VIRTUAL TUTORIAL
O-RAN FUNDAMENTALS
SYNCHRONIZATION OVERVIEW

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OUTLINE

- What is O-RAN?

- O-RAN Overview
  - Functional Splits
  - Deployment

- Time Accuracy in eCPRI
  - Overview
  - O-RAN Synchronization Plane
WHAT IS O-RAN
First, What Is RAN?

- **RAN history**
  - GRAN GSM Radio Access Network → 2G
    - TDMA, CDMA
  - UTRAN = UMTS Radio Access Network → 3G
    - W-CDMA radio access technology
  - E-UTRAN = Evolved UMTS Radio Access Network → 4G
    - MIMO, OFDM, Long Term Evolution (LTE) → 4G LTE
  - NG-RAN = 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 (Open RAN Alliance) → 5G O-RAN
4G VERSUS 5G ARCHITECTURE

Evolved Packet Core (EPC) in 4G
- Transport network implements Telecom Boundary clocks type A/B

BBU in 4G:
- BBU recovers sync from the network
- BBU implements IEEE 1588 and SyncE
- BBU implements Telecom Slave clock (T-TSC)

RRU in 4G:
- RRU recovers sync from CPRI signal alone
- Jitter performance is a key parameter for timing devices used in RRU

EPC

Core Network (CN) in 5G
- Transport network implements Telecom Boundary clocks type C/D

BBU in 5G:
- BBU is split in 2 nodes (CU and DU)
  - CU (optionally) and DU both implement IEEE 1588 and SyncE
  - CU (optionally) and DU both implement Telecom Boundary clock (T-BC)
  - DU needs to implement clock classes C or D depending on the Operator

RRU in 5G:
- RRU cannot recover sync from eCPRI signal alone
  - RU needs to implement IEEE 1588 and SyncE (IEEE 802.1CM TSN)
- Jitter performance is a key parameter for timing devices used in RRU

- Transport network implements Telecom Boundary clocks type A/B
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."
FUNCTIONAL SPLITS – O-RAN SPECIFIC

Figure 1: Functional split options

- Central RAN (LLS)
- Split RAN (HLS)
- Dual split RAN (HLS+LLS)
- Remote CU-UP (HLS)
- Central CU-UP (HLS)
- Cell site RAN (monolithic)

Figure 4: Example functional placement scenarios

- IQ Decompression
- Preceding
- Digital Beamforming
- iFFT and CP addition
- Digital to Analog
- Analog Beamforming
VARIOUS DEPLOYMENT EXAMPLES*

Scenario B – Initial Priority Focus

*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
TIME ACCURACY IN eCPRI

SPECIFICATIONS
The 3GPP time alignment error (TAE) (or relative time error (TE\text{R})) represents the largest timing difference measured between any two elements of the cluster.

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

O-RAN CUS–plane spec also defines two classes of O-DU:

- Class A has $\pm$15 ppb frequency error limit
- Class B has $\pm$5 ppb limit

### Table 2 - Time and phase requirements for cluster based synchronisation

<table>
<thead>
<tr>
<th>Class level of accuracy</th>
<th>Maximum relative time error requirements (Note 1)</th>
<th>Typical applications (for information)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3A</td>
<td>5 $\mu$s</td>
<td>LTE MBSFN.</td>
</tr>
<tr>
<td>4A</td>
<td>3 $\mu$s</td>
<td>NR intra-band non-contiguous (FR1 only) and inter-band carrier aggregation; with or without MIMO or TX diversity.</td>
</tr>
<tr>
<td>6A</td>
<td>260 ns</td>
<td>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.</td>
</tr>
<tr>
<td>6B</td>
<td>130 ns</td>
<td>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.</td>
</tr>
<tr>
<td>6C</td>
<td>65 ns</td>
<td>LTE and NR MIMO or TX diversity transimission, at each carrier frequency.</td>
</tr>
</tbody>
</table>

**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 [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 synchronisation requirement on the transport network.
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.
O-RAN OVERVIEW
SYNCHRONIZATION PLANE
**O-RAN S-PLANE**

- Timing and Synchronisation 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 topologies:

- **Configuration 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.

- **Configuration 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.

- **Configuration 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.

