Getting D-RAN in Sync with COTS HW & Open Source Software

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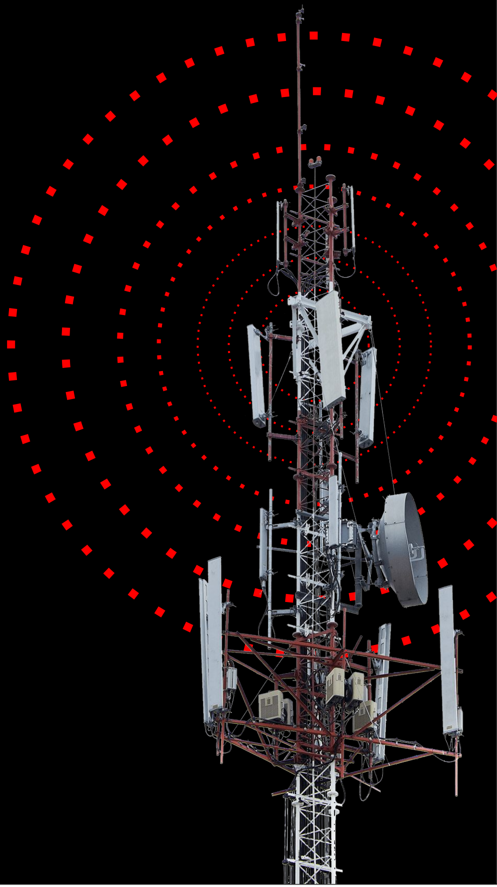

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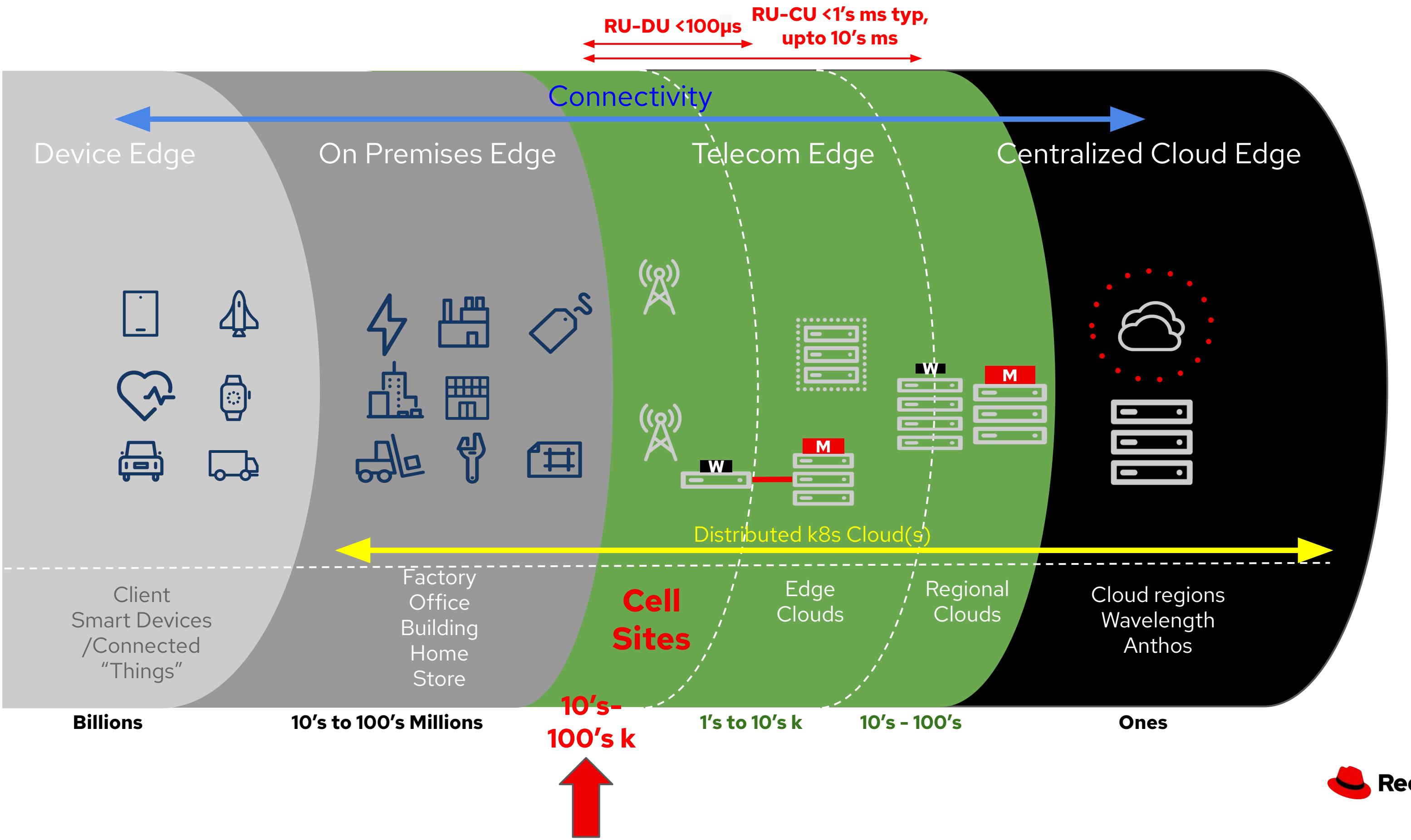
Agenda

