# IEEE
# Future Networks

# Optical Transport Networks

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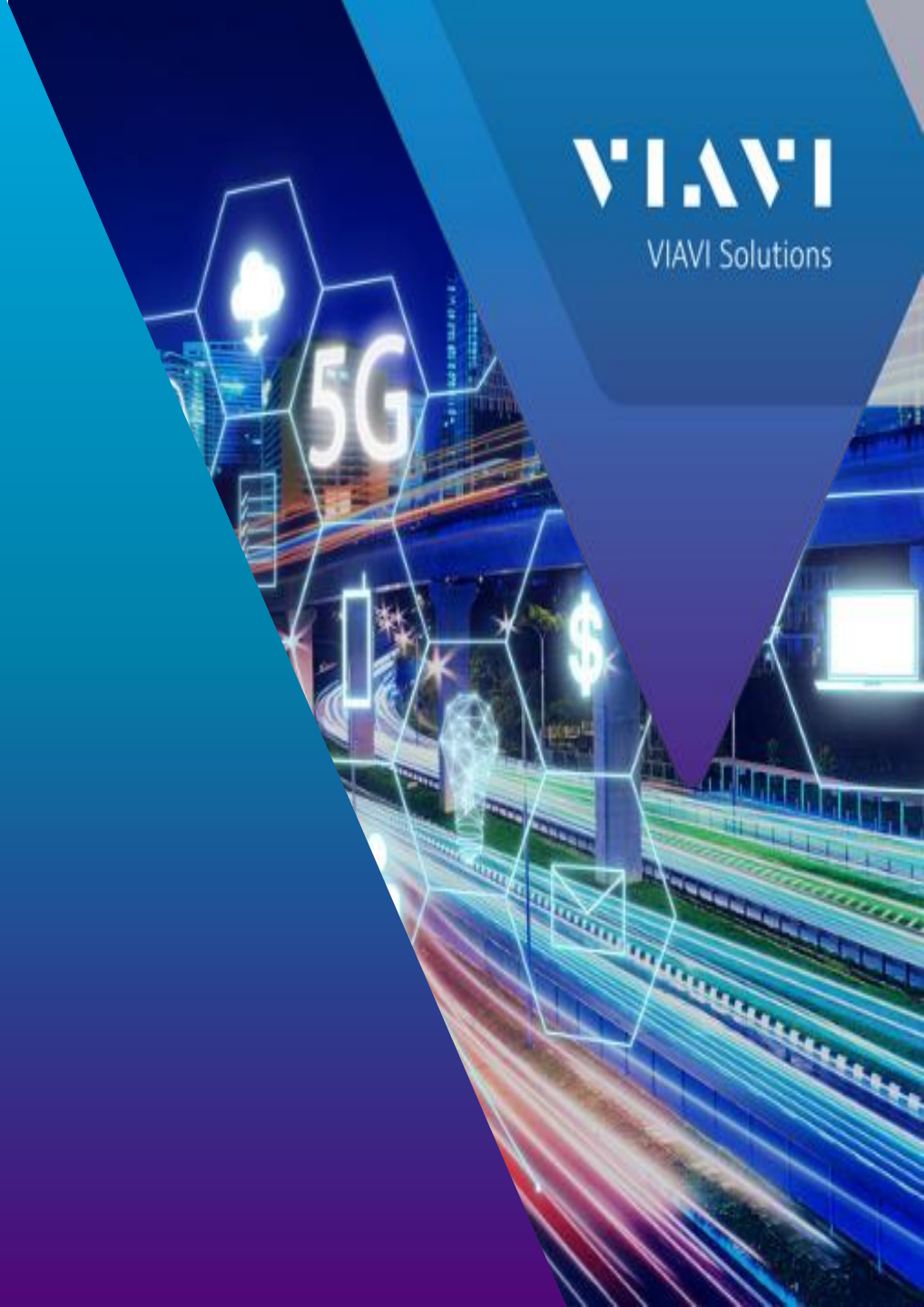
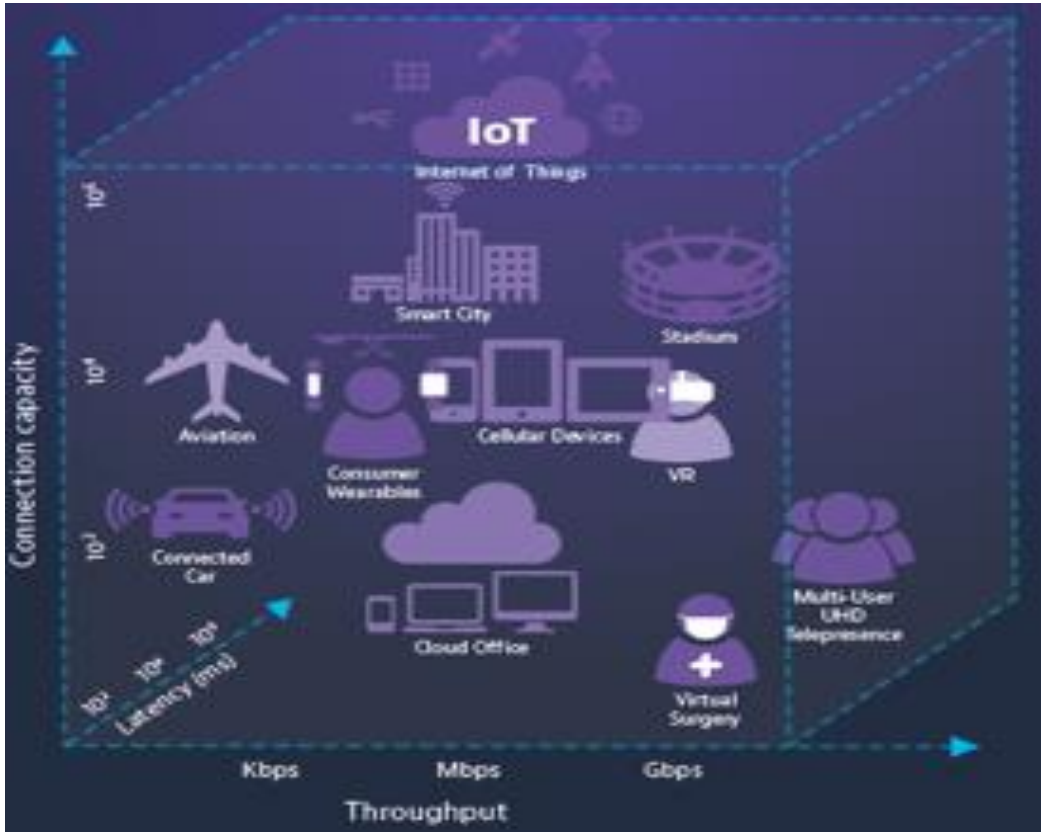
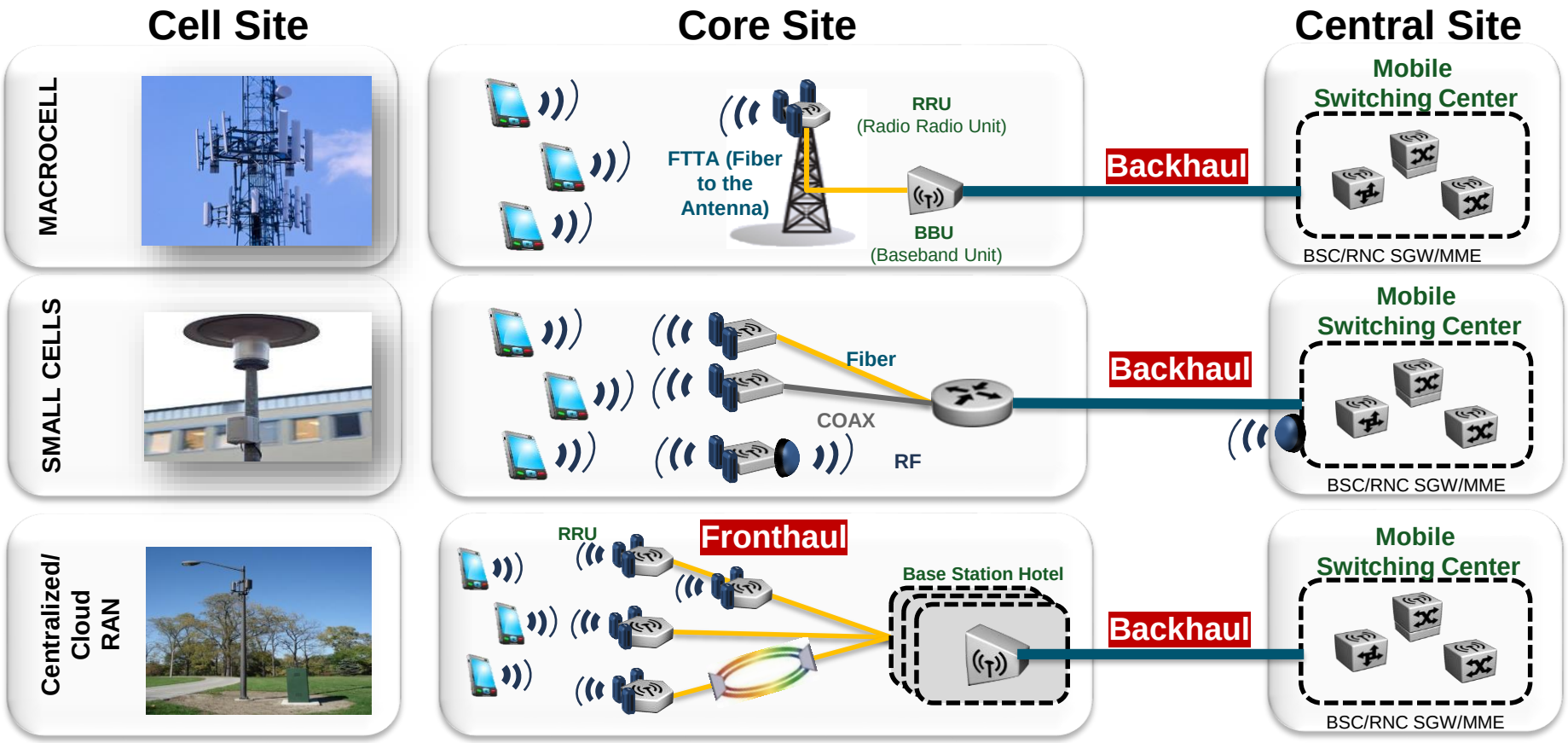


