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Sync trends across the Industries

November 2025

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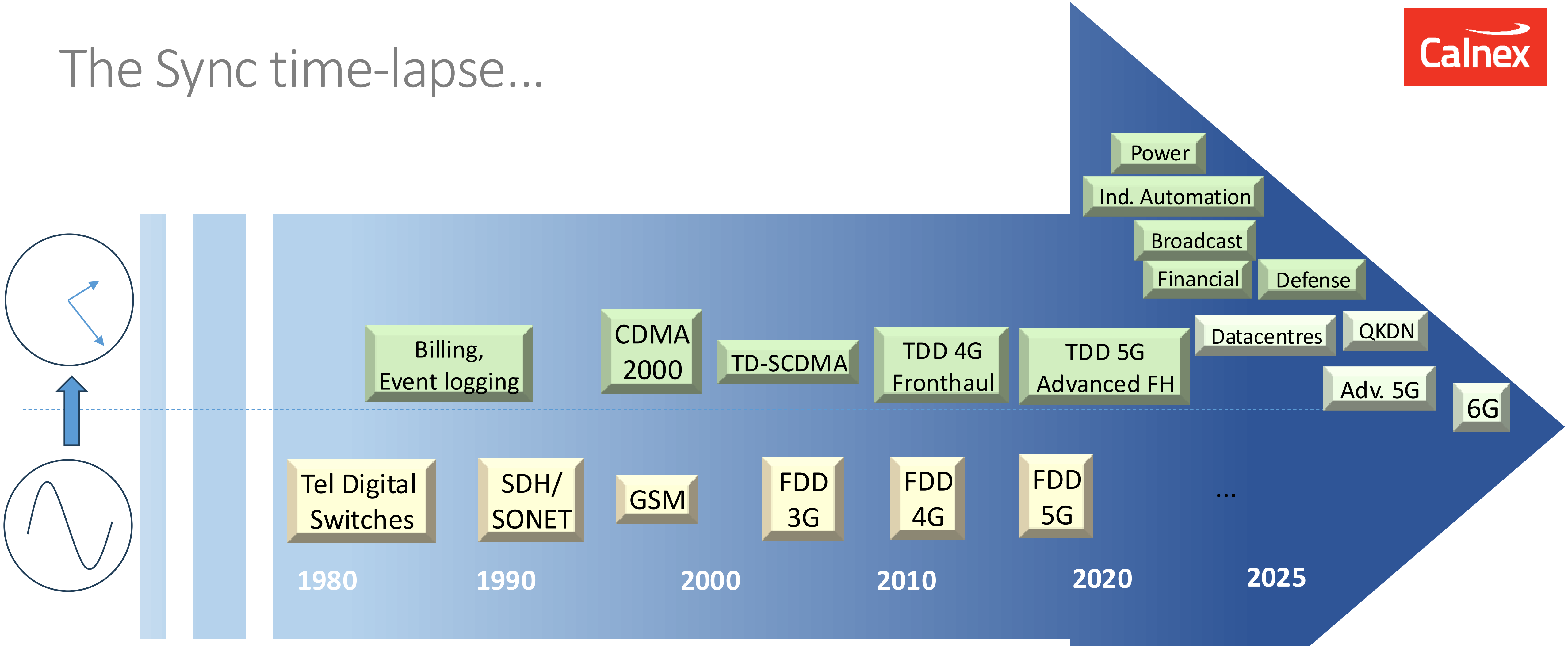
Summary

- Increasing Time/Sync Deployments
- Focus on subsystems
- Resilience is non-negotiable
- Towards 6G

- *Conclusions*

Time and Sync are deployed deeper and wider

The Sync time-lapse...



PREVIOUSLY: Telco needs drive generational changes in Time/Sync approaches

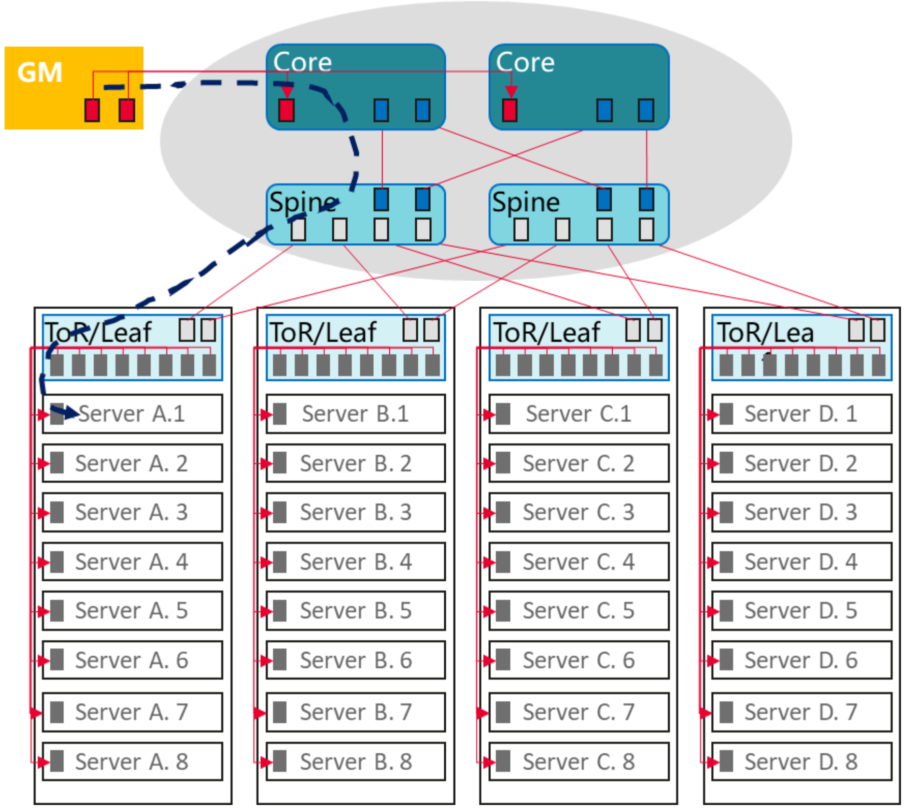
NOW: Accurate time and sync deployed in many sectors

2027: Transport technologies become increasingly relevant, e.g. NTN

Synchronization in data centres

Enhanced Sync enables:

- Consistent operation between distributed data centres, minimizing latency.
- Event logging; Diagnosis and analysis of problems
- Power consumption reduction
- Improvements of the overall performance of Artificial Intelligence and Machine Learning (AI/ML).
- Also, supports regulatory requirements (financial)



From ITU-T G Suppl.92

Sync solutions have been implemented by major data centre operators
Ongoing efforts to provide standardized solutions

