2026 TUTORIAL
O-RAN FUNDAMENTALS SYNCHRONIZATION OVERVIEW

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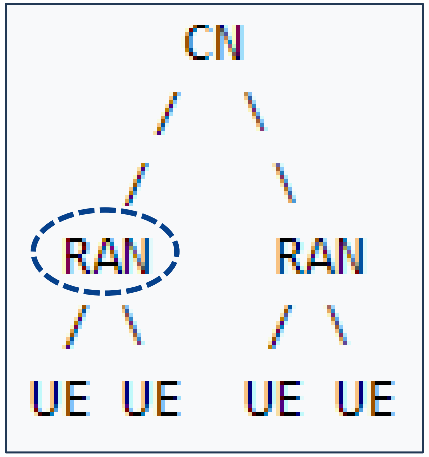
WORKSHOP
ON
SYNCHRONIZATION
AND
TIMING SYSTEMS

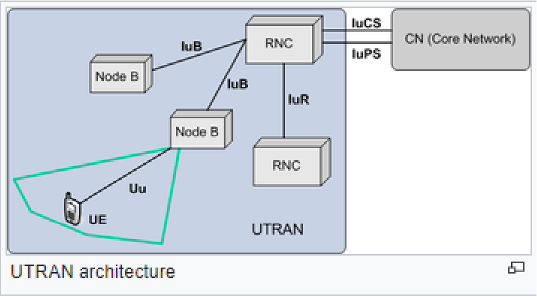
RADIO ACCESS NETWORK

THE RADIO ACCESS NETWORK

- **RAN history**
  - <u>GRAN</u> GSM Radio Access Network → 2G
    - TDMA, CDMA
  - <u>UTRAN</u> = UMTS Radio Access Network → 3G
    - W-CDMA radio access technology
  - <u>E-UTRAN</u> = Evolved UMTS Radio Access Network → 4G
    - MIMO, OFDM, Long Term Evolution (LTE) → 4G LTE
  - <u>NG-RAN</u> = Next Generation Radio Access Network → 5G
    - MIMO, mmWave, ESA (Beam Forming)
    - *Governed by IMT-2020 3GPP (3rd Generation Partnership)*
    - Operator Led Alliance formed in 2018 (<u>Open</u> RAN Alliance) → 5G O-RAN

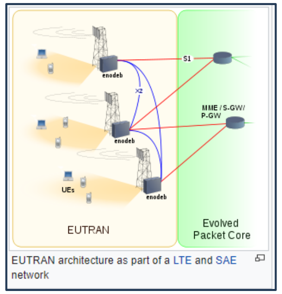


Higher Speed
Lower Latency



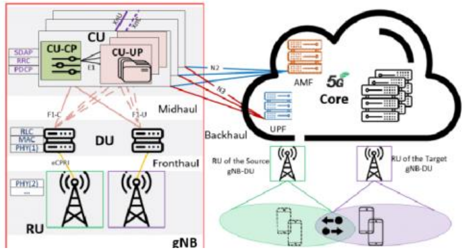
UTRAN architecture

UTRAN

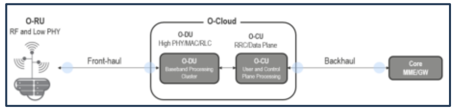


EUTRAN architecture as part of a LTE and SAE network

E-UTRAN



NG-RAN



O-RAN

BIG IDEAS FOR EVERY SPACE

5G DRIVES TIGHTER SYNCHRONIZATION REQUIREMENTS

Class level of accuracy	Maximum relative time error requirements (Note 1)	Typical applications (for information)
3A	5 µs	LTE MBSFN.
4A	3 µs	NR intra-band non-contiguous (FR1 only) and inter-band carrier aggregation; with or without MIMO or TX diversity.
6A	260 ns	LTE intra-band non-contiguous carrier aggregation with or without MIMO or TX diversity, and inter-band carrier aggregation with or without MIMO or TX diversity. NR intra-band contiguous (FR1 only) and Intra-band non-contiguous (FR2 only) carrier aggregation, with or without MIMO or TX diversity.
6B	130 ns	LTE intra-band contiguous carrier aggregation, with or without MIMO or TX diversity. NR (FR2) intra-band contiguous carrier aggregation, with or without MIMO or TX diversity.
6C (Note 2)	65 ns	LTE and NR MIMO or TX diversity transmissions, at each carrier frequency.

NOTE 1 – The maximum relative time error requirements represent the largest timing difference measured between any two elements of the cluster. See Appendix VII of [b-ITU-T G.8271.1] for illustration of how requirements are specified in a cluster. In 3GPP terminology this is equivalent to time alignment error (TAE).

NOTE 2 – Level 6C is an internal equipment specification, and does not result in a synchronization requirement on the transport network.

ITU-T G.8271 Table 2 - Time and phase requirements for cluster-based synchronization

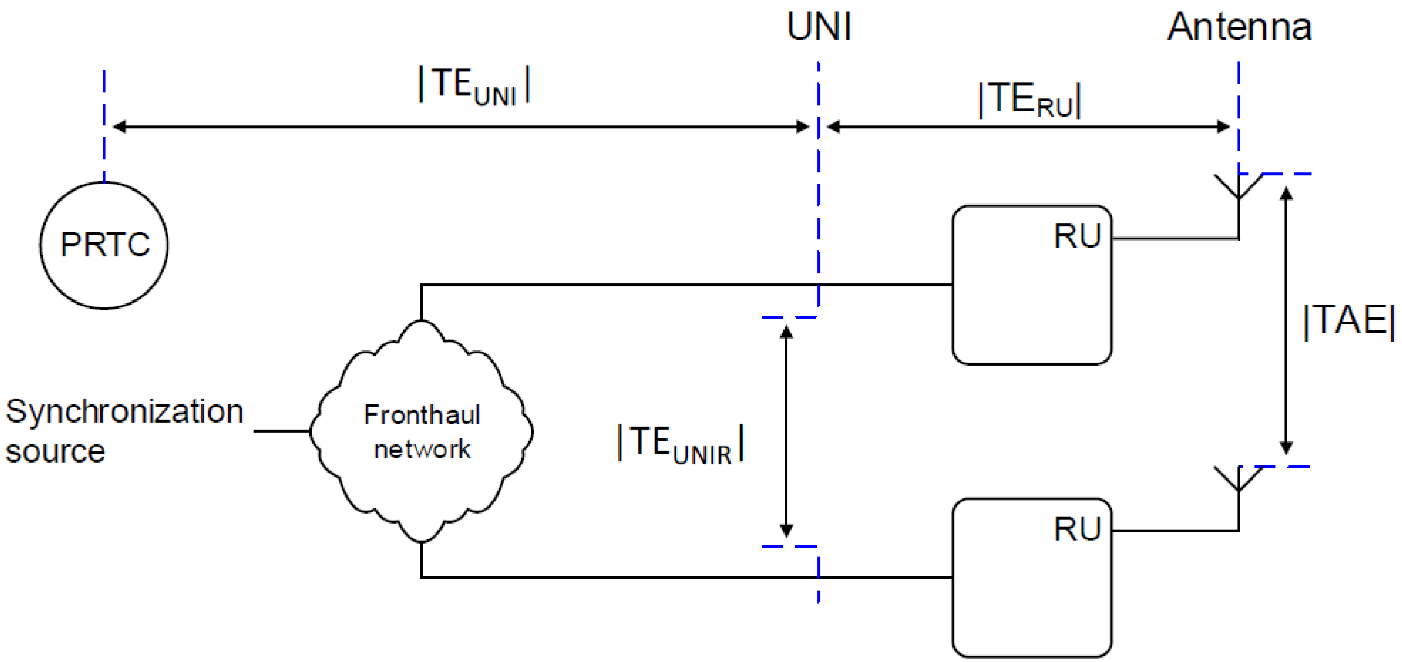
The 3GPP time alignment error (TAE) (or relative time error (TE_R), as used in ITU-T terminology) represents the largest timing difference measured between any two elements of the cluster