# What is 5G?

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



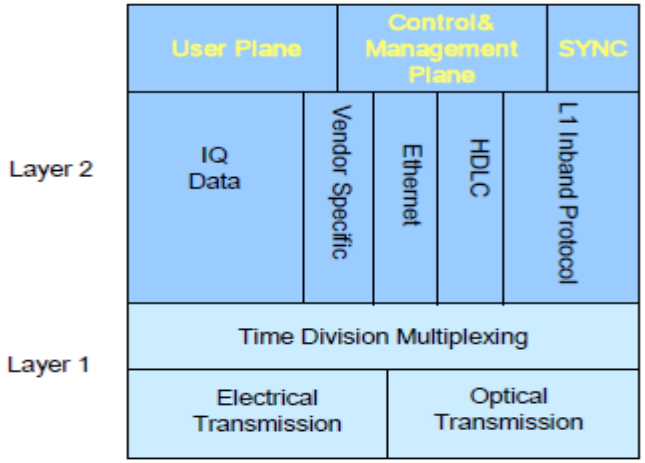
# Definition Backhaul, Fronthaul, CRAN



# 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

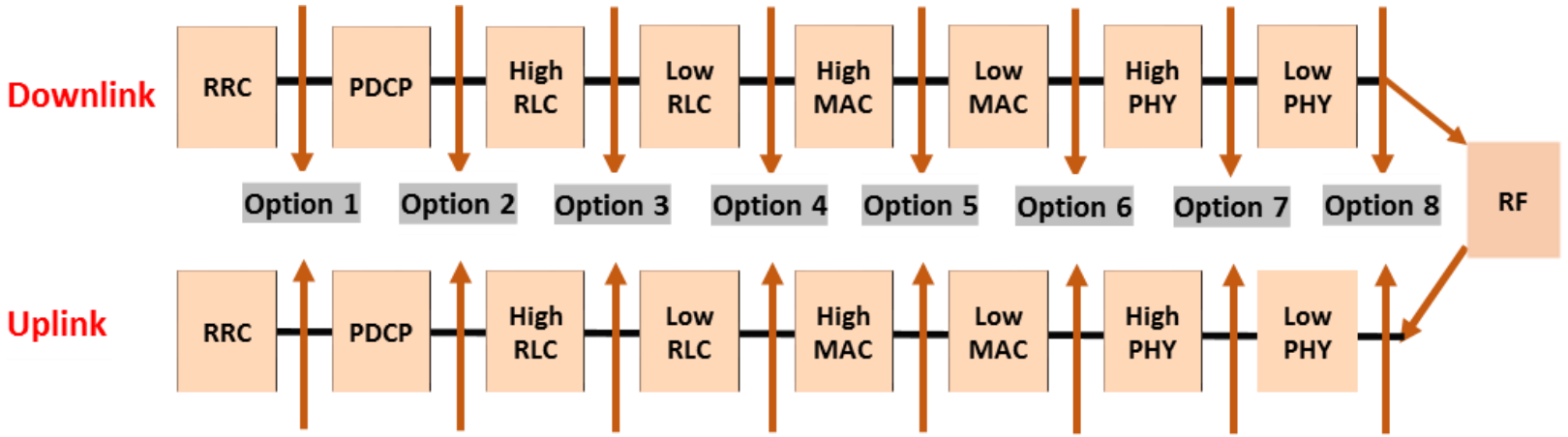
- CPRI Technology can be scaled up to a certain level with WDM and OTN
- Bandwidth requirements increase with number of antennas and signal bandwidth
- CPRI may not meet the requirements of massive MIMO applications