- ➢ **What is D-RAN site ?**
- ➢ **Synchronization requirements in context of D-RAN**
- ➢ **D-RAN site and synchronization topologies**
- ➢ **Representative D-RAN site configurations**
- ➢ **D-RAN Server node synchronization HW & SW implementation**
- ➢ **D-RAN synchronization function and -chain performance**
- ➢ **Q&A session**

Edge Classification

Four Edge Conversations



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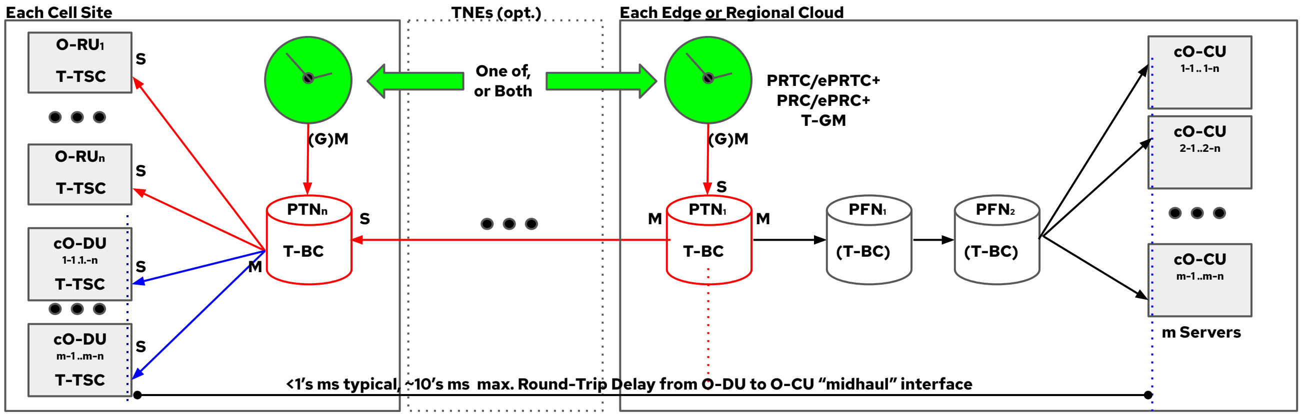
5G (cloud) D-RAN recap - with transport node @cell site



Performance Critical Synch Path, abs|TE| & rel|TE| G8275.1 (possibly with SyncE); high / enhanced sync performance requirements

Less Performance Critical Synch Path, abs|TE| only; G8275.1, SyncE optional; Relaxed sync performance requirements

Non-Critical synchronization path, PTP use is optional (may use relaxed PTP impl. Including .2 or enterprise profiles or NTP instead of PTP)

TNE = Transport Network Element (typ. Switches and/or routers, or CWDM / DWDM optical)
PTN = Packet Transport Node (e.g. Switch / Router)
PFN = Packte Fabric Node (Switches)

Distributed (D-)RAN:

- DU's serving sectors of a site are co-located at site
- Can still be cloudified (vs. PNFs)
- In cloud, typ. run in servers with RT kernel + HW acceleration resources
- DUs serve only single site cells (from 1 to 12+ sector/band combinations per server)
- Few, typ. 1 to 3 servers/ cell site

"Easy" for the cloud nodes wrt. Synchronization support:

- Switch / CSR takes care of the site networking
- Switch / CSR will handle the critical synchronization path (G.8275.1, typ. a Class C Boundary Clock)
- Physical GNSS/T-GM at site or edge cloud; or integrated with switch/CSR
- As a consequence of the above, servers need to be slave only, and with somewhat relaxed performance as compared to T-BC and/or O-RU's slave performance (as in this case, the only node clock needs to get synchronized in DU servers)
- From O-RAN perspective, this is WG4 LLS-C3 synchronization configuration, as well as initial target on WG6 specs

The two main ITU-T Telecom Profiles for RAN

Attribute	G.8275.1 (FTS)	G.8275.2 (PTS)
Transport	PTP over Ethernet Multicast (forwardable or non-forwardable)	PTP over IPv4 or IPv6 Unicast; IP QoS with DiffServ for sync packets
Domain Number	24 to 43	44-63
Hybrid w/ SyncE	May be required on O-RU sync path depending on topology & O-RU	Optional
BMCA Algorithm	Alternate BMCA (A-BMCA), as specified by ITU-T	
PTP Packet Rates	Fixed; Sync/Delay-Req-Resp 16 PPS, Announce 8 PPS	Variable up to 128 PPS: 1/2/4/8/16/32/64/128 PPS
Every Hop PTP Aware	Yes, FTS, typically all T-BC's	No, PTS
Phase/Freq Sync	Both	
Unicast Negotiation	No	Yes (Must)
PTP over VLAN	No	Optional; L2 QoS requires VLAN tags
Opt. TLVs for link speed	No	Yes
Local Priority	Yes	
Slave Redundancy	Yes, use is optional / operator specific, typ. Required in C-RAN configs	
#major slave conf. options	~16	~64 + IP network etc. aspects

G.8275.1 Full Timing Support (FTS)

- This is baseline expectation for every partner & customer case
- SyncE is not necessarily required for slave-only DU nodes
- If SyncE is supported, it is expected to improve slave accuracy and if supported, must be spec compliant (including ESMC support)
- SyncE support in nodes acting as T-BC in O-RU synchronization transfer path is typically required
- L2 Transport, easy to configure