ITU-T Supplement on synchronization in Datacentres

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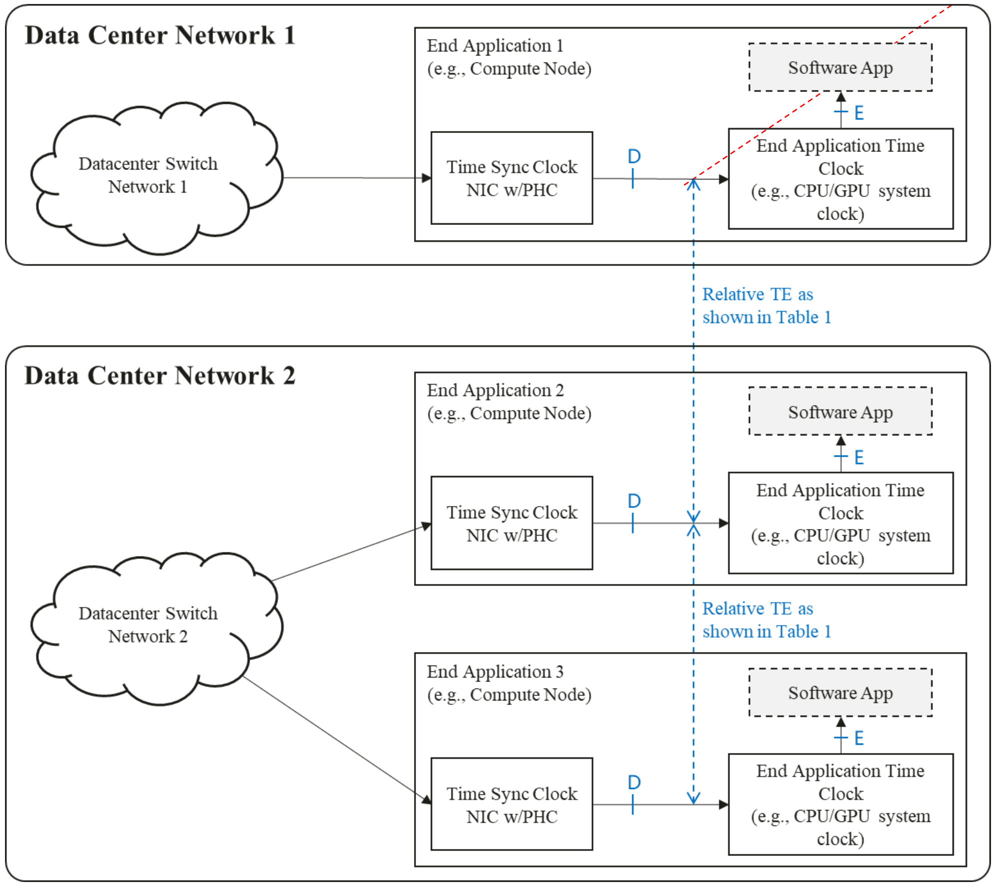
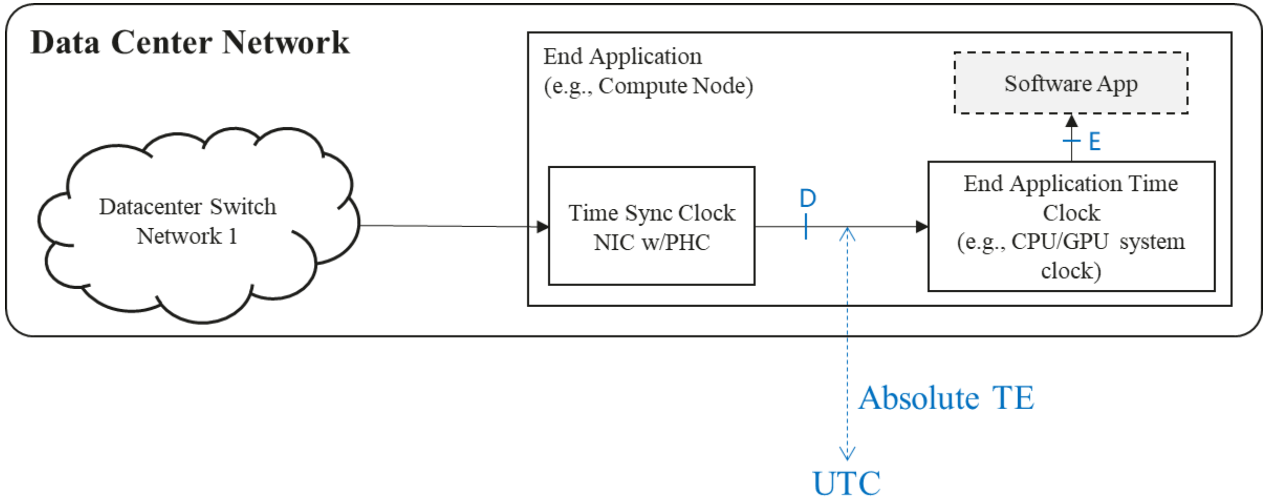


Table 1 - From draft ITU-T G Suppl.DCSync (June 2025)

Accuracy Class at Time Sync Clock	rTE between Time Sync Clocks	Typical applications
1	5µsec	Distributed databases, applications profiling
2	1µsec	High-Frequency Telemetry, Multi-node performance analysis tools
3	200nsec	Congestion control based on one way delay Time synchronized collective communication

The Absolute TE req't at Time Sync Clock output is half the rTE req't shown in Table 1

ITU-T Supplement on synchronization in Datacentres

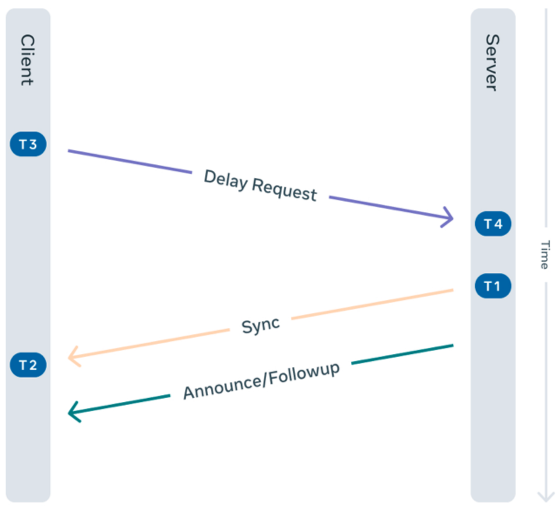


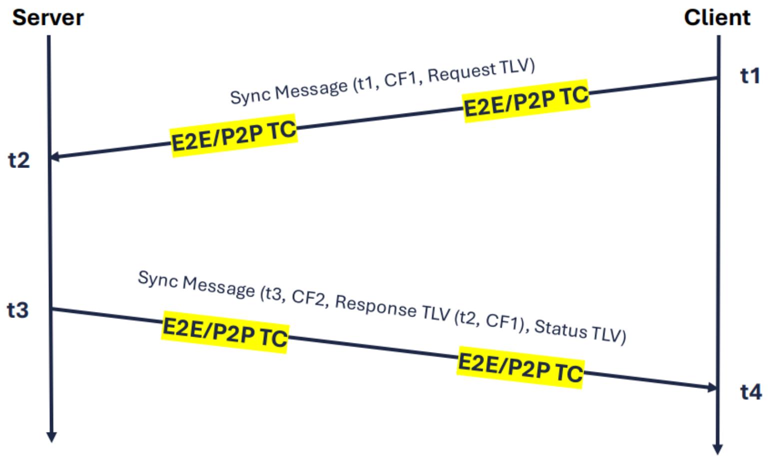
Accuracy Class: End Application Time Clock vs. Time Sync Clock	TE req's: End Application Time Clock vs. Time Sync Clock (from ref. point D to E)	Implementation Notes
A	2µsec	Typically, without PTM
B	200nsec	Typically, with PTM
C	50ns	Typically, physical clock signal (e.g. PPS OUT of Time Sync Clock, IN to End Application Time Clocks)

