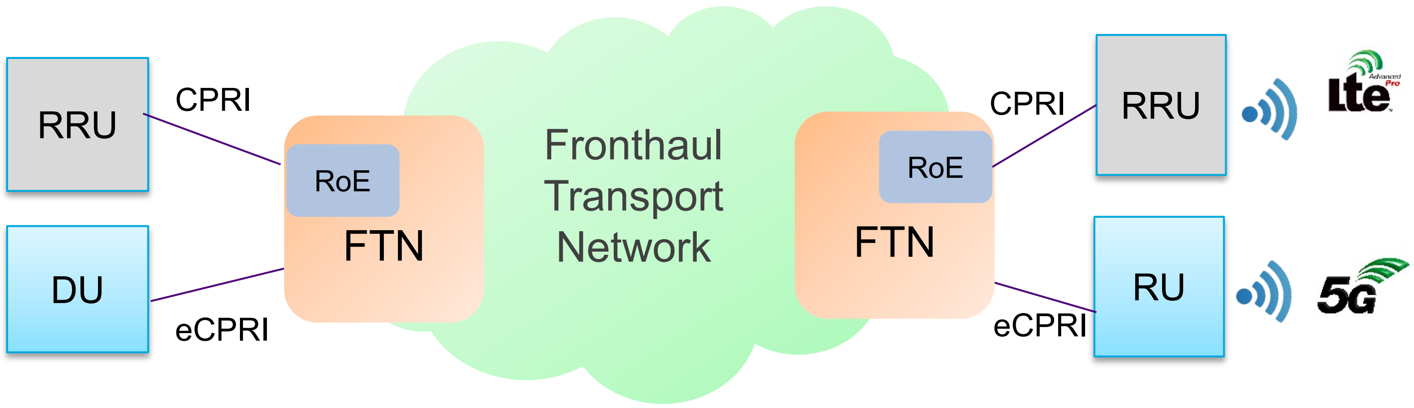
- SLAs for midhaul are similar to backhaul
  -> Similar transport network technology for mid- and backhaul
  -> Ethernet over WDM

- SLAs for fronthaul much more stringent
  -> Initially Dark Fiber and WDM
  -> NG-PON and TSN in future
  -> China already experimenting with TSN/FlexE/SPN in Fronthaul



Fronthaul Transport Networks

- Fronthaul Transport Nodes (FTN) carry CPRI and eCPRI traffic
- Initially CPRI and eCPRI carried over separate wavelengths or fiber
- Future: CPRI and eCPRI carried over same wavelength/fiber
  - Necessitates Radio over Ethernet (RoE/IEEE 1914.3) to convert CPRI to Ethernet



IEEE 802.1cm: Timing Sensitive Networks

- IEEE 802.1cm describes fronthaul and synchronization requirements
- 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

IEEE 1914.1: Packet-based Fronthaul Transport Network

- Architecture for the transport of mobile fronthaul traffic
- Analyzes different functional splits
- Purpose:
  - enables critical 5G use cases such as mMIMO, CoMP, CRAN
  - simplifies network design, lowers costs by leveraging mature Ethernet-based solution
  - Fronthaul architecture: unified management & control, common networking protocol and network elements -> migration to C-RAN/V-RAN
  - Improves bandwidth efficiency, network scalability, sync performance and supports cooperative radio modes

3gpp Synchronization Requirements

- 3gpp technical specs such as 36.104/38.104
- SLA's derived from Time Alignment Error TAE
  - TAE: Largest timing difference between two antenna
- Different categories dependent on wireless service needs

3GPP feature	RAN	
	LTE	NR
MIMO or TX-diversity transmission	Category A+	Category A+
Intra-band contiguous carrier aggregation	Category A	BS Type 1: Category B BS Type 2: Category A
Intra-band non-contiguous carrier aggregation	Category B	Category C
Inter-band carrier aggregation	Category B	Category C
TDD	Category C	Category C
Dual Connectivity	Category C	Category C
COMP	Not specified in 3GPP	Not ready in 3GPP
Supplementary Uplink	Not applicable for LTE	Not ready in 3GPP
In-band Spectrum Sharing	Not ready in 3GPP	Not ready in 3GPP
Positioning	Not specified in 3GPP	Not ready in 3GPP
MBSFN	Not specified in 3GPP	Not ready in 3GPP

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eCPRI Synchronization Requirements

- SLA’s derived from Time Alignment Error TAE
- SLA’s defined in terms of absolute Time Error |TE|
  - TE: time difference against a reference (absolute) or between two radios (relative)
- Category C: defines absolute TE
- Category A+, A, B: define relative & absolute TE
- Variations in TE: depend on implementation of timing functions such as Telecom Slave Clock

Category	Time Error
A+ (relative)	20-32 ns
A (relative)	60-70 ns
B (reltive)	100-200 ns
C (absolute)	1100 ns

White Paper: Timing and Synchronization Standards in Wireless Networks

Summary

- 5G poses stringent requirements for latency and bandwidth for xhaul networks
- New functional split options will be necessary for mobile broadband and fixed wireless access services
- Dark fiber and WDM will be dominant in early 5G xhaul networks
- Timing Sensitive Networks (TSN) will become essential for volume deployments in 5G xhaul
- Xhaul Networks must be properly characterized for bandwidth, latency and synchronization.