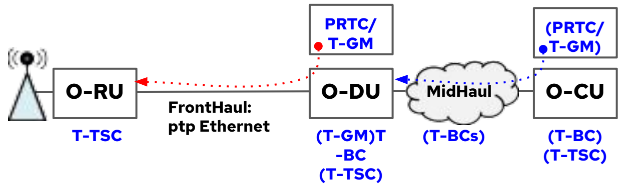
G.8275.2 Partial Timing Support (PTS)

- Doubts on ability of meeting the performance (accuracy) requirements, especially on larger networks
- Most operators are NOT going after this
- "May" work well enough in small / limited configs such as D-RAN site with one-two nodes in sync path with direct connections
- At this point, only one ask for this for FH interface, but will also be required as part of APTS
- Due to IP transport and more options, more complicated to configure then .1 FTS profile
- IPv6 support is dependent on NIC HW support

G.8265.1 PTP Telco Profile For Frequency Sync

- No-one is asking for this so far - if needed, let us know !
- Frequency only, no phase/time support
- Supported by LinuxPTP, but not in our perf. validation plans

O-RAN “LLS-Cx” Synchronization Reference Configs

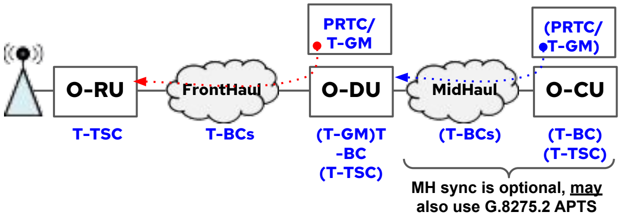


WG4 Configuration LLS-C1

FH Direct connection to O-RU(s) from O-DU; sync source in O-DU

WG9 C1, Option A: T-GM Embedded in O-DU
WG9 C1, Option B: T-GM Directly Connected to O-DU
WG9 C1, Option C: T-GM connected to O-DU via chain of network nodes)

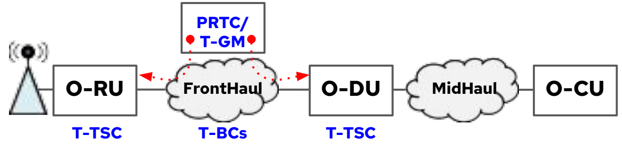
Our Focus Today



WG4 Configuration LLS-C2

FH Network connection to O-RU(s) from O-DU; sync source in O-DU

WG9 C2, Opt. A: O-DU is the nearest common T-BC
WG9 C2, Opt. B: nearest common T-BC not O-DU

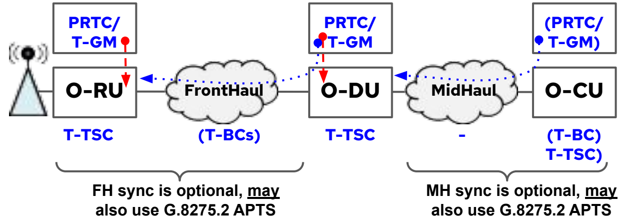


WG4 Configuration LLS-C3

Network connection to O-RU from O-DU & sync source in FH network

WG9 C3, Option A: T-GM is the nearest common master
WG9 C3, Option B: nearest common master is not T-GM
WG9 C3, Option C: T-GM in Mid/Back-haul
WG9 C3, Option D: T-GM in Mid/Back-haul with T-BC chain

DONE :)



WG4 Configuration LLS-C4

Network connection to O-RU from O-DU & local sync sources

WG9 C4, Option 1: GNSS at Cell Site (e.g. in O-RU / xNB)
WG9 C4, Option 2: GNSS at Cell & Edge + APTS network

Note:

In clouds, synchronization is part of cloud infrastructure, and decoupled from RAN instances

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O-RAN LLS-Cx Decomposition for Cloud Features

Key Features	O-RAN CUS LLS-C1; FH Directly connect to O-RU from O-Cloud; Sync source in O-cloud	≈ O-RAN CUS LLS-C2; FH Network connection to O-RU from O-Cloud; sync source in O-Cloud	O-RAN CUS LLS-C3; Network connection to O-RU from O-Cloud & sync source in FH network	O-RAN CUS LLS-C4; Direct or Network connection to O-RU's from O-Cloud & sync sources in RU and O-Cloud
Mgmt Cfg/Metrics/Events (local and system evt. notifications)	Yes			
Node Linux Clock Synchronization from NIC Clock (e.g. phc2sys)	Yes			
G.8275.1 Full Timing Support T-TSC (G.8273.2 class A-D)	Yes (class A/B or better)	Yes (Class **B/C** or better)	Yes (class A or better)	Opt. (class A/B or better)
G.8275.2 Partial Timing Support (T-TSC-A/P)	Alternative Option vs. G.8275.1, less requested esp. on LLS C2/C3 configurations due to accuracy uncertainties			
G.8275.x FTS/PTS T-TSC redundancy	Yes, when redundant network connectivity available (mode common in C-RAN than D-RAN, but applies to both)			
PPS out/in (x-connect in multi card configs)	Yes, If supported in HW (O/I)		Yes, If supported in HW (O)	If supported in HW (O/I)
10 Mhz out/in (x-connect in multi-card configs w/ SyncE)	Yes, If supported in HW (O/I)		Yes, If supported in HW (O)	If supported in HW (O/I)
G.8275.1 FTS T-BC (class A-D: >=B); one/multiple NICs	Yes (typ. class B or better)	Yes (typ. **class C** or better)	(N/A in node, in-RU-path node T-BC's typ. Class C or better)	Opt. (class B/C or better)
G.8262 (or G.8262.1) SyncE; one/multiple NICs	Typically Yes w/ 8275.1 T-BC, when node on O-RU sync path		Option, typ. not in nodes	Opt. typically w/ T-BC
G.8275.2 PTS T-BC; one/multiple NICs	Alternative to G.8275.1, accuracy concerns in large configs		-	Alternative for G.8275.1
G.8275.1 FTS T-GM (Ext/Int >=PRTC-A)	Option, if supported in HW (GNSS receiver)		-	Yes, if supported in HW (GNSS receiver)
G.8275.2 PTS T-GM (Ext/Int,>=PRTC-A)	Option, if supported in HW (GNSS receiver)		-	Yes, if supported in HW (GNSS receiver)
G.8275.x FTS/PTS T-GM redundancy	Yes, when redundant HW available (mode common in C-RAN than D-RAN, applies to both)		-	Yes, when redundant HW available
G.8275.2 APTS	-	-	-	Optionally Yes