| 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

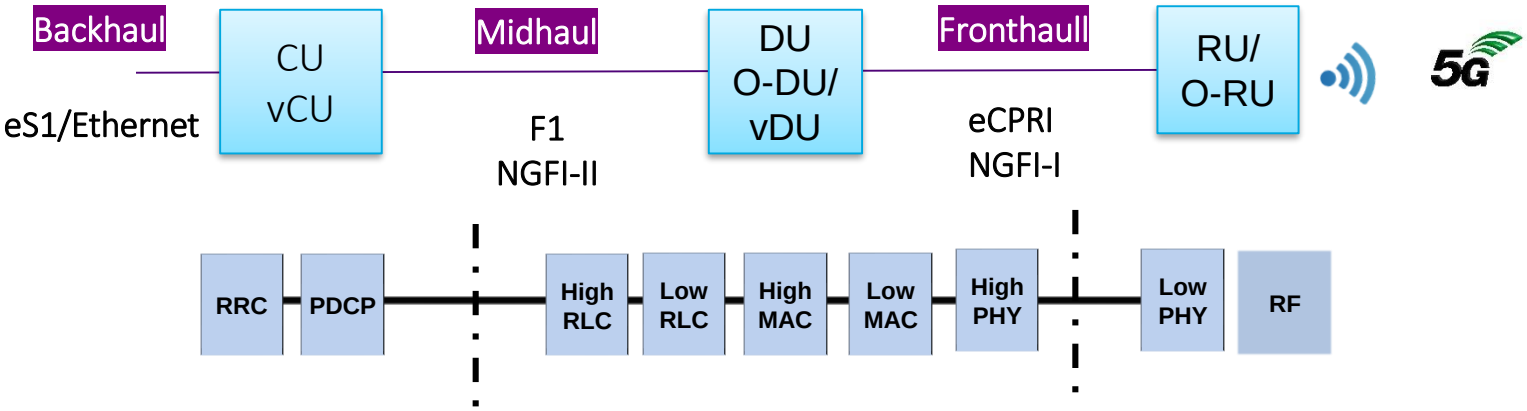
- Solving the bandwidth problem of 4G requires redistribution of functions between BBU and RRH
- Backhaul network interfaces with BBU (S1) which holds most functions from RRC to PHY
- RRH hosts the RF functions



# Evolving xhaul Networks

Today:


Tomorrow:




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
- 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 | $10^{-6}$ |

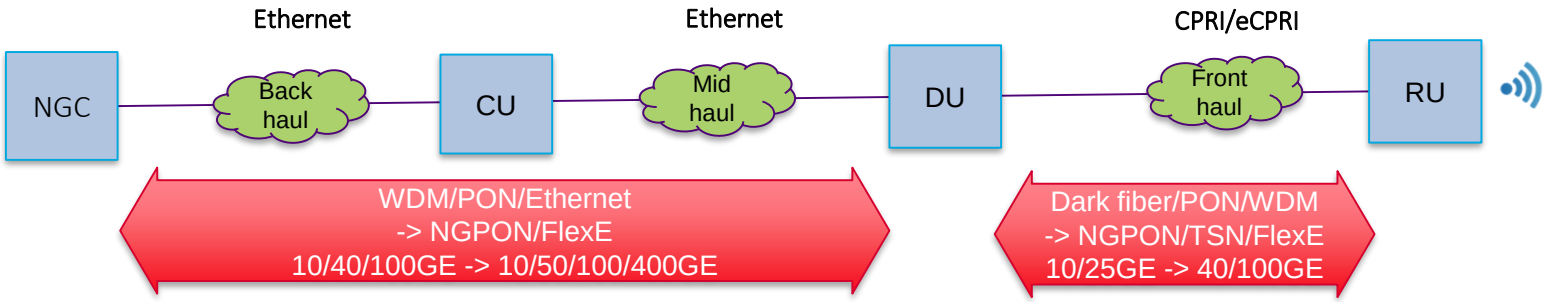
  - Class 2: eCPRI (Split option 7)
    - Requirements for split options E, $I_D$, $II_D$, and $I_U$ (eCPRI Transport Networks)

| 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 |

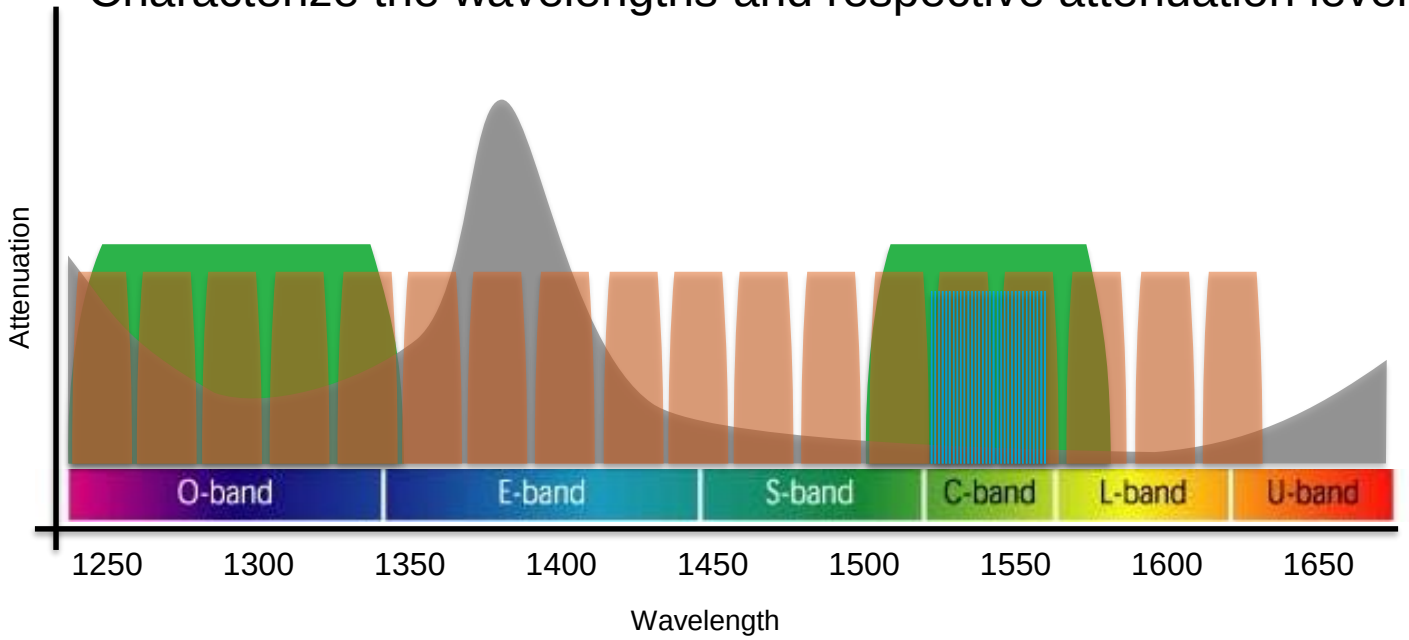
# xHAUL Transport Network Technologies

- Backhaul and Midhaul
  - Bandwidth -> Big Pipes
  - WDM, PON or switched/routed network
  - FlexE in future
- Fronthaul:
  - Latency/jitter -> Delay sensitive
  - Initial deployments: Dark fiber and WDM
  - Future: NG-PON and TSN/FlexE