- Both 4G and 5G targets are 3 µs (±1.5 µs to common reference, or PRTC)
- TAE down to 130 ns between clusters of RUs (i.e. ±65 ns from same DU)

BIG IDEAS FOR EVERY SPACE RENESAS

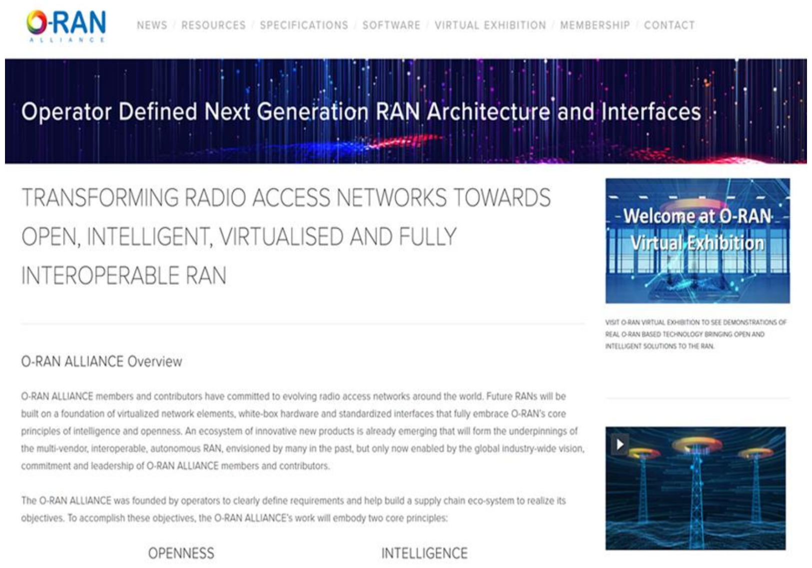
TIME ERROR BUDGETS

- **The eCPRI specification sets time error (TE) budgets for the user network interface (UNIT)**
  – Allow for the time alignment error (TAE) requirements for four (4) categories of 3GPP features and RANs are met
  – Will focus on eCPRI timing accuracy categories A, B and C, and time synchronization deployment Cases 1.1 and 1.2
    – because these are most relevant to Open RAN applications
- **Reference Points and Definitions for eCPRI Fronthaul Networks**
  – The synchronization source could be a PRTC+T-GM, or DU that is directly or remotely synchronized by a PRTC.



SO WHAT IS O-RAN?

- **O-RAN (Open Radio Access Network)**
  - Operator Led Alliance
  - Initially formed in 2018
    [ORAN Forum + CRAN (China Mobile initiative)]
- **Use Standard Interfaces, Standard off-the-shelf Components, Standard functional splits, etc.**
  - Maximize common-off-the-shelf Hardware, Merchant Silicon
  - Minimize Proprietary Hardware
  - ***Use of GPP's + SW …***
- **Standardized Open Software and API**
  - Specified API and Interface
  - Adoption through Standardization
  - Explore Open source where appropriate
- **Driven for "open"ness**
  - The interfaces are standardized
  - Operators can mix/match different component vendors for the CUs, DUs, or RUs.
  - The components are interoperable, protocols are clearly defined



ORAN Alliance following 3GPP and IMT-2020 for Open Network Architecture

"Mission is to re-shape the RAN industry towards more intelligent, open, virtualized and fully interoperable mobile networks."