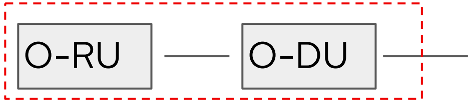
Note: CUS LLS-Cx Configs are sufficiently "nebulous" to be un-usable as spec due to large variety of options within ea. - trust but verify, i.e. **focus on feature set & specific reqs. vs. LLS-Cx**

Why “advanced” Synchronization in the D-RAN Servers ?

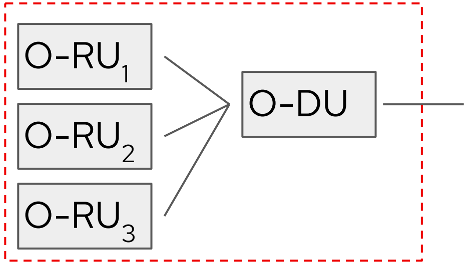
- **Cost Savings through site HW Reduction**
  - Cost and/or site energy consumption reduction -- CapEx + OpEx savings
  - Operational simplification -- OpEx Savings
  - Integration simplification - same tools and interfaces, less managed elements
  - Installation and commissioning simplification
  - Equipment and Spares Inventory Reduction
  - Site lease cost reductions through space and/or energy savings
- **Elimination of a need to replace, expand or add to existing PNFs**
  - CSR fan-out port capacity expansion
  - CSR processing capacity reduction (in some cases this is licensed based on throughput, and RUs need lots of BW)
- **Complete Elimination of...**
  - Cell Site router | switch and associated extra interfaces & optics / cabling
  - Cell Site GNSS appliances
  - FHGW PNFs → support for integrated FHGW function (e.g. CPRI-ORAN LLS); typically FPGA based implementations
- **DU instances on site are topologically in-line with the O-RUs anyway**

What's at ~~The~~ a D-RAN site ?

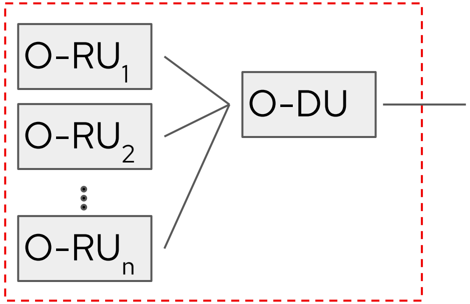
Single band, single sector, 1 DU server



Single band, three sectors, 1 DU server

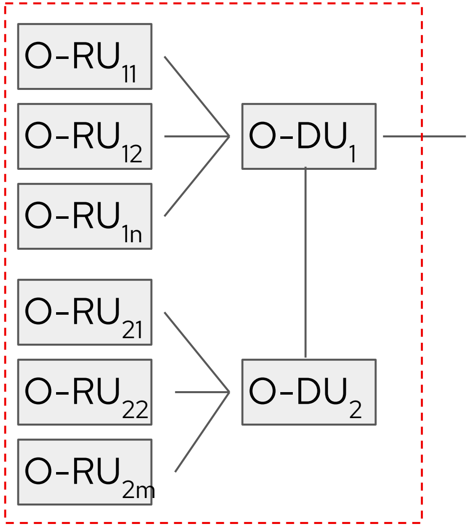


>1 band, n sectors, 1 DU server



Server capacity vs. sector type combination determines how many servers are required per site to serve the load; Presently can be as low as 3 hi-end sectors to as high as 15 or more LTE sectors / 1-skt server - going up as server processing & HW acceleration capacity improves

>1 band, x sectors, 2 DU servers

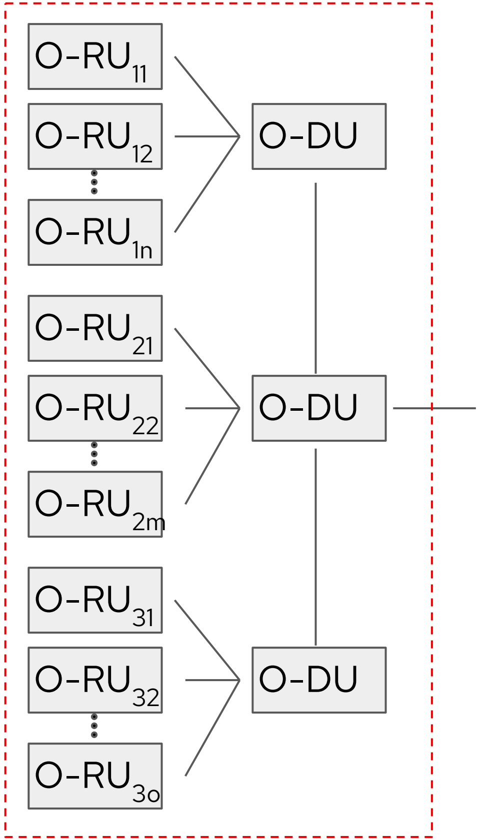


There are a wide variety of site types...