# WDM Technologies

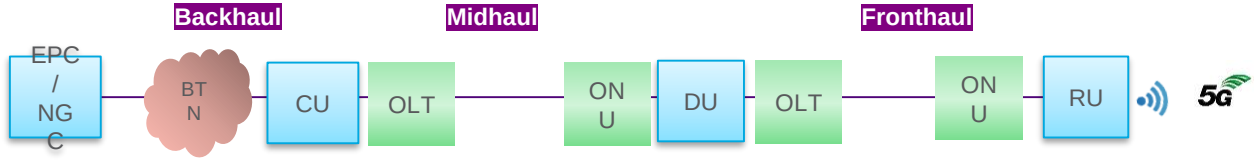
- Wideband WDM channels spaced ~100 nm apart
- CWDM channels are spaced 20 nm apart
- DWDM channels are spaced ~0.4 to 0.8 nm apart
- DWDM enables a much higher density, therefore a better usage of the fiber
- Characterize the wavelengths and respective attenuation level




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

# PON in xhaul networks

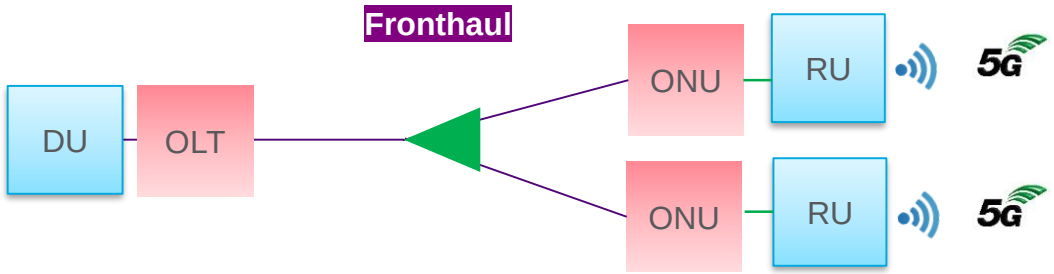
- PON networks can be planned for different use cases in access networks:
  - Convergence vs. wireless only:
    - Legacy TDM PON with overlay WDM for converged fixed/wireless networks
    - Dedicated PON for (only) wireless networks
  - Lower layer split (fronthaul/Fx) vs. higher layer split (midhaul/F1) vs. mixed fronthaul/midhaul




*BTN: Backhaul Transport Network*

# TDM PON in fronthaul (latency sensitive) networks

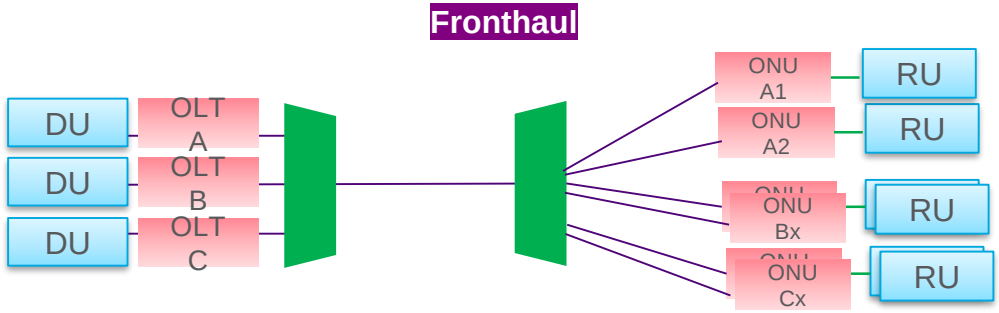
- TDM PON: challenge: upstream latency in several ms range!
- Need to reduce upstream latency:
  - Differentiated services: prioritize fronthaul traffic above all others
  - Dynamic Bandwidth Allocation (DBA): considers dynamic upstream traffic and buffer status
  - Cooperative DBA: OLT and DU/CU coordinate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



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

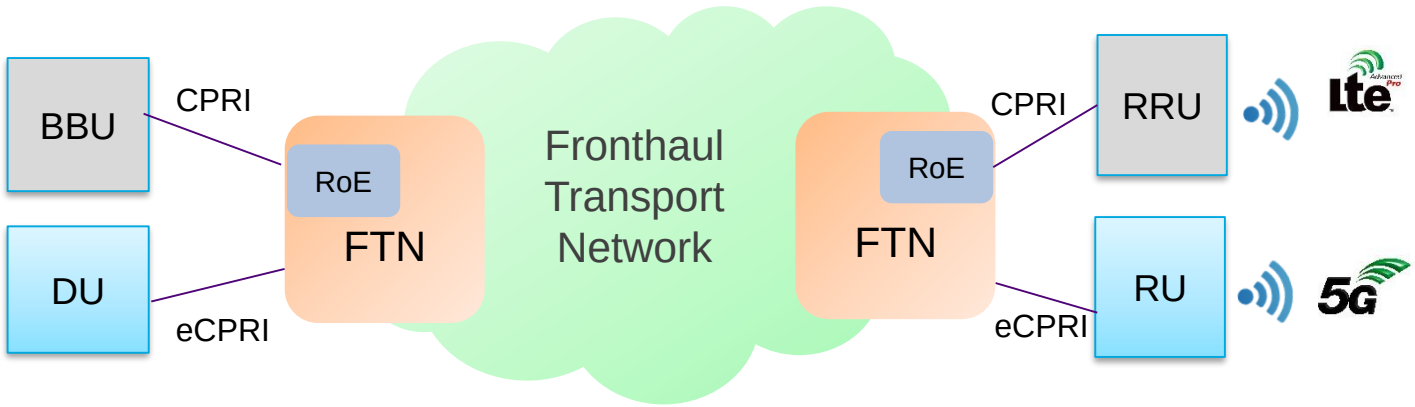
- WDM PON
  - Path loss: fiber + mux/demux + connectors
  - Link distance: mostly below 10 km
  - Delay: fiber transmission + WDM processing
  - Separate links for data, management, and synchronization (SyncE/PTP)
  - Bidirectional optics preferred for saving fiber and operational/fiber management costs.

-> Advances in PON technologies are making them an attractive choice for xhaul networks.