O-RAN OVERVIEW

ARCHITECTURE & FUNCTIONAL SPLITS

5G – FUNCTIONAL SPLIT AND OPTIONS

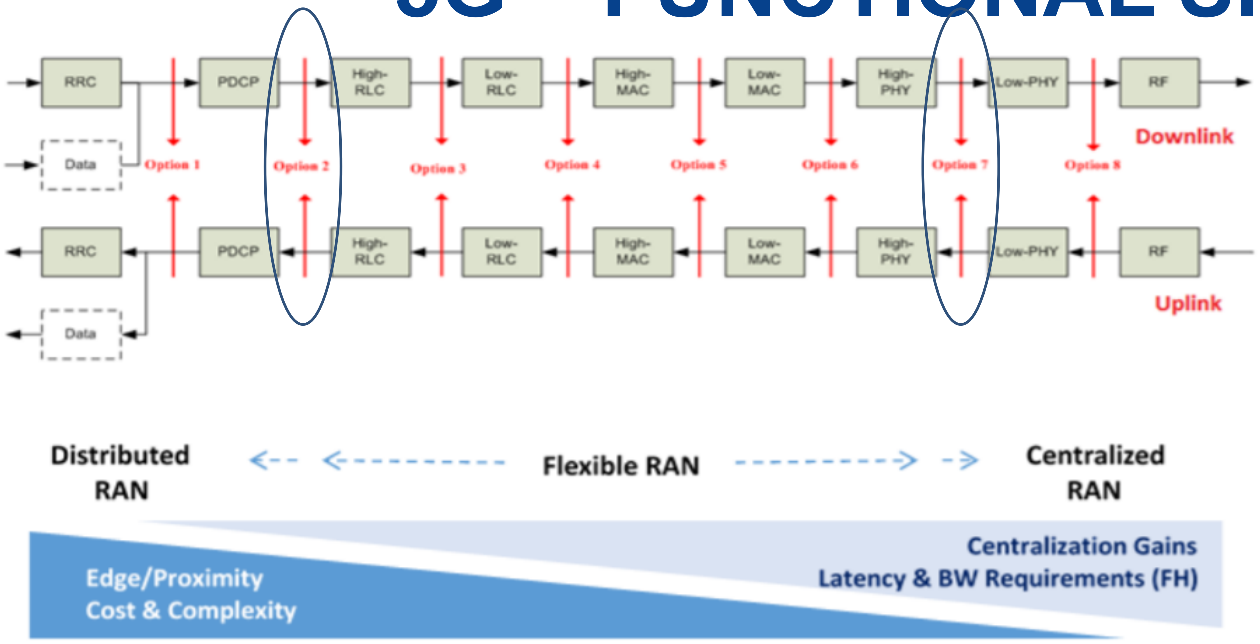


Figure 1: Functional split options

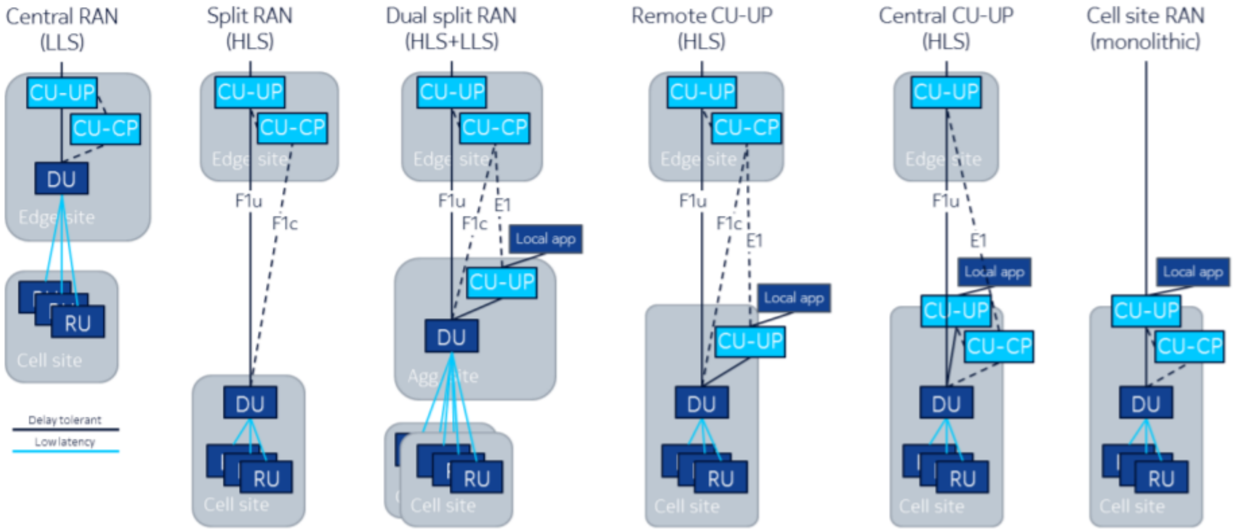
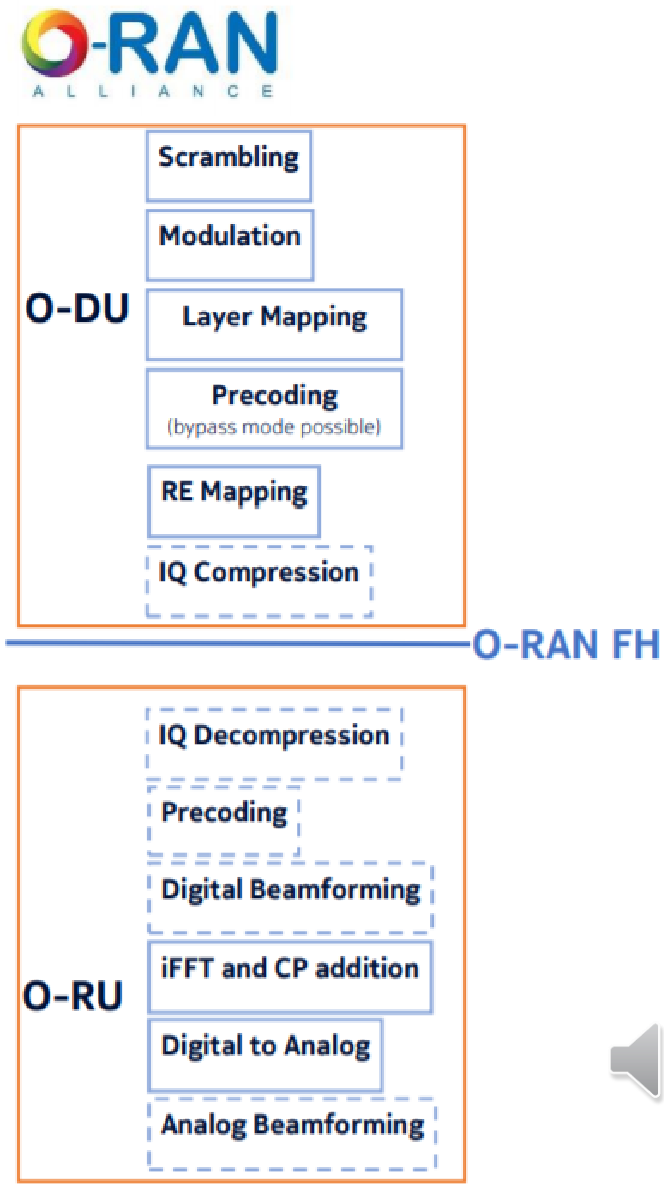
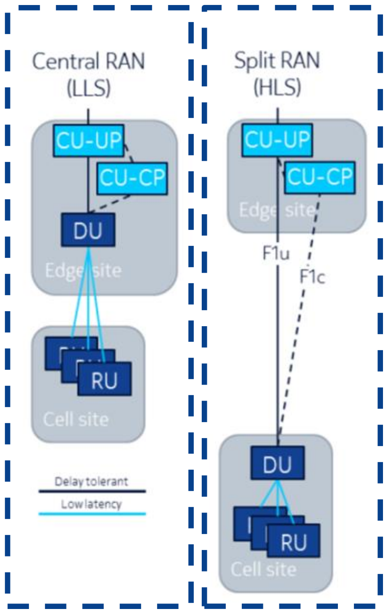