- #sectors, sector type/BW/MIMO conf
- PNF vs. Virtualized fraction
- Greenfield (rare) vs. Brownfield
- Target deployment environment (e.g. rural/urban)
- Technology Mix - e.g. 3/4/5G, DSS, …
- Fiber availability / MH|BH network capacity
- Legacy equipment (RUs, CSRs, GWs, BBUs …)
- not static, sites evolve over time, e.g. add bands / RUs

Even in Greenfield network, common to have ten++ of distinct site types, much more diversity on brownfield

>1 band, x sectors, 3 DU servers



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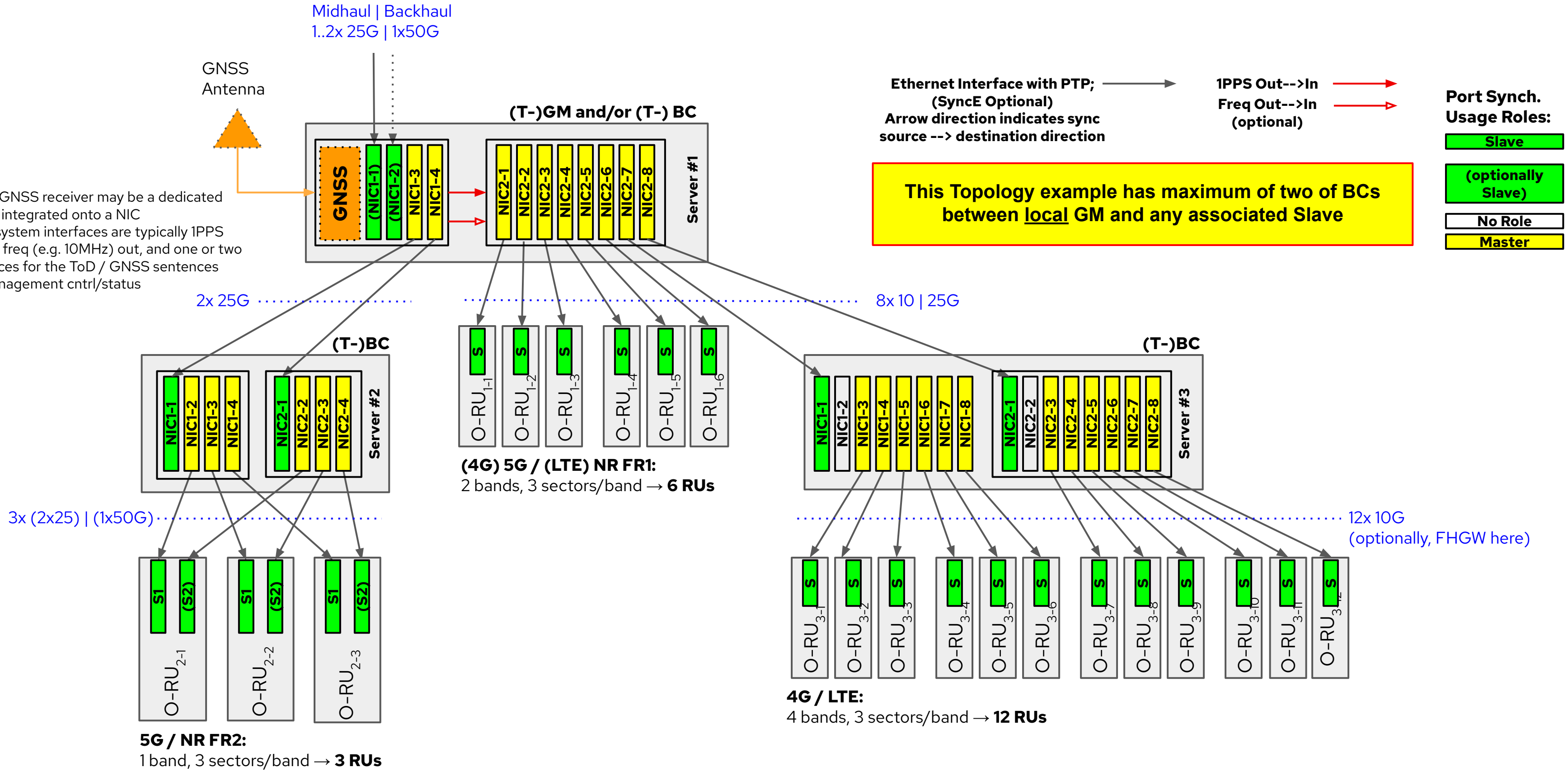
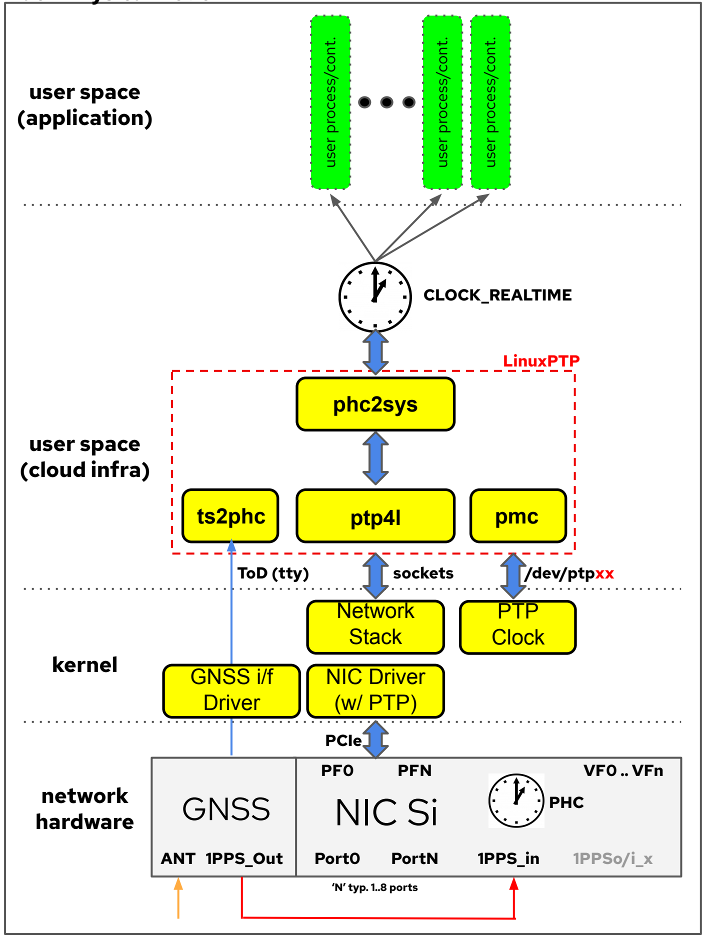
Dense, High-Capacity 21-sector D-RAN site example