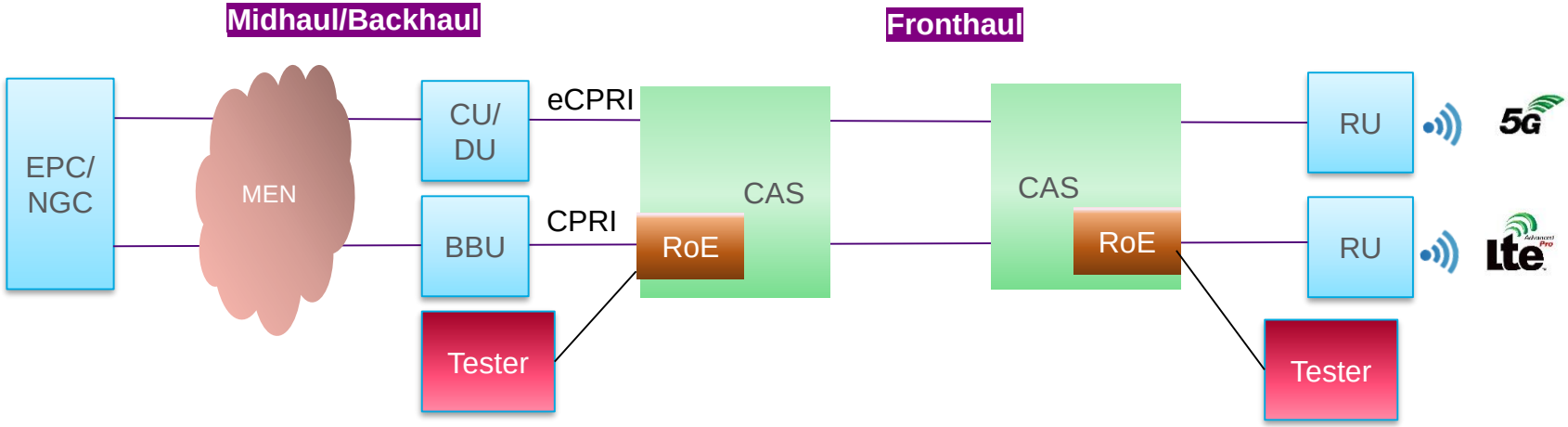
# Fronthaul Transport Networks

- 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



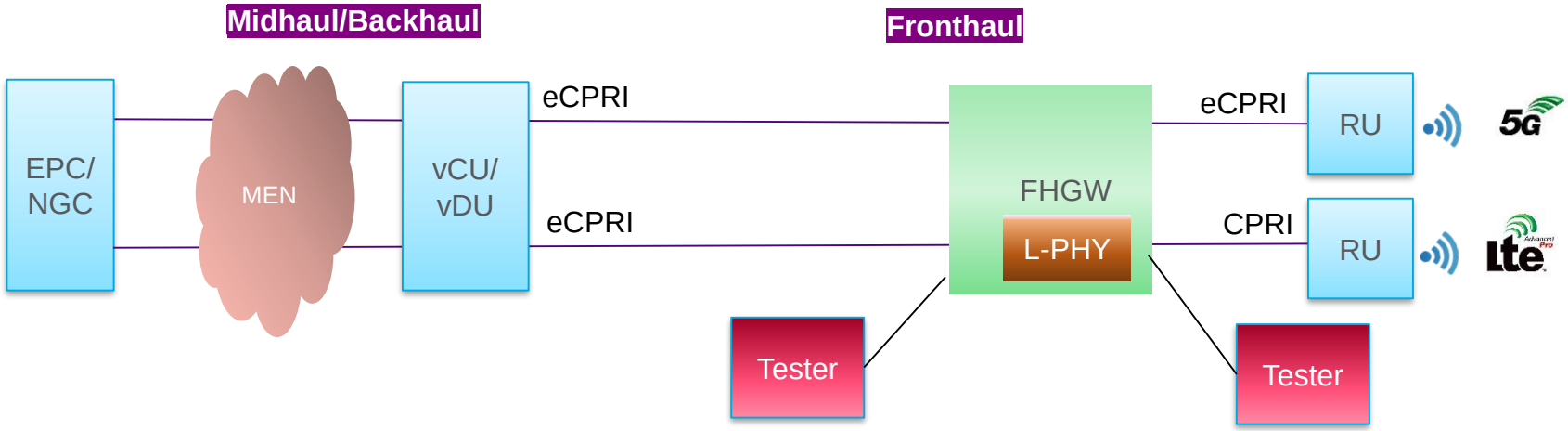
# Converged Access Switch/Fronthaul Gateway

- Converged access switches bring together CPRI and eCPRI fronthaul:
- CPRI converted to Ethernet (RoE):
- RoE Test applications:
  - Structure agnostic:
    - CPRI sync,
    - bulk BERT (all IQ channels)
  - Structure aware:
    - CPRI sync
    - Channelized BERT (per AxC)
    - Control word transparency  (e.g. C&M, VSB)



# Converged Access Switch/Fronthaul Gateway

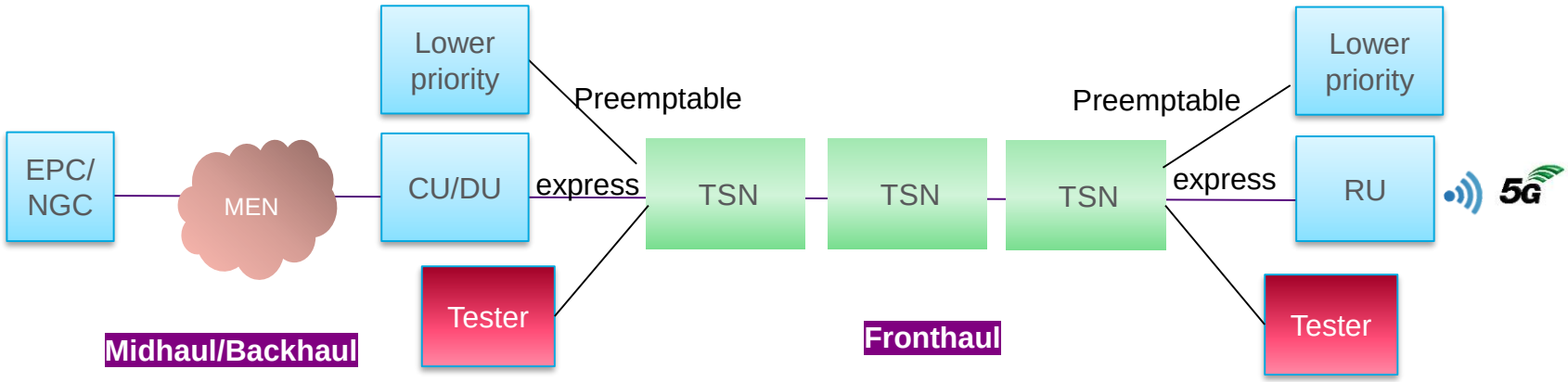
- Low PHY enables connection of CPRI radios to virtualized CU/DU
- Test applications TBD:
  - Provide eCPRI master and slave function
  - Emulate CPRI slave
  - Test Time Domain IQ against Frame Domain IQ



# Timing Sensitive Network (TSN) Switch

- TSN switches prioritize express traffic in accordance with respective IEEE standards