PTP-based Solutions for datacentres

- Data centres may need to use different PTP profiles to address different use cases and network topologies.
  - PTP based on Ethernet local link multicast communication
    - ITU-T G.8275.1 profile can be used as a baseline.
  - PTP based on IP unicast communication
    - IEEE IM/ST/PNCS Working Group currently developing IEEE P1588.1, a client-server PTP (CSPTP) based on IP unicast communication.
    - Simple PTP as an alternative until P1588.1 is released
- To ensure the highest accuracy of time delivery, the PTP profile for data centres should support full PTP timing support from the network.
  - In case of unicast, full timing support with transparent clocks may still generate some error (but limited by the longest distance, e.g., could be controlled within 10 us)

SPTP exchange





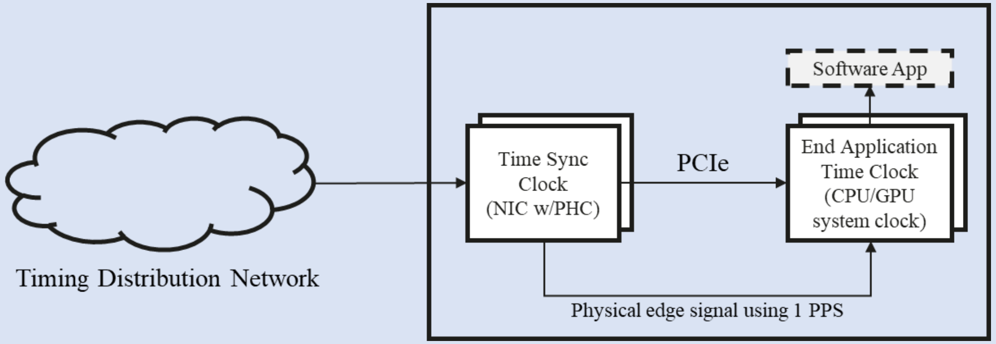
Subsystem Timing becomes a significant factor

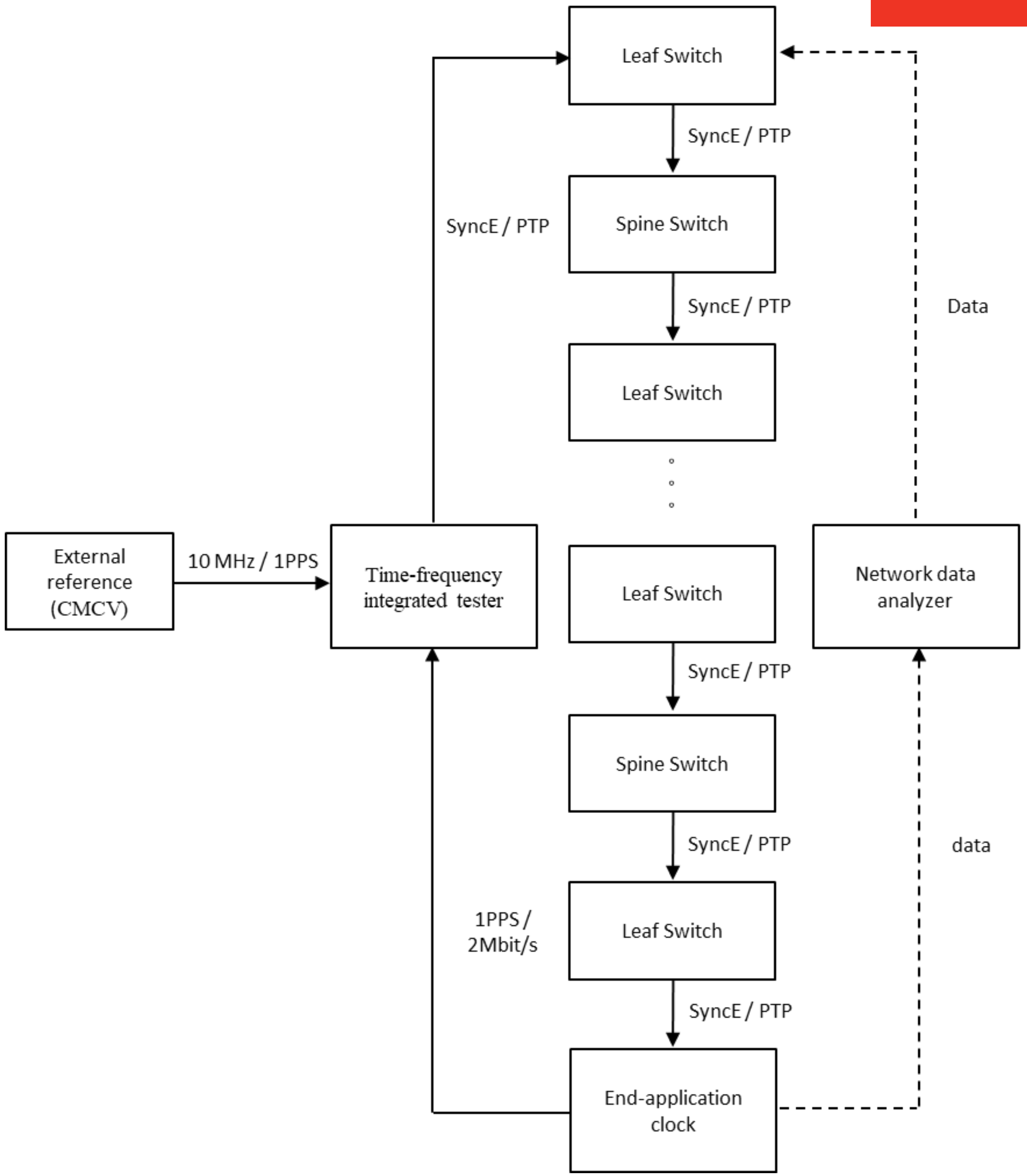
Sync Verification points for Data centres

Both network testing and lab testing required

New concepts for testing the CPU/GPU system clock performance

- PTM (Precision Time Measurement)
- TGPIO* (Time-Aware GPIO)





*Pin clocked by timekeeping hardware

From WD13-72 (Q13/15 Paris , June 2025)

PTM (Precision Time Measurement)

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PREVIOUSLY:

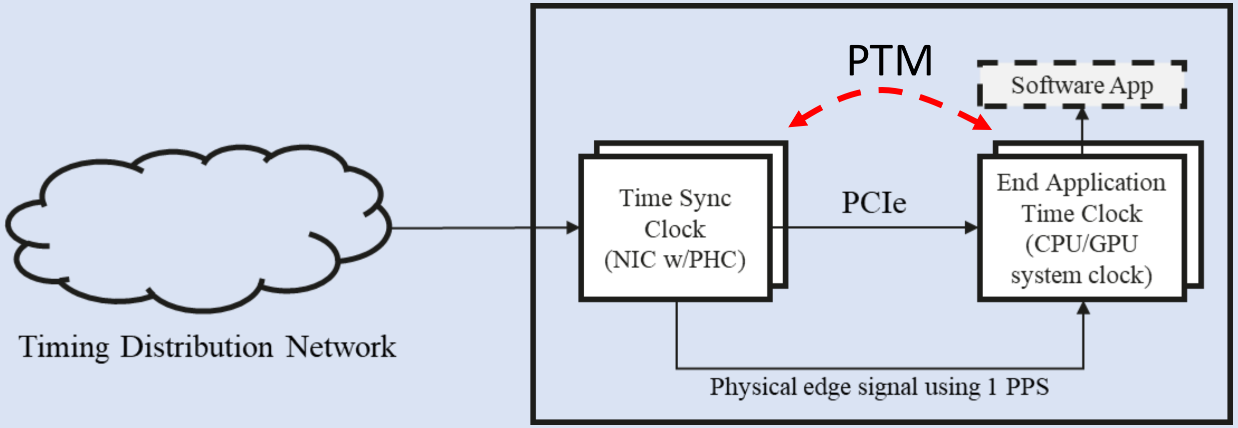
Hardware protocol used to sync HW elements using Transaction Layer Protocol (TLP) messages over PCIe bus

NOW:

Test and verification of PTM performance will allow the next level of deployment accuracy

2027:

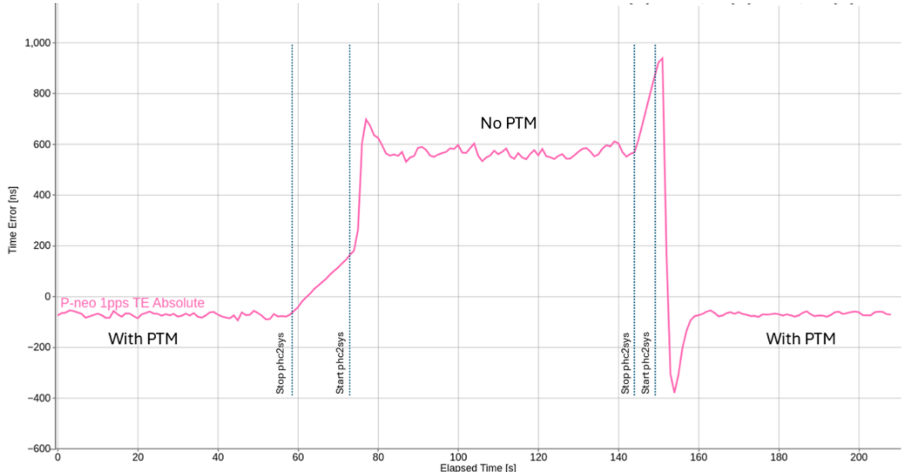
SW applications run under the same strict timing boundaries currently limited to the network layer.



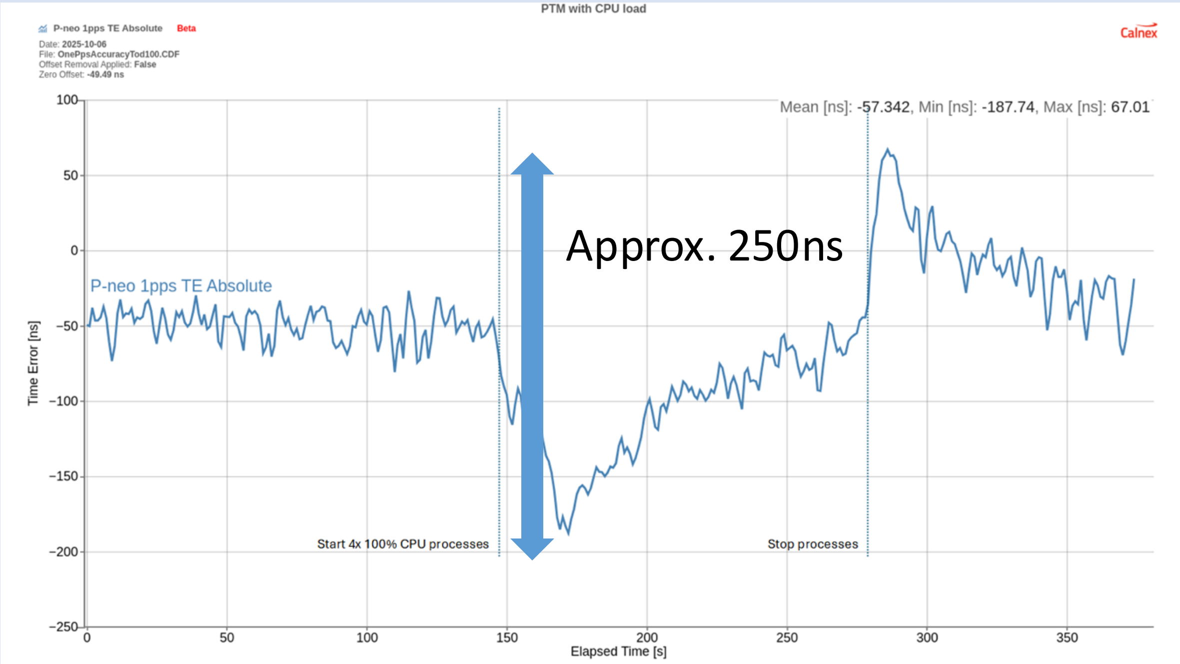
Example data:

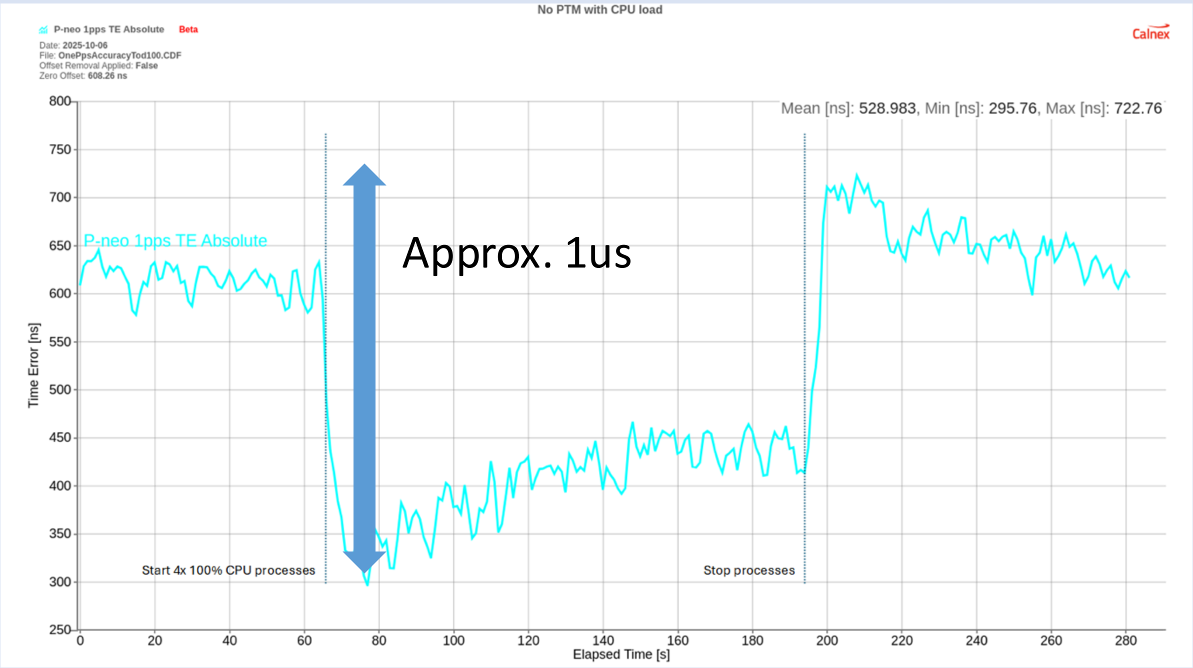
Time Error on the NIC PPS output, using the timecard as a clock/PPS reference

PTM to enhance accuracy



Impact of Load: with and without PTM





With PTM:
phc2sys *is* impacted by changes of CPU load but manages to go back around its baseline when the CPU load is constant.

Without PTM:
Impact on time error is higher.
Even with constant CPU load, unable to recover to base line.

High Speed Optical Interfaces

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PREVIOUSLY*:

With the increase of data rates, new optical interfaces increasingly used, e.g.,

- Coherent optics
- PAM4

NOW*:

Work ongoing to minimize the impact on performance:

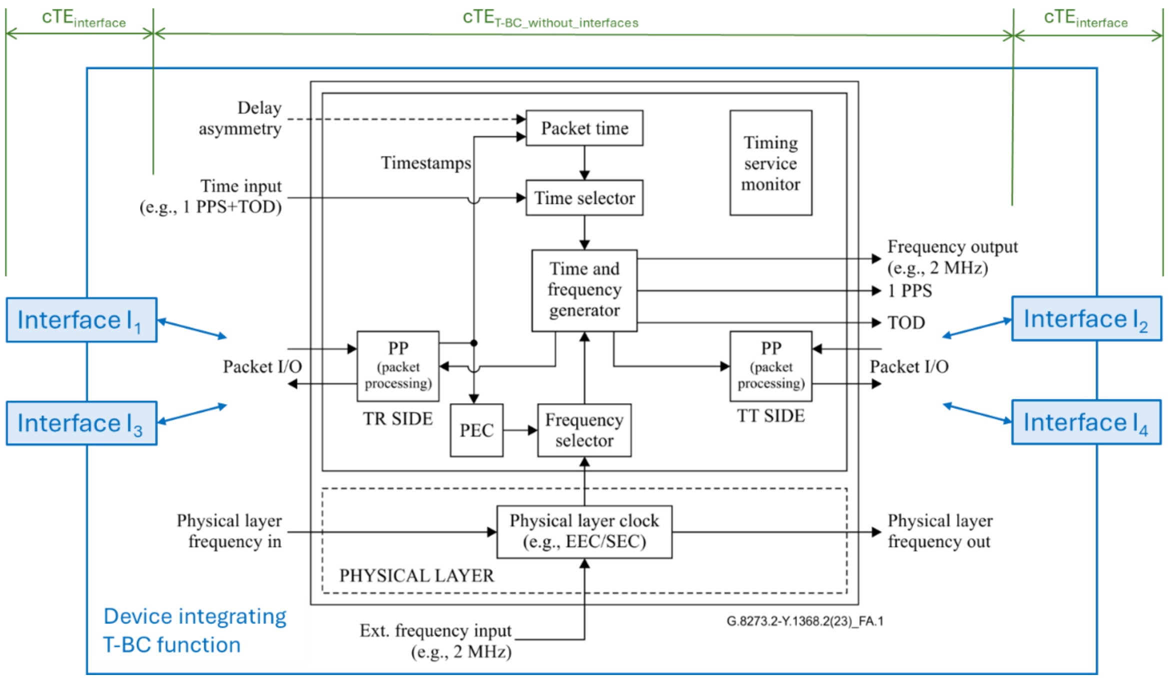
- classify optical pluggables as a % of T-BC cTE
  - e.g., **class C.10** = **10%** of the cTE for a **class C** clock
- Asymmetry compensation: store known Tx and Rx delay data in the optical pluggables

2027:

Widespread **and standard** use of the above techniques

New interfaces to increase performance:

- LPO (Linear Pluggable Optic)..?



***More detailed explanations are available via online resources, inc. previous ITSF papers**

Timing performance with LPO (studies ongoing)

Key points:

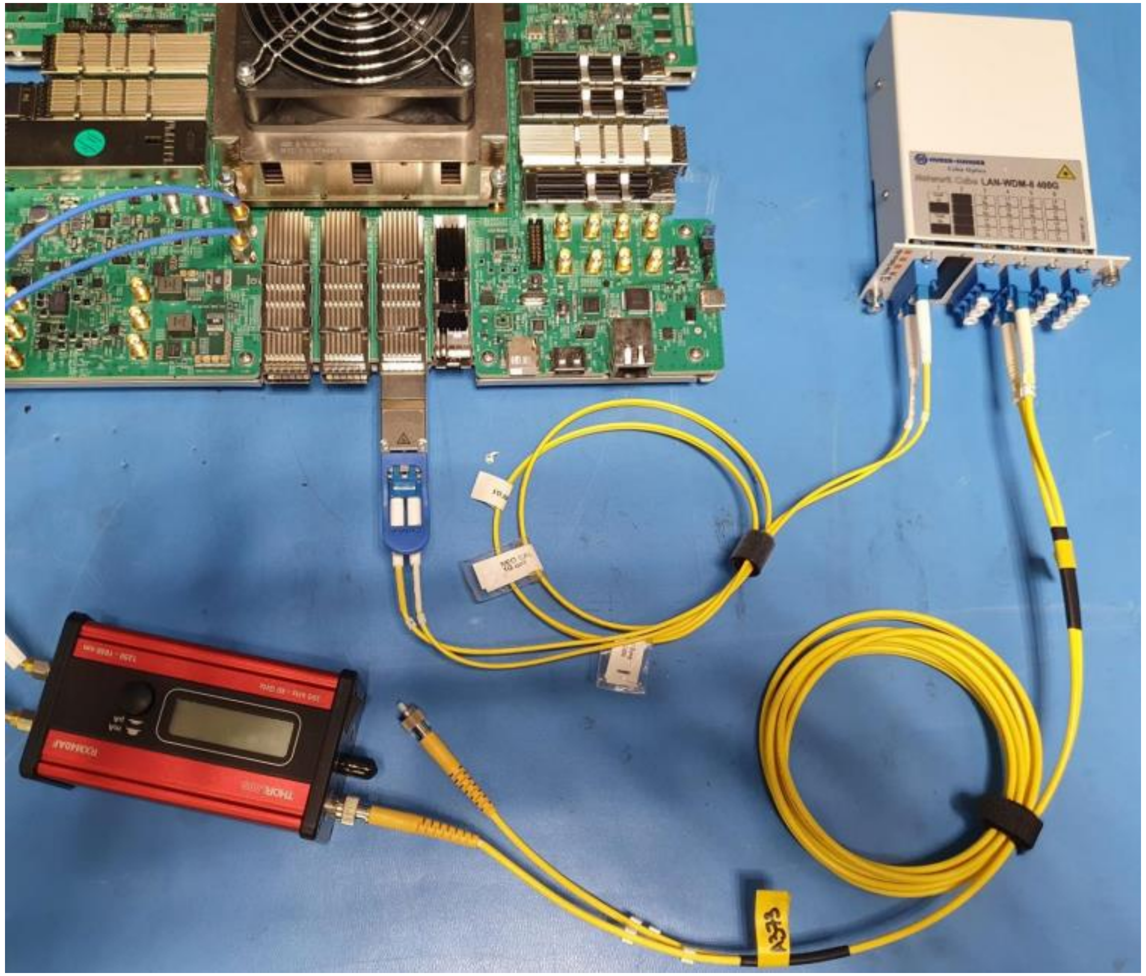
Pros:

- Tx Latency = Rx Latency = 0.5ns
- Minimal latency variation

Cons:

Very High Bit Error rates (more than can be corrected by FEC) unless Host device contains DSP

Example testbed topology:



The need for resiliency continues to increase

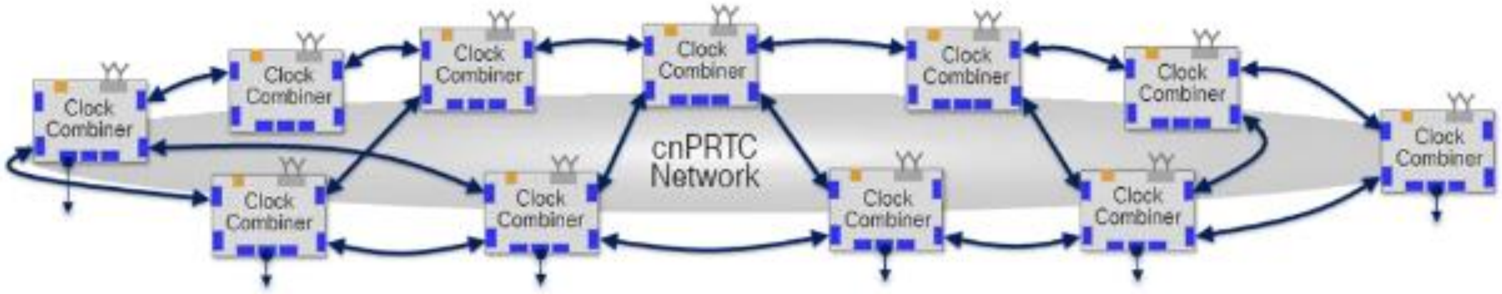
The need to increase resiliency

- Synchronization is essential for key infrastructures like telecom, power, transport, and finance, with serious risks if disrupted.
- GNSS is a primary timing source but is vulnerable to errors, interference, spoofing, and jamming.
- Other timing threats exist, such as at the packet layer.
- These issues have been discussed extensively, leading to efforts like **IEEE P1952** to improve timing resilience.

The need for redundancy and robustness in sync in telecom has always been a major requirement. Now even more so, and across multiple applications

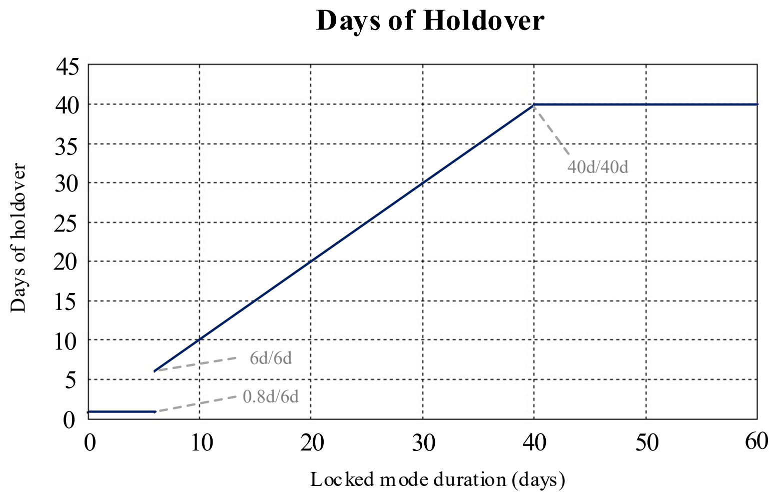
How to increase resilience in Sync?

- **Architecture**: Redundant PRTC / Grandmaster and Redundant paths
- **Geographical distribution** of GNSS Receivers; use of multiple constellations (GPS, Galileo, etc.)
- Increased **Holdover**: via physical layer support (SyncE), or enhanced PRTCs (ePRTC, cnPRTC)
- Increased **monitoring** solutions (E.g., G.8275 Annex F)
- **Protection** at timing protocol (incl. PTP over MACSec)



cnPRTC (Coherent PRTC):

PRTCs network at the highest core or regional network level to maintain network-wide ePRTC time accuracy, even during periods of GNSS loss