Figure 4: Example functional placement scenarios

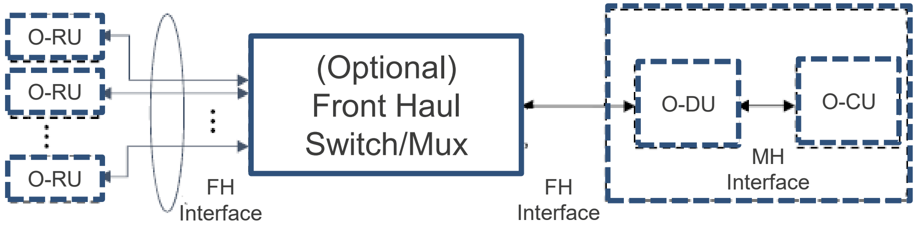


VARIOUS DEPLOYMENT EXAMPLES*

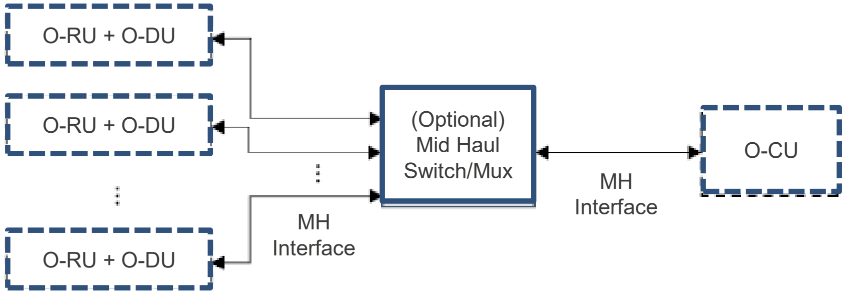


Scenario B – Initial Priority Focus

The CU server/software co-located with the DU
... or hosted in a regional cloud data center.



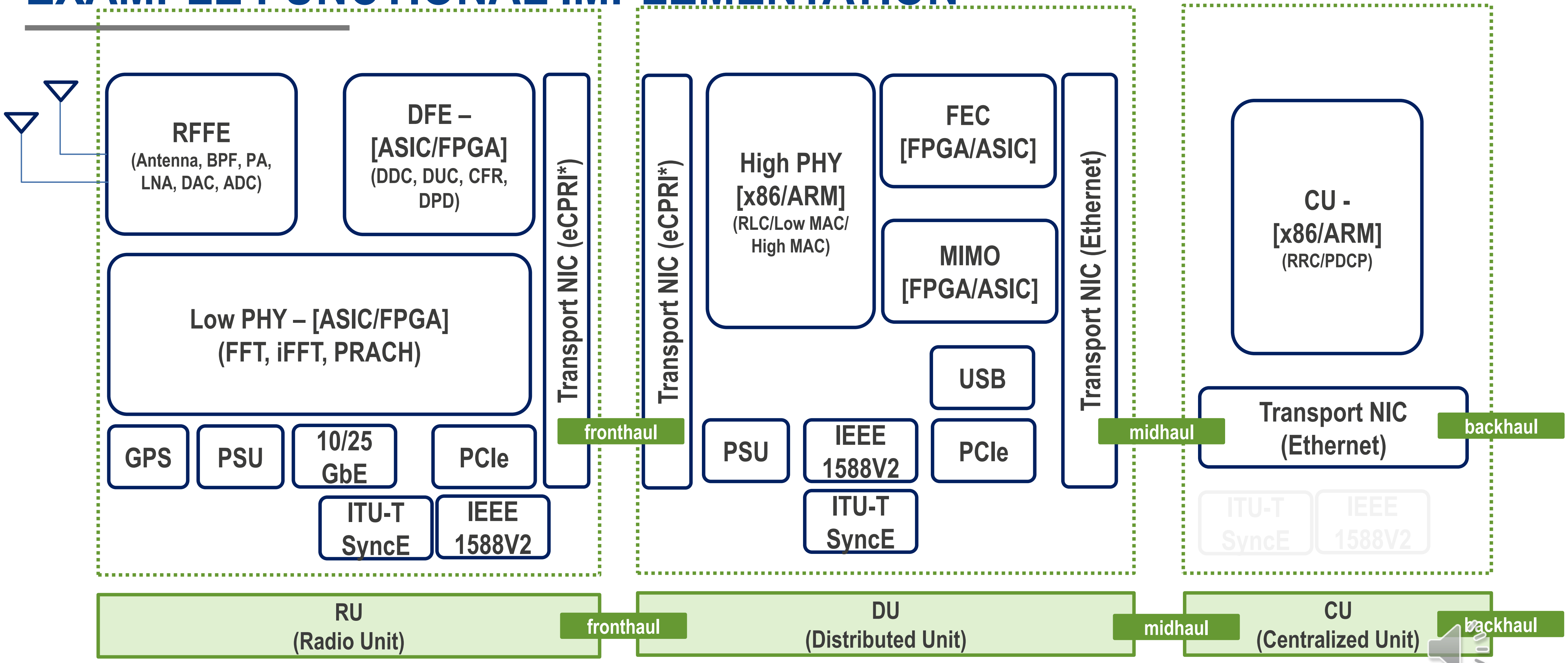
Central RAN, with Fronthaul Switch



Split RAN, with Midhaul Switch

Closer to Traditional 5G - Source: NGMN-2018

EXAMPLE FUNCTIONAL IMPLEMENTATION



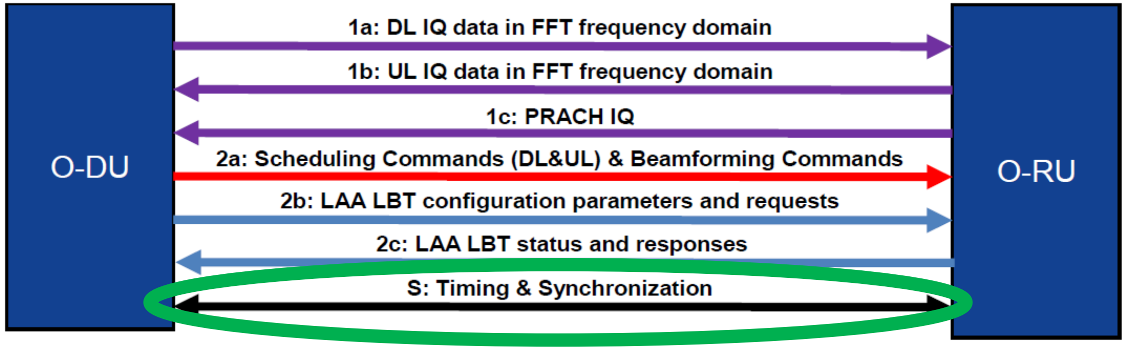
Source: Example based on TIP OpenRAN 5G NR BS Platform Requirements
** eCPRI/RoE as well as CPRI support will be needed for coexistence/transition*