Note:
- Integrated GNSS receiver may be a dedicated PCIe card or integrated onto a NIC
- GNSS subsystem interfaces are typically 1PPS out, optional freq (e.g. 10MHz) out, and one or two serial interfaces for the ToD / GNSS sentences output & management cntrl/status



Precision Time Protocol (PTP) in Linux / k8s nodes

Each Physical Node



Key Components of the node PTP implementation

- HW specific synchronization SW support features are implemented in HW device drivers
- HW Clock (PHC) support in NIC Si is required for high accuracy
- **Linuxptp** is an Open Source project implementation of the PTP SW stack for Linux
- **ptp4l** implements Boundary Clock (BC) and Ordinary Clock (OC), it synchronizes PTP hardware clock (PHC) to remote master clock
- ptp4l is very flexible, and can be configured to support specific profiles, assuming that HW & driver supports associated features (e.g. PHC, L3 vs. L2 transport, accuracy targets)
- **phc2sys** synchronizes two or more clocks in the system, typically used to synchronize the system clock from PTP / PHC
- **pmc** - PTP management client; 1588 basic management access for ptp4l
- **ts2phc** synchronizes PHC(s) from external reference signals, such as 1PPS_in and ToD messages - used in certain HW assisted T-BC, and GNSS driven T-GM configurations
- In k8s clusters, synchronization functions are configured and monitored with k8s, and associated general CM, PM and FM event and metrics tools.

And many other Si & HW Partners

G.8275.1 FTS G.8273.2 T-TSC & T-BC Summary

Parameter	Class-A	Class-B	Class-C	(Class-D); Still WIP in ITU-T	Notes
Max. Absolute Time Error; max|TE|	≤ 100 ns	≤ 70 ns	≤ 30 ns	(≤ 15 ns)	Unfiltered measurement, absolute value
Max. Absolute Time Error; max|TE_L|	-	-	-	≤ 5 ns	0.1Hz low-pass filtered, 1000s measurement, absolute value
Max. Constant Time Error; cTE	≤ ±50 ns	≤ ±20 ns	≤ ±10 ns	(≤ ± 4 ns)	Averaged over 1000s
Max. dynamic Time Error, 0.1Hz Low-Pass Filtered; dTE_L (MTIE)	≤ 40 ns		≤ 10 ns	(≤ 3 ns)	Mask, 1000s observation interval constant temp., 10000s for A/B variable temp.
Max. dynamic Time Error, 0.1Hz Low-Pass Filtered; dTE_L (TDEV)	4 ns		2 ns	(≤ 1 ns)	Mask, 1000s observation interval constant temp.
Max. dynamic Time Error, 0.1Hz High Pass Filtered; dTE_H	70 ns p-p		FFS	(15 ns p-p)	Peak-to-peak value, 1000s measurement

Note1: Additional requirements apply for Time Error Tolerance (no direct perf. limits but no alarms / reference switching / holdover entry allowed) & possibly hold-over performance (mostly use / operator case specific)

Note2: Accuracy required is primarily determined by Use Case requirements & number of elements on the synchronization transfer path

An example of T-BC config test result subset (25G, PTP i/f)

Mask results:

All Mask Results	Pass

Mask Sync PDD Result	Pass
Mask Sync CDF Result	Pass
Mask Sync Packet MTIE Result	Pass
Mask Sync Packet TDEV Result	Pass
Mask Sync FPC Result	Pass
Mask Sync FPR Result	Pass
Mask Delay Req PDD Result	Pass
Mask Delay Req CDF Result	Pass
Mask Delay Req Packet MTIE Result	Pass
Mask Delay Req Packet TDEV Result	Pass
Mask Delay Req FPC Result	Pass
Mask Delay Req FPR Result	Pass
Mask 2Way Time Error Result	Pass
Mask 2Way Time Error (Filtered) Result	Pass
Mask 2Way Dynamic MTIE LF Result	Pass
Mask 2Way Dynamic TDEV LF Result	Pass