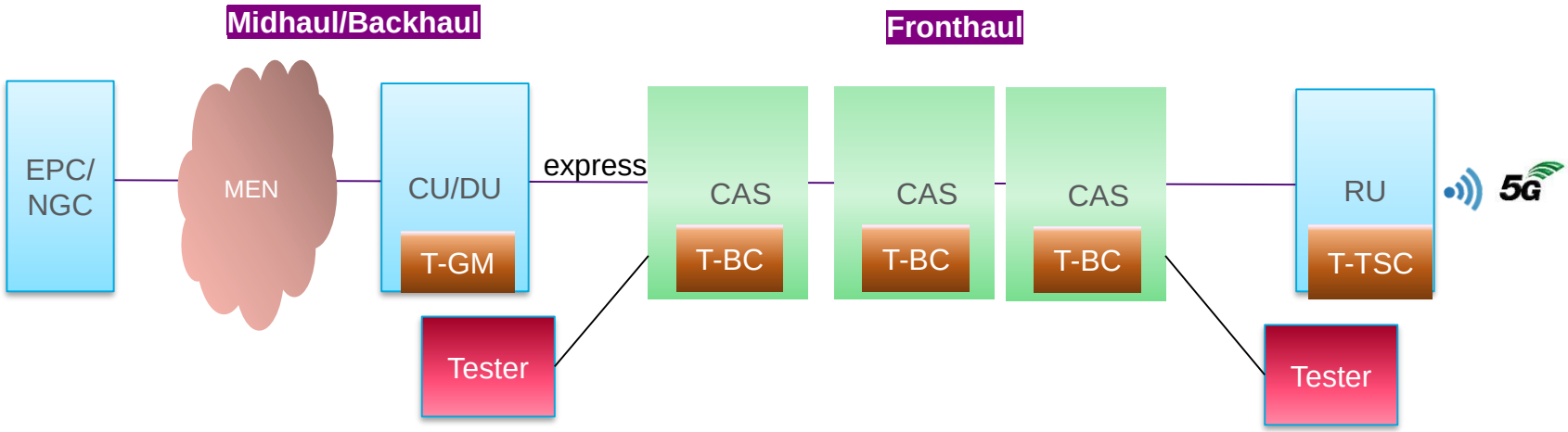
- TSN test applications::
  - Emulate express and preemptable traffic
  - Provide different traffic profiles (frame size, burst,…)
  - Measure packet loss, delay and jitter for different type of traffic and profiles



# Converged Access Switch/Fronthaul Gateway

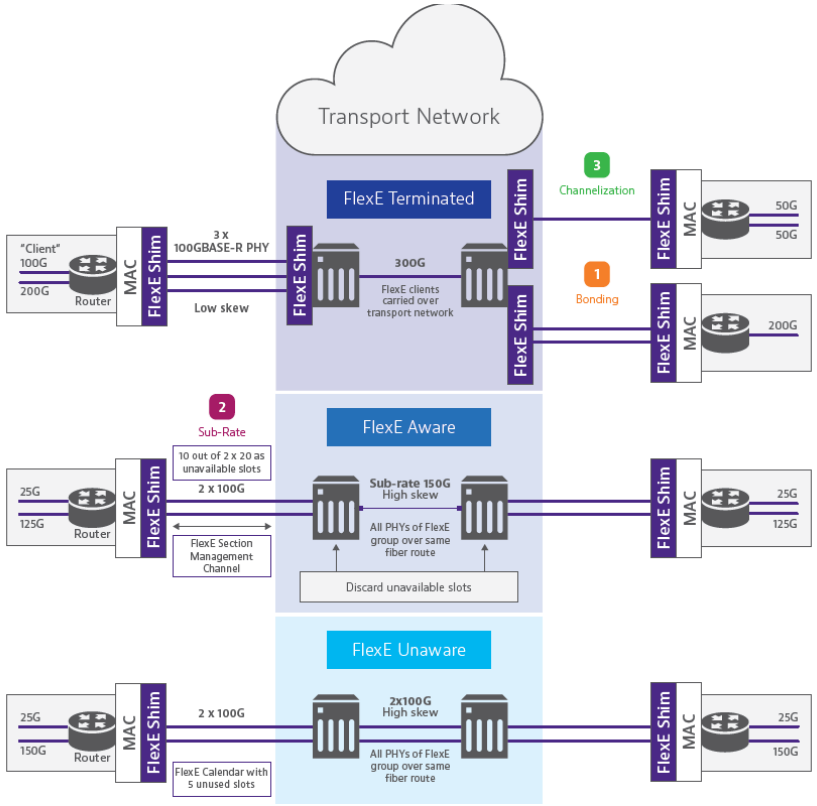
- Converged access switches provides T-BC function to deliver strict 5G timing requirements:

- Synchronization applications::
  - PTP:
    - Emulate PTP master and slave,
    - Perform time error measurements and compare against ITU-T G.827x limits
  - SyncE
    - Emulate SyncE master and slave
    - Measure frequency offset
    - Verify ESMC



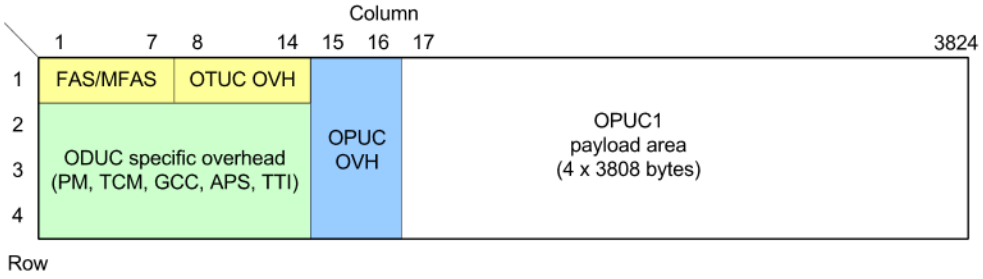
# FlexE/SPN Technology

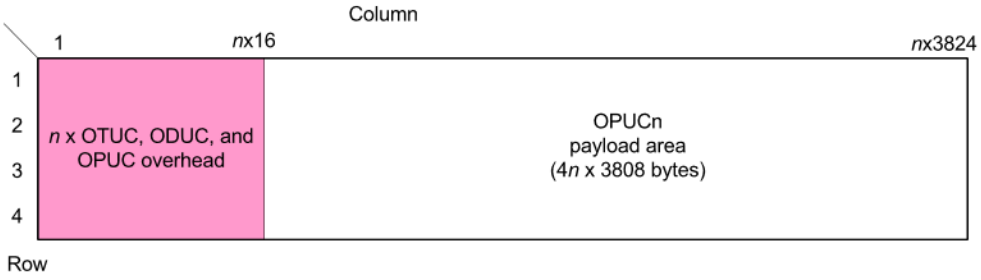
- FlexE provides hard separation between different types of services -> SLA's of each service can be met without impacting the other services (aka Network Slicing)!
- Example:
  - Service 1: eMBB: bandwidth sensitive
  - Service 2: uRLLC: delay sensitive
- Slicing Packet Network (SPN) -> ITU-T G.mtn (Metro Transport Networks)
- Verify bandwidth, latency, jitter for different slices