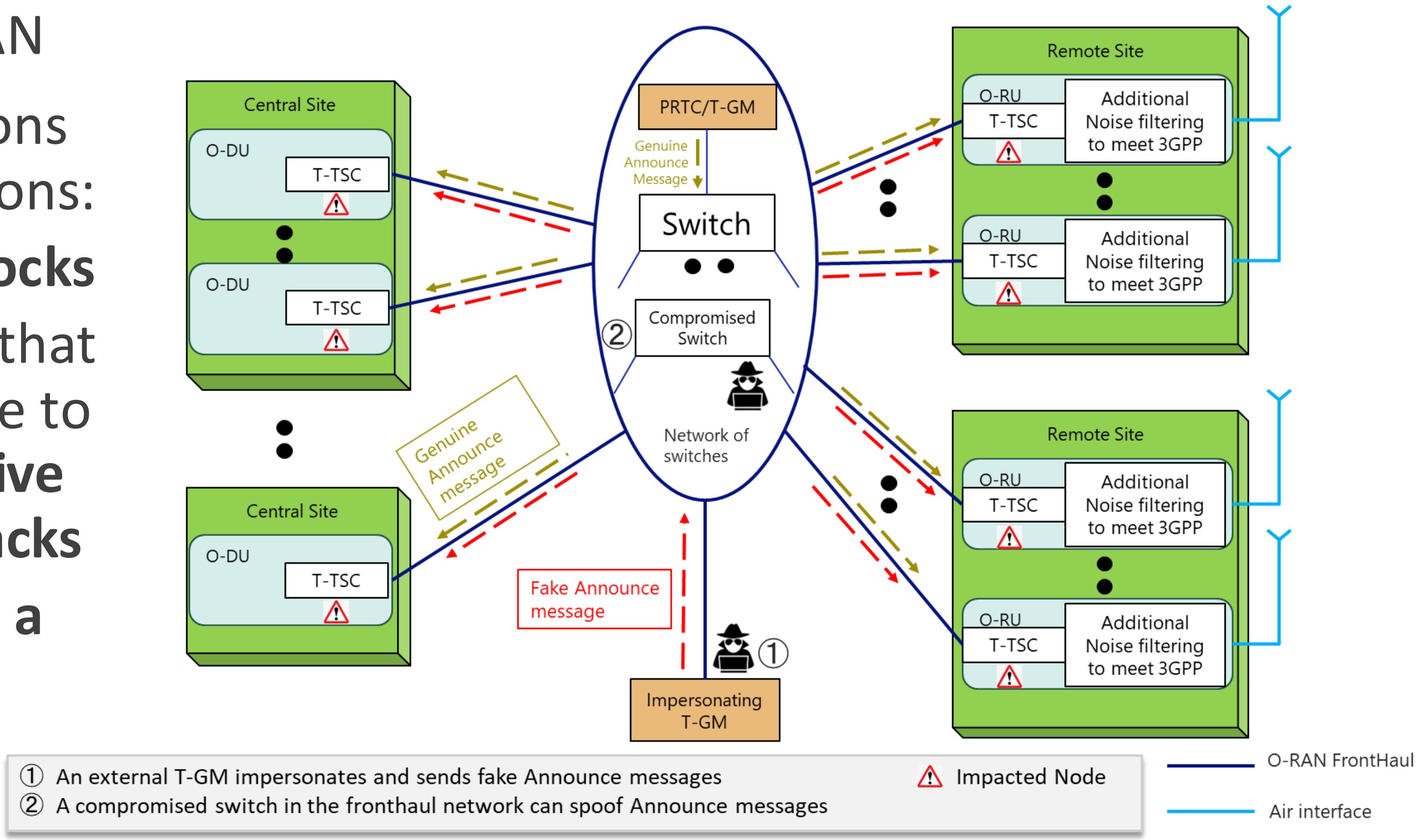


Enhanced PRTC specified in G.8272.1

[ITU News: New ITU clock concept for more resilient synchronization networks - ITU]

Security scenarios for PTP

- Addressed in both ITU-T and O-RAN
- Requirements and test specifications in O-RAN, with reference to solutions:
  - prevent **spoofing of master clocks**
  - protect against **MITM attacks** that degrade the clock accuracy due to **packet delay attacks** or **selective interception and removal attacks**
  - protect for **DoS Attack against a timeTransmitter**



MACSec vs. 1588 TLV: O-RAN with normative requirements

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- O-RAN.WG11.TS.SRCS.0-R004-v13.00, Security Requirements and Controls Specifications:
  - **SEC-CTL-OFSP-4**: The Open Fronthaul Synchronization architecture **may** support **MACsec** for securing PTP messages. (…*MACsec as a mechanism to provide source authentication, message integrity, and replay attack protection for S-plane*.)
  - **SEC-CTL-OFSP-3:** The Open Fronthaul Synchronization architecture **may** support IEEE 1588-2019 [27] Authentication TLV for securing PTP ANNOUNCE messages. (…*IEEE 1588-2019 AUTHENTICATION TLV (clause 16.14) to provide source authentication, message integrity, and replay attack protection for PTP ANNOUNCE messages within a PTP domain*.)

For event messages, care must be taken to make sure that time stamping accuracy is not decreased when updating the **AUTHENTICATION TLV. This can be especially demanding for 1-step clocks.** Another aspect to consider is that **PTP messages are sent in clear text making them at risk of man-in-the-middle attacks delaying PTP event messages in a manner that impacts the timing accuracy**. It should also be noted that the **PTP integrated security mechanism only addresses PTP security, not any other L2 protocol**. This will impact the security posture if the goal is to be consistent with a zero trust architecture (ZTA).

MACsec provides security using end-to-end and hop-by-hop modes on Ethernet links. …However, PTP over MACsec implementation has its challenge related to timestamping of PTP event messages. …. This can be more demanding for 1-step clocks than 2-step clocks. … **A benefit of using MACsec is that all ethernet frames can be encrypted to provide confidentiality and integrity protection, decreasing risk of MitM attacks**.

MACsec is being considered to provide confidentiality and integrity protection on the Open Fronthaul S-Plane. Hop-by-hop **MACsec has additional benefits** protecting all traffic on the LAN segment, not only S-Plane.

Towards 6G and beyond

Non-Terrestrial Networks (NTN)

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PREVIOUSLY:

- Non-Terrestrial Networks are part of 3GPP specifications for 5G and will be part of 6G.
- Initial work done in Transparent mode, NTN Network will be used to bounce the signal.

NOW:

- (Rel19 - 20) will include NTN with a regenerative - or packet-processing - payload, in which a **complete gNB is placed on the satellite**
- LEO satellites are used for 5G. Current releases focus on FDD with loose time sync requirements
- The latency is too large for timing signals to be sent, unless they are using Transparent mode.

2027:

- Solution: GNSS on the cell phone . The satellites will also have GNSS capability, hence impacts from latency can be controlled.