NOTES:

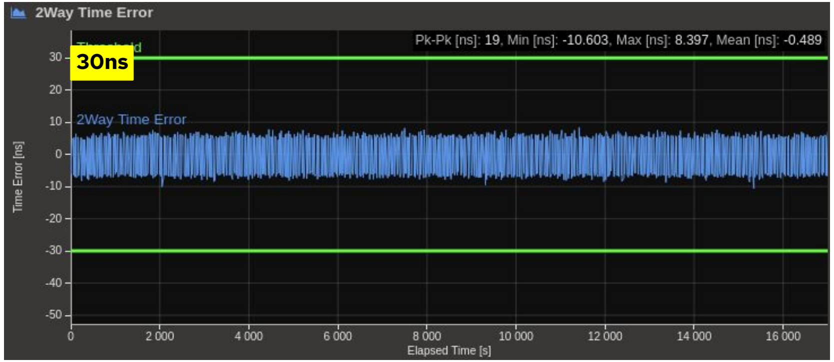
- No SyncE used
- T-TSC slave performance is equivalent or better with same HW
- Slave test perf. Results presented in ITSF'20

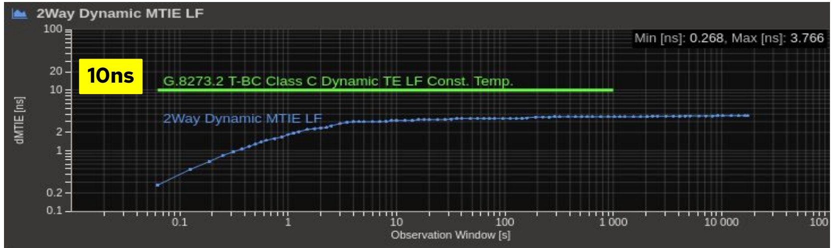
2Way Time Error **30ns** PASS

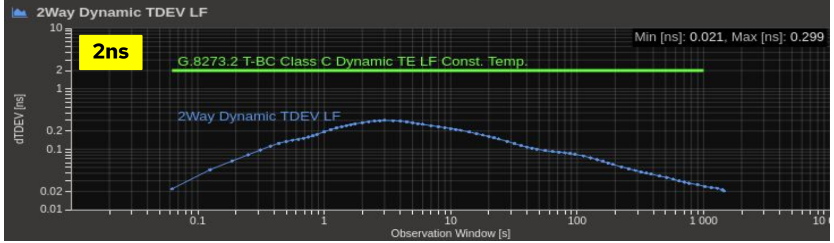
Metric Statistics	
Pk-Pk [ns]	19
Mean [ns]	-0.489
Min [ns]	-10.603
Max [ns]	8.397
Max-Min [ns]	19

10ns

Metric Statistics	
Constant Time Error [ns]	-0.485
Min [ns]	-0.639
Max [ns]	-0.44
Max-Min [ns]	0.199







LinuxPTP is up to the task:

- TE Generation perf. to G.8273.2 Class C
- Good enough for many RAN use cases
- Results are highly dependent on the HW capabilities and specific configurations
- Will re-test w/ SyncE when HW+SW available

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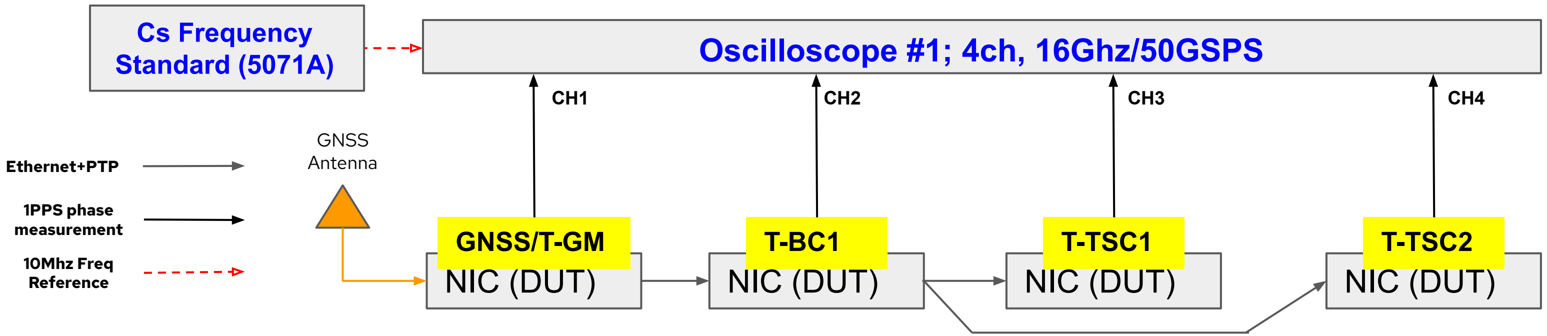
D-RAN site sync chain, physical test setup