Page 10

O-RAN OVERVIEW

SYNCHRONIZATION PLANE

O-RAN S-PLANE



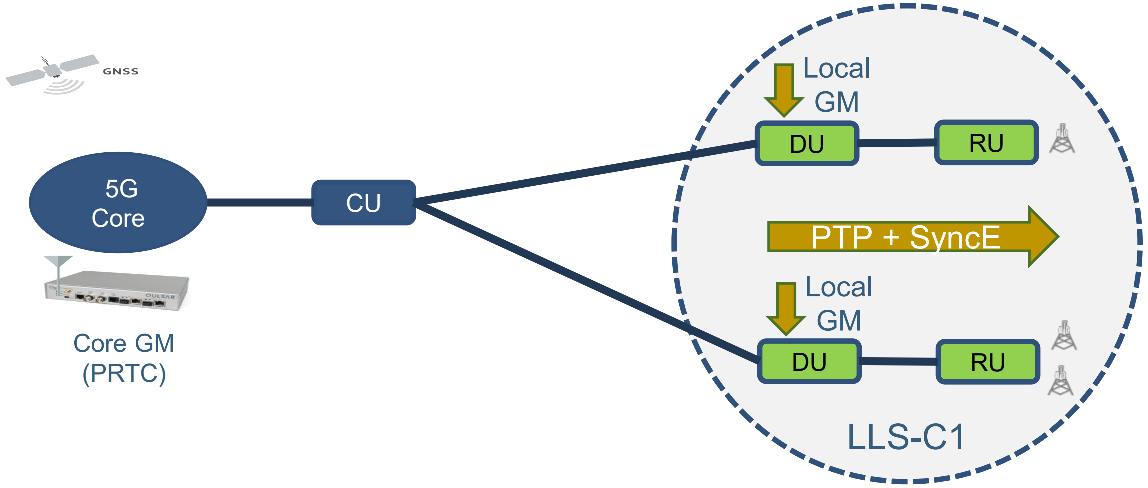
- Timing and Synchronization Plane
  - Using SyncE SSM & IEEE 1588 PTP packets
  - Relative time error between the O-DU and O-RU should be within a limit of 3μs (±1.5 μsec)
- Current Version on O-RAN specification assumes transport of PTP directly over L2 Ethernet (ITU-T G.8275.1 full timing on-path support)
  - transport of PTP over UDP/IP (ITU-T G.8275.2 partial timing support from the network) is also possible

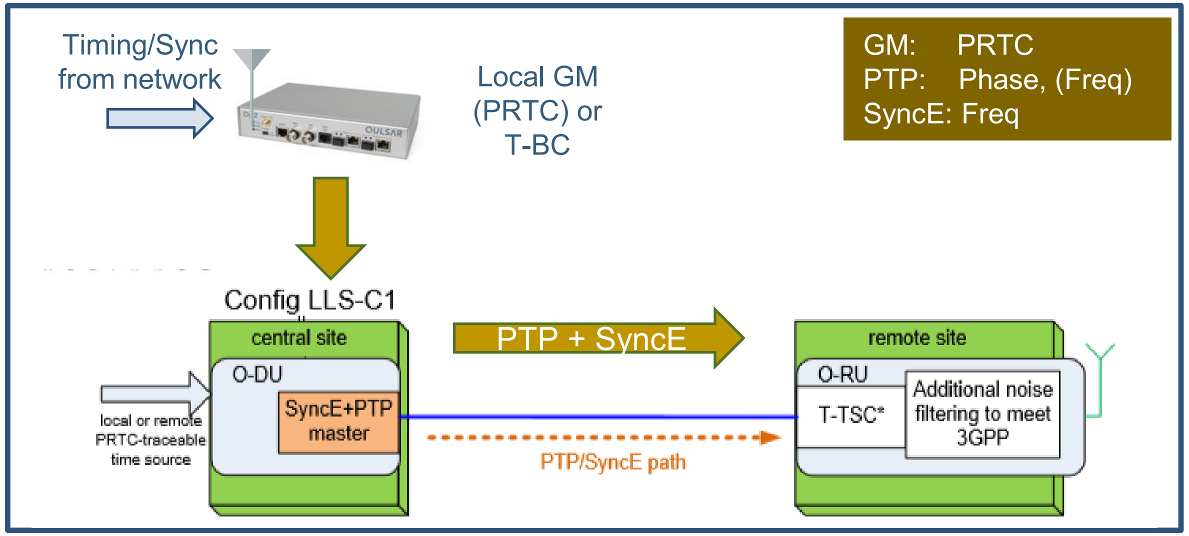
Four (4) O-RAN synchronisation configurations, or Lower-Layer Split:

- **LLS-C1**: the O-DU is part of the synchronisation chain towards the O-RU. Network timing is distributed from O-DU to O-RU via direct connection between O-DU site and O-RU site.
- **LLS-C2**: the O-DU is part of the synchronisation chain towards the O-RU. Network timing is distributed from O-DU to O-RU between O-DU sites and O-RU sites. One or more Ethernet switches are allowed in the fronthaul network.
- **LLS-C3**: the O-DU is not part of the synchronisation chain towards the O-RU. Network timing is distributed from PRTC/T-GM to O-RU typically between central sites (or aggregation sites) and O-RU sites. One or more Ethernet switches are allowed in the fronthaul network.
- **LLS-C4**: the synchronisation reference is provided to the O-RU with no involvement of the transport network (typically with a local GNSS receiver).

How O-DU is synchronized is not in the scope of this classification of the synchronisation topologies – but it cannot be ignored!!!

ORAN S-PLANE: CONFIGURATION LLS-C1





Configuration LLS-C1

Point-to-Point, tightly coupled O-DU and O-RU.