# OTN Technology

- Delivers transparency, extended reach and network management
- Helps aggregate and switch lower rate RU signals
- Not efficient for variable traffic
- OTN B100G -> Flexible OTN (FlexO)
  - G.709.1 FlexO recommendation (2016)
  - Over n x 100 Gbps PHYs
  - Signal format n x ODUC -> ODUCn
- G.709.25-50 (25 and 50G OTN interfaces)
- Validate FEC, ODU headers (PM/TCM,..), client signal transparency



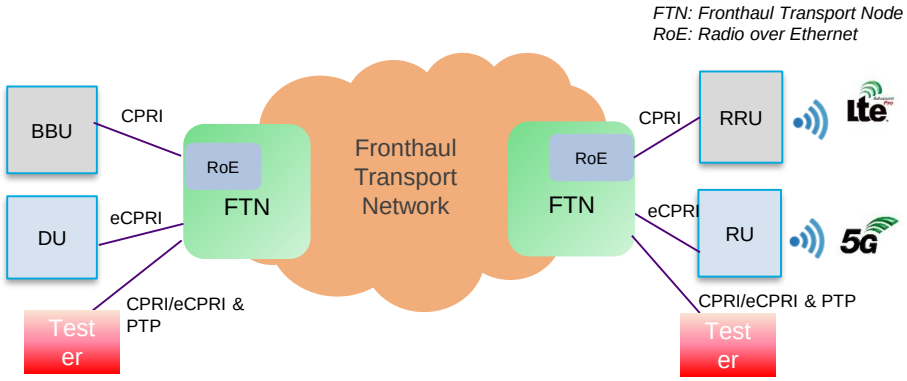



# Converged 4G/5G fronthaul network

- 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

**Test applications:**

- CPRI to CPRI test (bit error, delay)
- eCPRI to eCPRI test
- Synchronization test

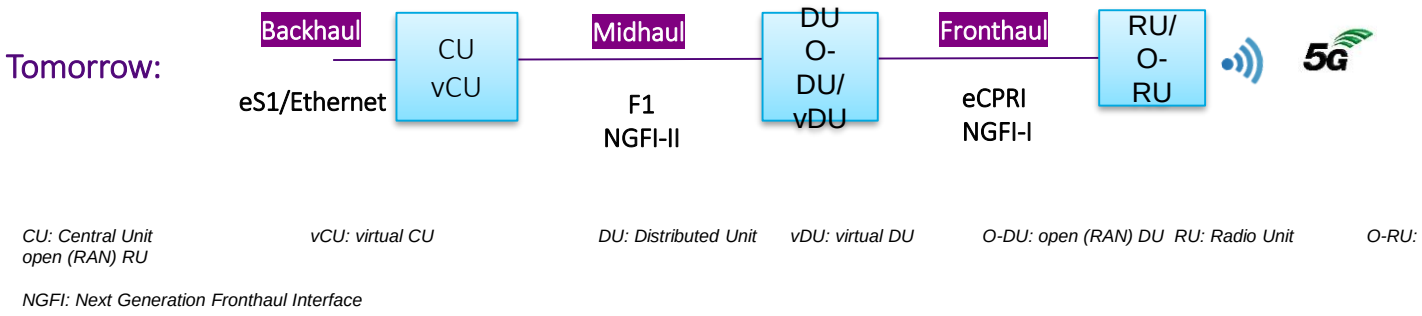


# Synchronization

# 5G Synchronization Network

- 5G requires synchronization!
  - GPS might not be viable, since millimeter wave radios need to be close to street level-> poor line of sight in dense/urban areas
  - 5G becomes more dependent on network synchronization

- eCPRI is **not** synchronized (unlike CPRI)
  - PTP/SyncE essential for 5G fronthaul



# eCPRI Synchronization Requirements

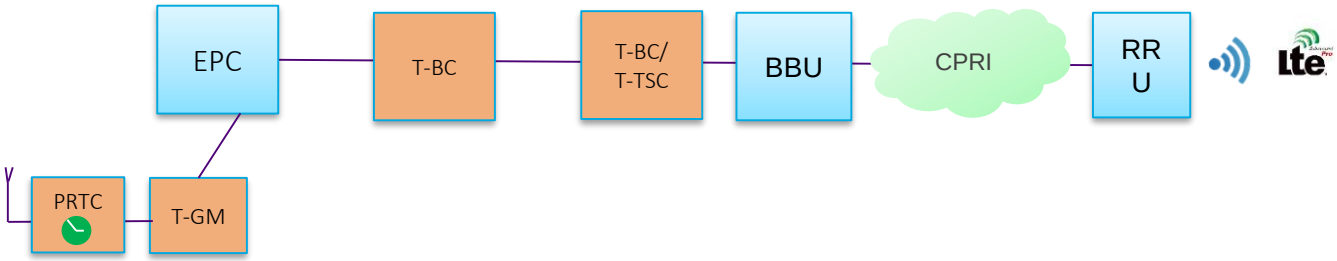
- SLA's defined in terms of absolute Time Error |TE|
- SLA's derived from Time Alignment Error TAE
- Different categories dependent on wireless service needs

| Category (note 1) | Time error requirements at UNI, \|TE\| | | | Typical applications and time alignment error (TAE) requirements at antenna ports of eREs (for information) | |
|---|---|---|---|---|---|
| | Case 1 (note 2) | | Case 2 (note 3) | Typical applications | TAE |
| | Case 1.1 (note 4) | Case 1.2 (note 5) | | | |
| A+ | N.A. | N.A. | 20 ns (relative) | MIMO or TX diversity transmissions, at each carrier frequency | 65 ns (note 6) |
| A | N.A. | 60 ns (relative) (note 7) | 70 ns (relative) | Intra-band contiguous carrier aggregation, with or without MIMO or TX diversity | 130 ns (note 6) |
| B | 100ns (relative) (note 7) | 190 ns (relative) (note 7) | 200 ns (relative) | Intra-band non-contiguous carrier aggregation, with or without MIMO or TX diversity, and<br>Inter-band carrier aggregation, with or without MIMO or TX diversity | 260 ns (note 6) |
| C (note 8) | 1100 ns (absolute) (note 9) | | 1100 ns (absolute) (note 9) | 3GPP LTE TDD | 3 us (note 10) |

# Network based synchronization

- PTP/SyncE requires special switch/router function
  - Boundary Clock (T-BC) function ensures proper synchronization