- **Configuration 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!!!*
TOPOLOGIES

LLS-C1

central site
O-DU
PLFS+PTP
master

remote site
O-RU
T-TSC
Additional noise filtering to meet 3GPP

PTP/PLFS path

LLS-C2

Config LLS-C2

central site
O-DU
PLFS+PTP
master

remote site
O-RU
T-TSC
Additional noise filtering to meet 3GPP

1 or more switches in a fabric topology

Figure is for illustrative purpose and does not provide deployment guidance (for example the number of switches in a clock chain and fabric topology).

LLS-C3

Config LLS-C3

central site
O-DU
T-TSC

remote site
O-RU
T-TSC
Additional noise filtering to meet 3GPP

Figure is for illustrative purpose and does not provide deployment guidance (for example the number of switches in network).

LLS-C4

Config LLS-C4

central site
O-DU

remote site
O-RU
Additional noise filtering to meet 3GPP

NO PTP and PLFS support required

Local PRTC time source

Fromhaul
(any allowed configuration)

Source of figures: O-RAN.WG4.CUS

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# O-RAN Sync`hronization for O-DU

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Time Source</th>
<th>PLFS Master Toward Fronthaul</th>
<th>PTP Master Toward Fronthaul</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLS-C1</td>
<td>Local or Remote PRTC</td>
<td>Yes</td>
<td>Yes</td>
<td>Point to point path from O-DU to O-RU</td>
</tr>
<tr>
<td>LLS-C2</td>
<td>Local or Remote PRTC</td>
<td>Yes</td>
<td>Yes</td>
<td>Via 1 or more T-BC/T-TC switches from O-DU to O-RU</td>
</tr>
<tr>
<td>LLS-C3</td>
<td>Local or Remote PRTC (incl. Fronthaul PRTC via PTS/PLFS)</td>
<td>No</td>
<td>No</td>
<td>Via 1 or more T-BC/T-TC switches from PRTC/T-GM in fronthaul network</td>
</tr>
<tr>
<td>LLS-C4</td>
<td>Local or Remote PRTC</td>
<td>No</td>
<td>No</td>
<td>No timing output from O-DU.</td>
</tr>
</tbody>
</table>

**ORAN Terminology:**

**O-DU** – open Distribution Unit, **O-RU** – open Radio Unit

Fronthaul – The network between the O-DU and O-RU

Mid-/Backhaul – The network connecting the O-DU to the O-CU (midhaul) or core network (backhaul)

PLFS (Physical Layer Frequency Signals) – same as ITU-T SyncE

Defined in O-RAN.WG4.CUS.0-v10.00 with performance requirements in Table 11.3.2.1-1, 11.3.2.2-1 and 11.3.2.3-1

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**Local** = Embedded PRTC, Direct PRTC, or Direct PRTC/T-GM via ETH

**Remote** = Mid/Backhaul PRTC via PTP/SyncE

Synchronizer DPLL, such as ClockMatrix™, is recommended for O-DU systems to cover all synchronization topologies.
# O-RAN SYNCHRONIZATION FOR O-RU

<table>
<thead>
<tr>
<th>Configuration</th>
<th>PLFS Input?</th>
<th>PTP Input?</th>
<th>Fronthaul Network Type</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLS-C1</td>
<td>Yes</td>
<td>Yes</td>
<td>FTS (with SyncE)</td>
<td>Point to point path from O-DU to O-RU</td>
</tr>
<tr>
<td>LLS-C2</td>
<td>Yes</td>
<td>Yes</td>
<td>FTS (with SyncE) or PTS*</td>
<td>Via 1 or more T-BC/T-TC switches from O-DU to O-RU</td>
</tr>
<tr>
<td>LLS-C3</td>
<td>Yes</td>
<td>Yes</td>
<td>FTS (with SyncE) or PTS*</td>
<td>Via 1 or more T-BC/T-TC switches from PRTC/T-GM in fronthaul network</td>
</tr>
<tr>
<td>LLS-C4</td>
<td>No</td>
<td>No</td>
<td>N/A</td>
<td>No timing input to O-RU.</td>
</tr>
</tbody>
</table>

## ORAN Terminology:

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Defined in O-RAN.WG4.CUS.0-v10.00 with performance requirements in Table 11.3.2.1-1, 11.3.2.2-1 and 11.3.2.3-1

* Use of PTS unlikely at O-RU due to tight timing constrains for 3GPP Timing Category A/B (Relative |TAE| ≤ 130 ns/260 ns, respectively)

Synchronizer DPLL, such as ClockMatrix™ or FemtoClock™3-Wireless, is recommended for O-RU systems to cover all synchronization topologies.
Timing is the **heartbeat** of the system