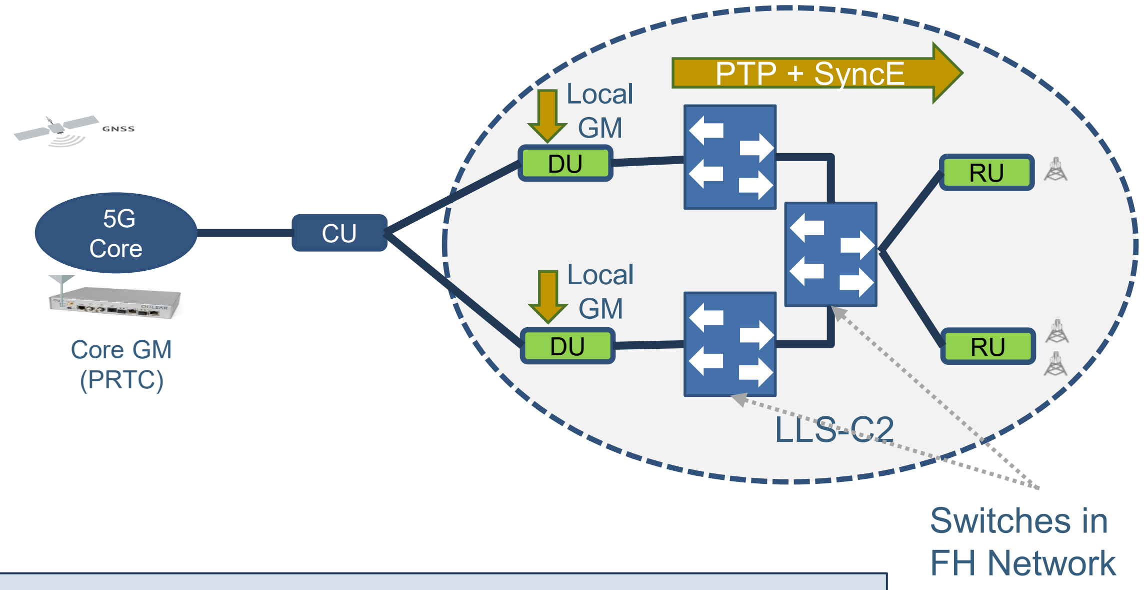
Use Cases:

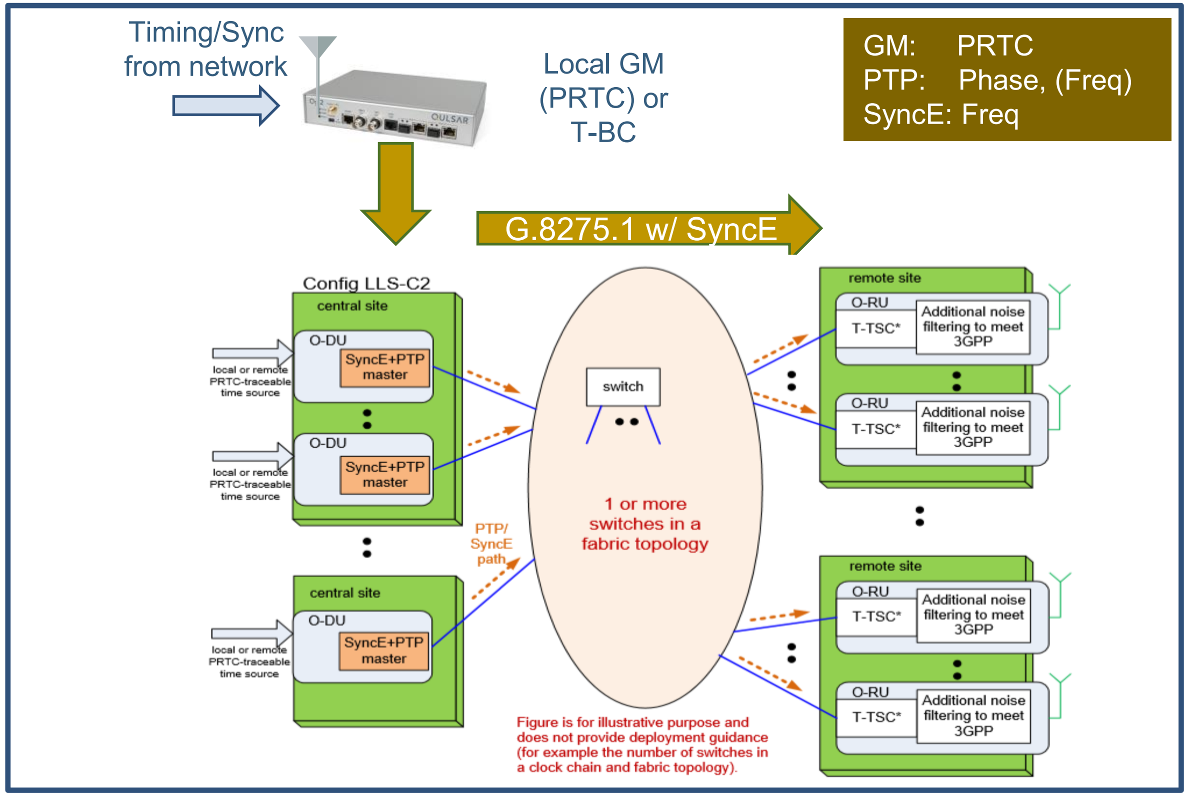
- Massive MIMO radios require tight baseband processing at O-RU and O-DU for split 7.2
- Rural, less dense cellular networks, private networks, etc.
- Mission critical, and URLLC or mMTC network slices

Timing and Synchronization

- Typical Sync Flow: **Local GM => O-DU (BC/TC) => O-RU (Slave)**
- G.8275.1 Telecom Profile - L2, full-on-path support, SyncE
- More Sync resiliency desirable for mission critical applications.