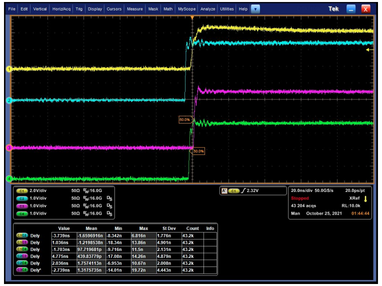


Jitter, Noise and Eye Diagram Analysis Tools

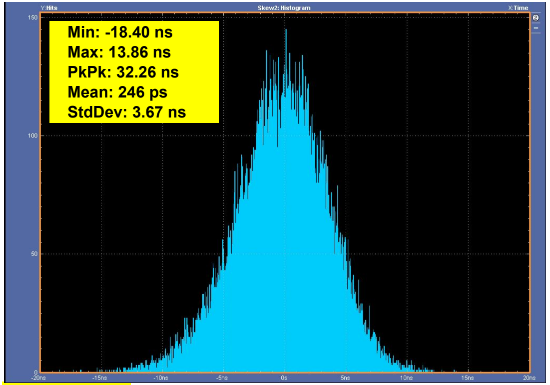
Options | View: Details | Expand

Select | Configure | Results | Plots

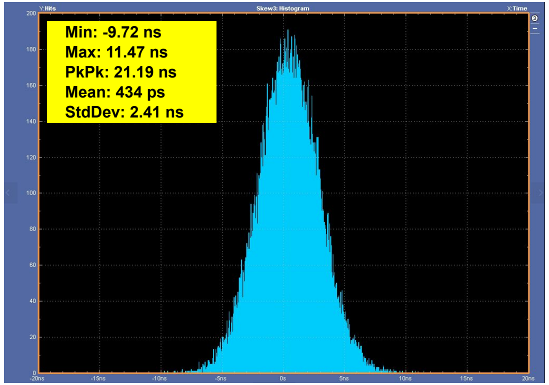
Description	Mean	Std Dev	Max	Min	p-p	Population	Max-cc	Min-cc
Skew1, Ch1, Ch2	-673.62ps	1.8573ns	6.7125ns	-8.4145ns	15.127ns	43200	T-GM → T-BC	
Skew2, Ch1, Ch3	-246.20ps	3.6725ns	13.863ns	-18.400ns	32.263ns	43200	T-GM → T-TSC1	
Skew3, Ch1, Ch4	434.05ps	2.4052ns	11.470ns	-9.7152ns	21.185ns	43200	T-GM → T-TSC2	
Skew4, Ch2, Ch3	427.82ps	3.4608ns	14.252ns	-17.078ns	31.331ns	43200	T-BC → T-TSC2	
Skew5, Ch2, Ch4	1.1084ns	2.0701ns	10.671ns	-6.9490ns	17.620ns	43200	T-BC → T-TSC2	
Skew6, Ch3, Ch4	680.61ps	3.5182ns	19.718ns	-14.005ns	33.723ns	43200	T-TSC1 → T-TSC2	



D-RAN sync. chain performance summary; 12hrs

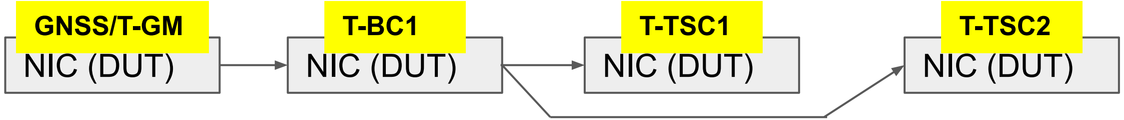


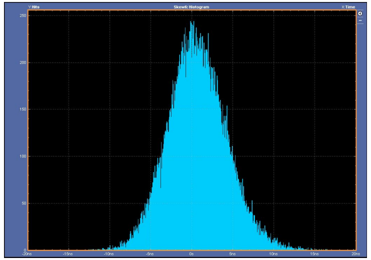
GM→SC1



GM→SC2

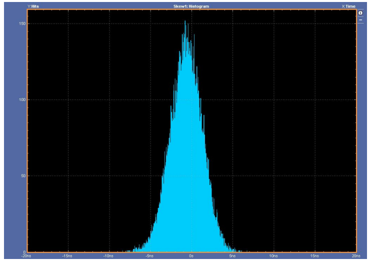
Notes:
* Timescales for all histograms are -20/+20 ns
* Scope sample rate 50Ghz at 4ch, 20ps/pt
* 43200 points (1PPS) / 12hrs test
* GNSS fed from Antenna, not GNSS Simulator





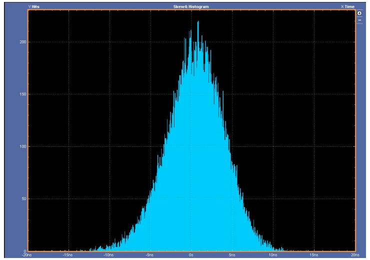
SC1→SC2

Min: -14.00 ns
Max: 19.72 ns
PkPk: 33.72 ns
Mean: 681 ps
StdDev: 3.52 ns



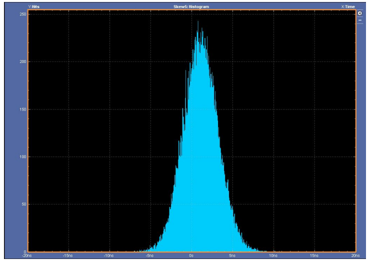
GM→BC

Min: -8.41 ns
Max: 6.71 ns
PkPk: 15.13 ns
Mean: 674 ps
StdDev: 1.86 ns



BC→SC1

Min: -17.08 ns
Max: 14.25 ns
PkPk: 31.31 ns
Mean: 428 ps
StdDev: 3.46 ns



BC→SC2

Min: -6.95 ns
Max: 10.67 ns
PkPk: 17.62 ns
Mean: 1.11 ns
StdDev: 2.07 ns

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