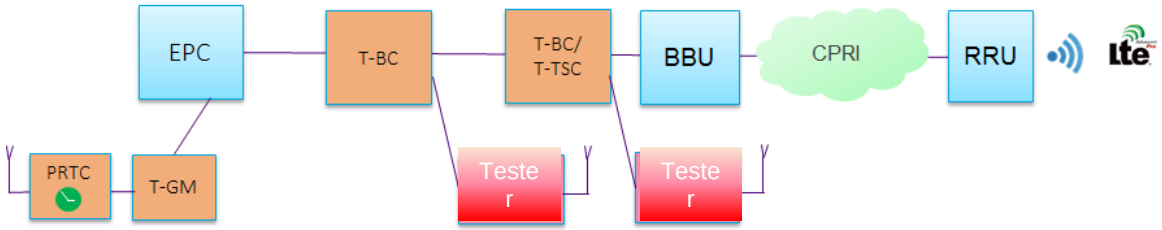
- For the end-to-end network synchronization
  - <u>All T-BC must:</u>
    - Work properly (connect to Grandmaster (T-GM)
    - Deliver minimum delay (time error)



# Backhaul Synchronization Test Applications

Time Error measurement at various reference points

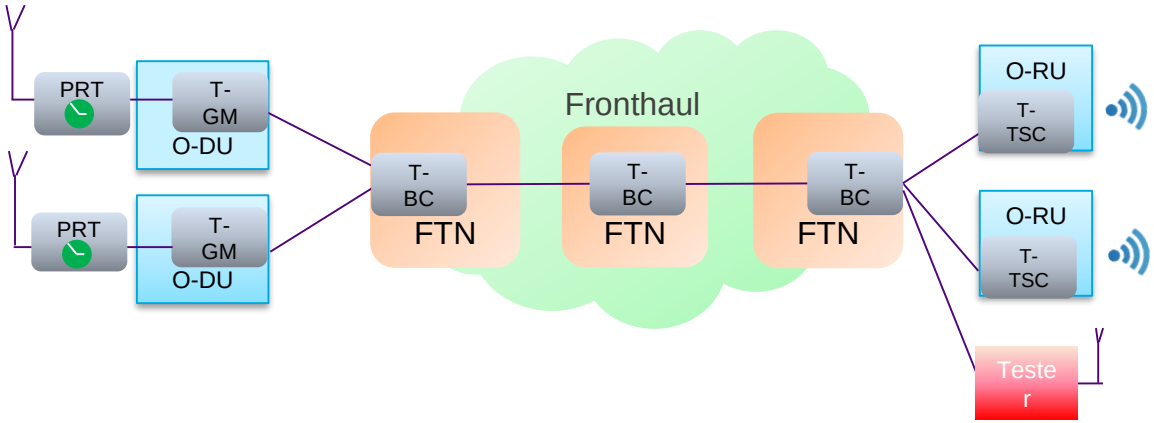
- Constant Time Error cTE
- Dynamic Time Error dTE (MTIE/TDEV)
- Maximum Time Error Max |TE|
- Metrics defined in ITU-T G.8271.1 (FTS)/G.8271.2 (PTS/APTS)




*PRTC: Primary Reference Telecom Clock* *T-GM: Telecom Grand Master.* *T-BC: Telecom Boundary Clock.* *T-TSC: Telecom Slave Clock*

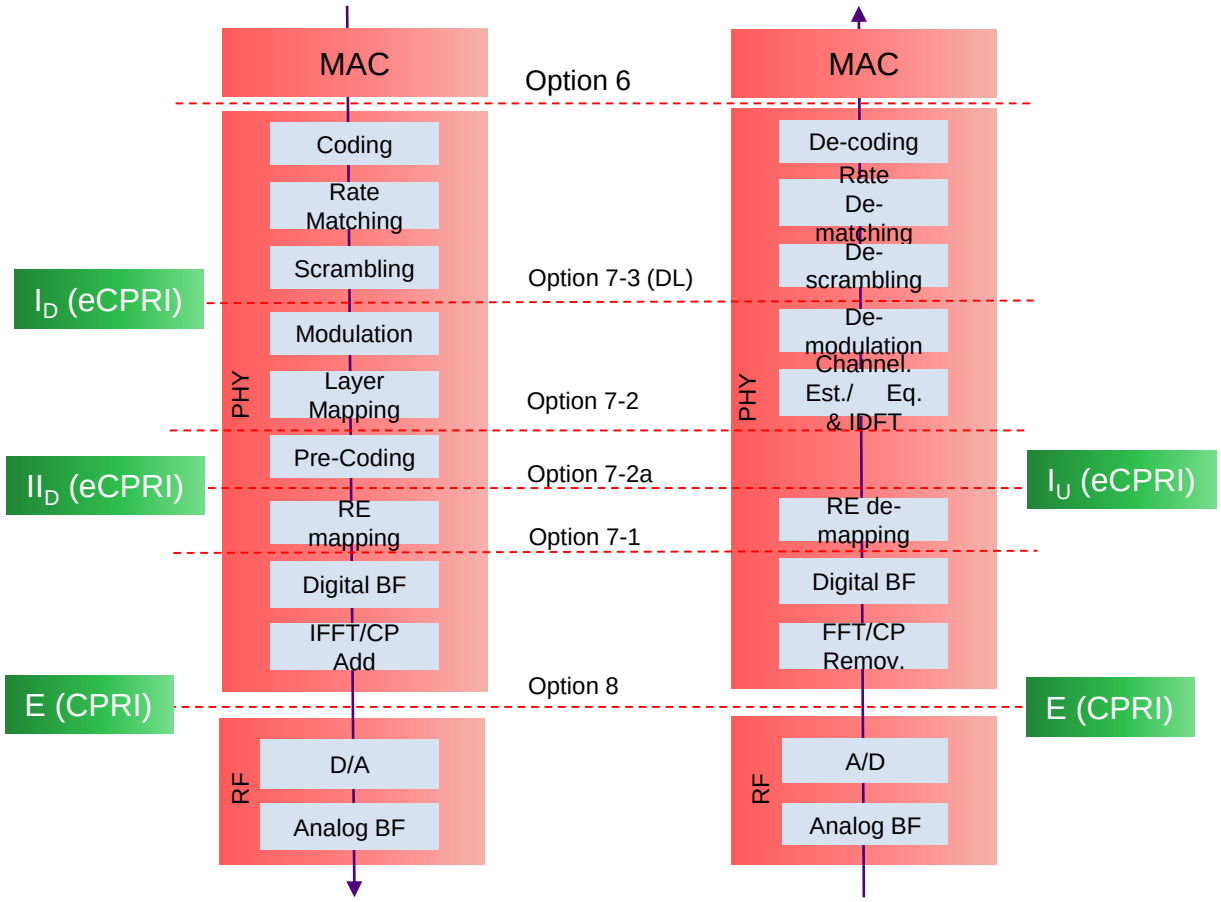
# Fronthaul Synchronization Test Application

- ORAN Priority: G.8275.1 profile: Time Error measurements at O-RU input
- Second priority G.8275.2 profile
- Absolute TE: against GNSS
- Relative TE: perform Absolute TE at different radios and aggregate



# Backup

# PHY Split



# PHY Split

- Option 7-3 has the lowest BW requirements
- Option 7-1: simple DU design, joint equalization
- eCPRI specification does not include C&M, OAM, and Sync services