ORAN S-PLANE: CONFIGURATION LLS-C2





Configuration LLS-C2

O-DU and O-RU connections through switches

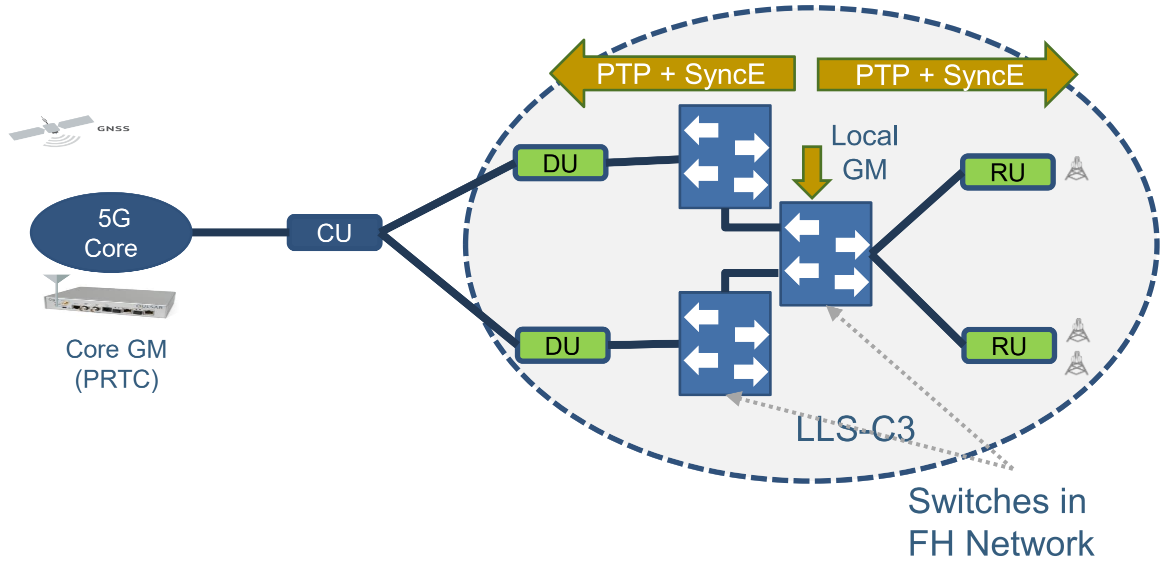
Use Cases:

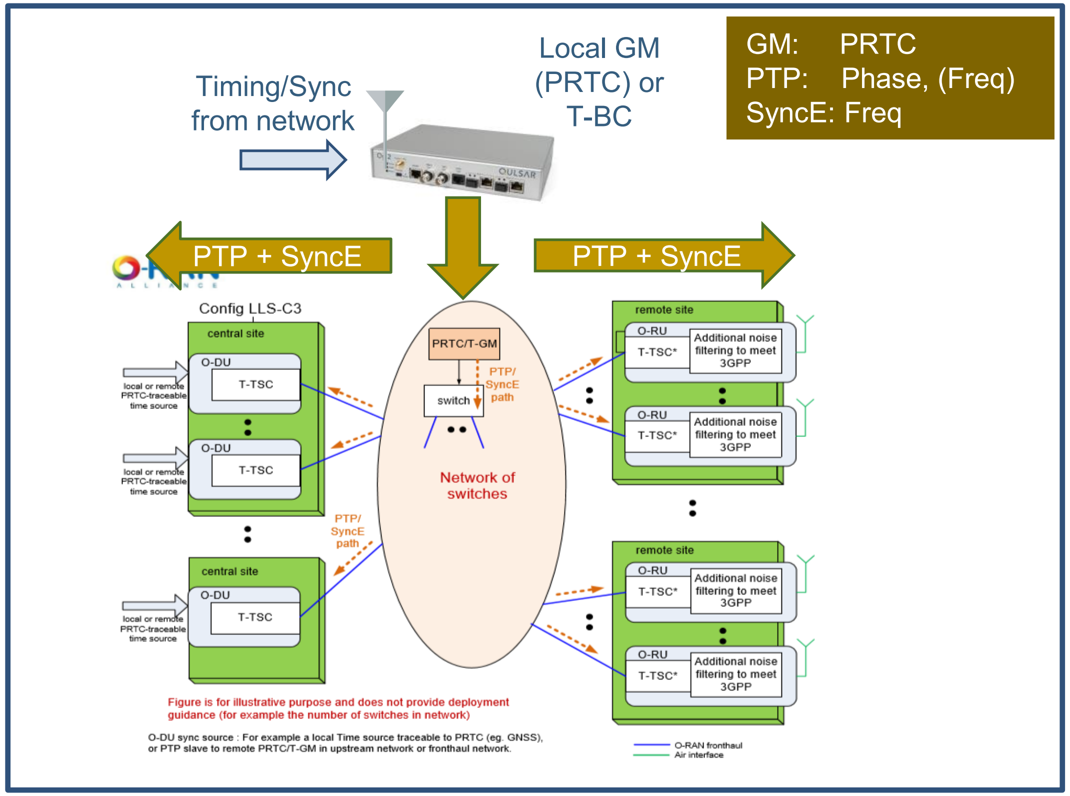
- 4G/5GNR radios in mesh configuration with DU(s) for load-balancing and BW optimization
- DU's stacked in Datacenters, CORD
- Fail-safe with redundant paths in FH network
- Smart cities, IIoT, eMBB or mMTC network slices

Timing and Synchronization

- Typical Sync Flow: **Local GM => O-DU (BC/TC) => FH Switches (BC/TC) => O-RU**
- G.8275.1 Telecom Profile - L2, full-on-path support, SyncE
- G8275.2 Profile can be used with PTP-unaware switches with high performance PTP servo at RU slaves. Less cost.

ORAN S-PLANE: CONFIGURATION LLS-C3





Configuration LLS-C3

O-DU and O-RU connections through switches like previous LLS-C2

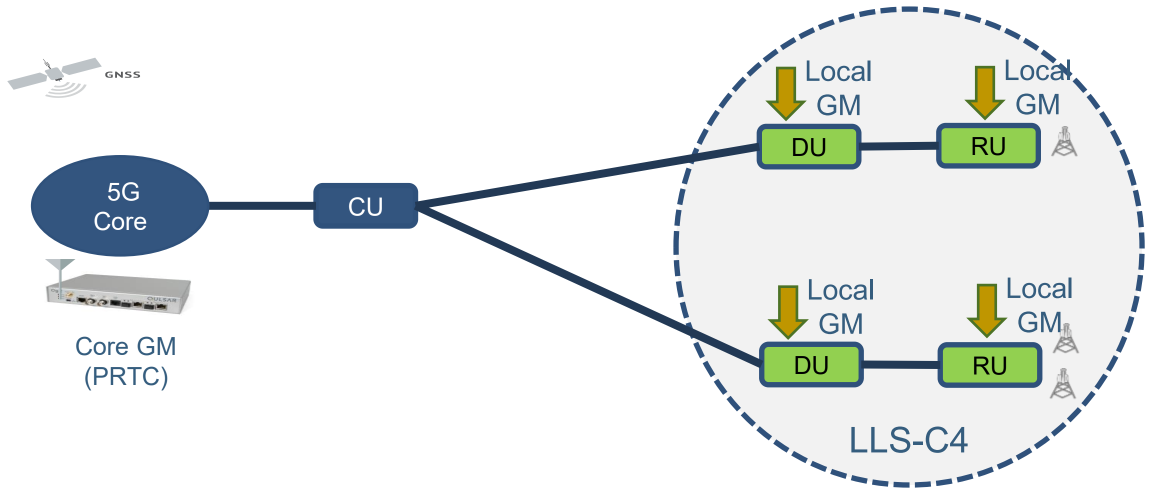
Use Cases:

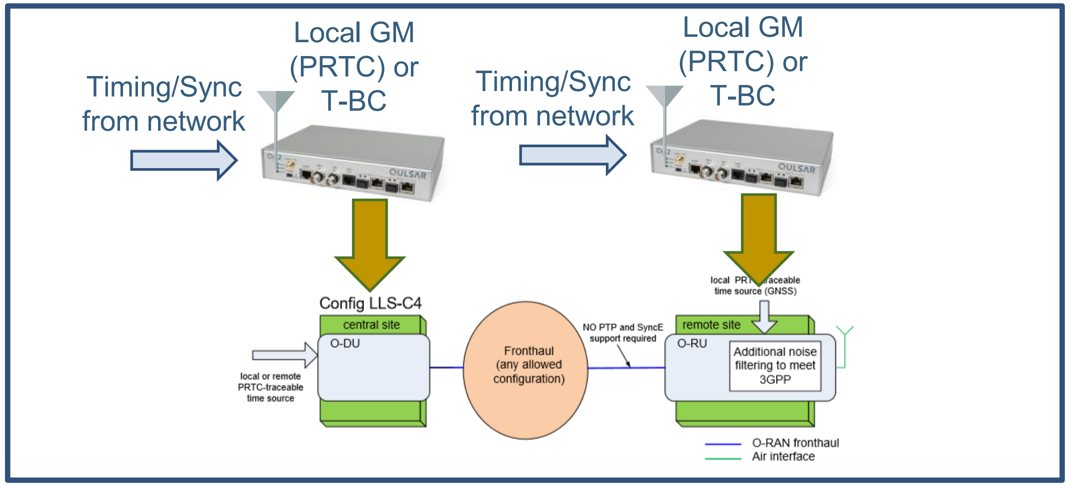
- 4G/5GNR radios in mesh configuration with DU(s) for load-balancing and BW optimization
- DU's stacked in Datacenters, CORD
- Fail-safe with redundant paths in FH network
- Smart cities, IIoT, eMBB or mMTC network slices

Timing and Synchronization

- Typical Sync Flow: **Local GM => FH Switches (BC/TC) => O-DU & O-RU**
- G.8275.1 Telecom Profile - L2, full-on-path support, SyncE
- Like LLS-C2 but inherently better precision due to less hops
- G8275.2 Profile can be used with PTP-unaware switches for with high performance PTP servo at RU slaves. Cost-effective

ORAN S-PLANE: CONFIGURATION LLS-C4



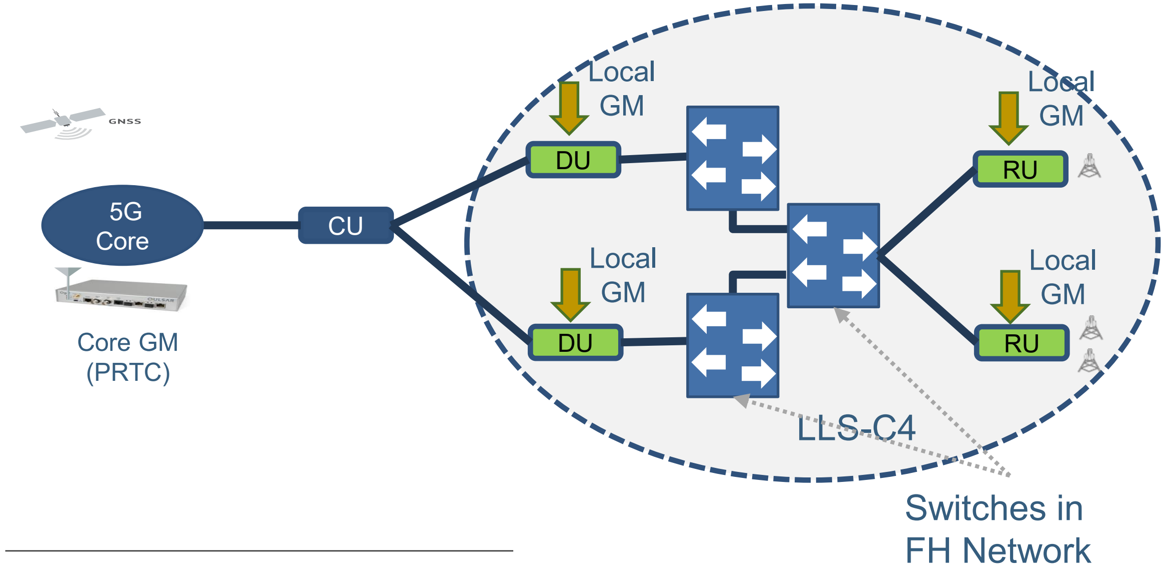


Configuration LLS-C4

O-DU and O-RU synchronizes directly to local GM (PRTC)

Use Cases:

- Mission critical applications
- Flexibility for different DU-RU topologies
- Can be used with all network slices



Timing and Synchronization

- Typical Sync Flow: **Local GM => O-DU and O-RU**
- Simplest solution - local PRTC, networking timing back-up
- Expensive option

O-RAN CLOCK TYPES

O-RAN Clock	O-DU	O-RU	FHM	FHB	FHG
Time Accuracy **$\|TE_L\|$**	≤ 1.420 µs (LLS-C1) ≤ 1.325 µs (LLS-C2) (to UTC)	Not applicable	Not applicable	Not applicable	Not applicable Or See O-DU
Frequency Accuracy **|freq_error|**	≤ 15 ppb (Class A) ≤ 5 ppb (Class B)	≤ 21 ppb (O-DU Class A) ≤ 27 ppb (O-DU Class B) ≤ 30 ppb (LLS-C3) ≤ 48 ppb (LLS-C4)	Not applicable	Not applicable	Not applicable Or See O-DU
Time Error **(max|TE|)**	See Time Accuracy	≤ 80 ns (Regular) ≤ 35 ns (Enhanced) ≤ 30 ns (LLS-C4)	See T-BC/TC Class C	See T-BC/TC Class C	IWF Or See O-DU

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