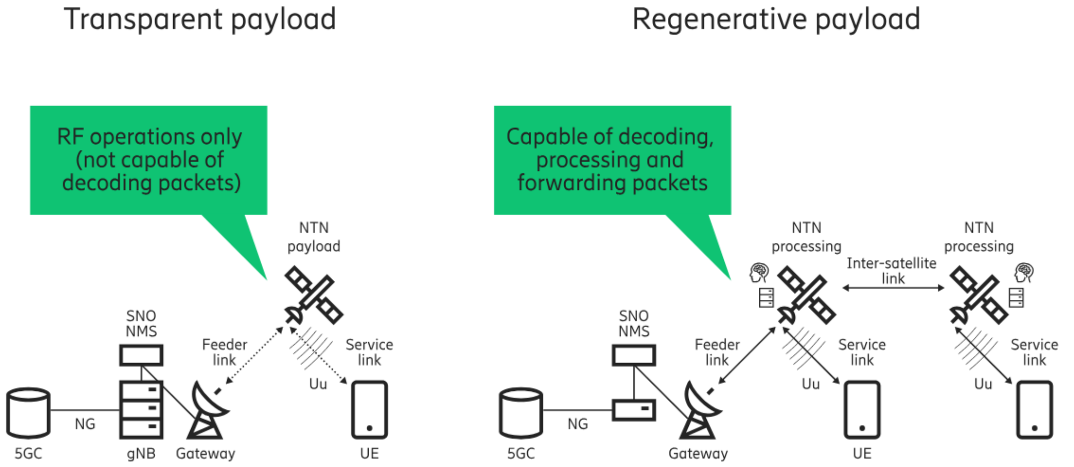
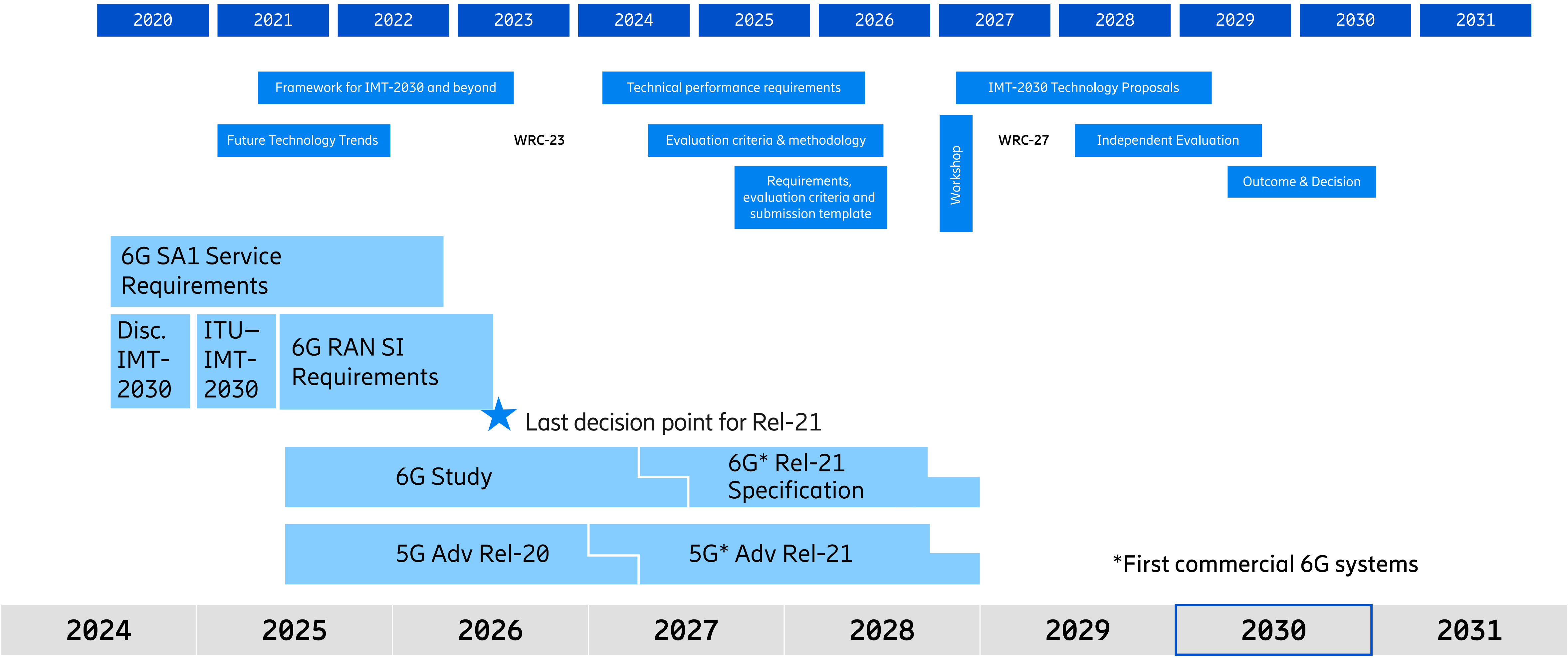


Figure from Ericsson blog:

[5G Non-Terrestrial Networks in 3GPP Rel-19 - Ericsson]

Future: Mobile towards 6G



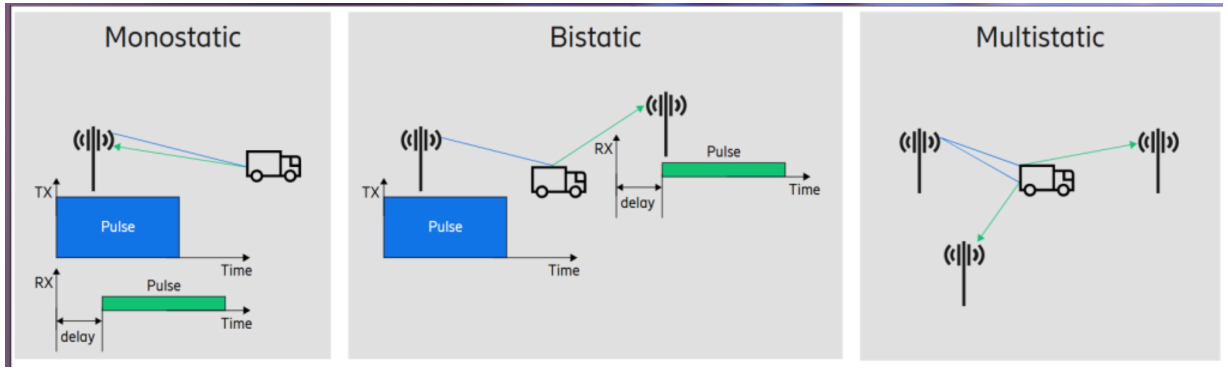
* Indicative timeline Ericsson view

ITU designates 6G as IMT-2030, with 5G referred to as IMT-2020, 3G as IMT-2000, and 4G as IMT Advanced.

[6G standardization timeline and principles - Ericsson]

Future: Expectations for sync in 6G

- Higher focus on coordination between base stations:
  - Coherent Joint transmission (C-JT)
  - Integrated sensing and Communication (ISAC)
  - Positioning (sub-meter)
- Use of Higher order modulation, leading to need for higher stability
- Key requirements: relative time and frequency stability
- Increased importance of timing delivery over the radio



ISAC scenarios

From Synchronization in 2030 perspective
(ITU Workshop on "Future Optical Networks for IMT2030, AI, broadband and more")

Forward looking: Sync in Quantum Key Distribution Network (QKDN)

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- ITU-T SG13 is now releasing Recommendations and Supplements on Quantum Key Distribution including sync implications
  - e.g. Y.Sup89 “Analysis of time synchronization in Quantum Key Distribution Networks”.
- ITU-T JCA-QKDN (Join Coordination Activity) coordinates standardization work on quantum key distribution networks (QKDNs). Related work:

Y.Sup80	**Use cases of quantum Key Distribution Networks**
ITU-T Y.3825	**Integration of quantum key distribution network and time-sensitive network - framework**
ITU-T Y.Sup69	**Analysis of Synchronization in Quantum Key Distribution Networks**

- Use cases for **Quantum time synchronization:**
  - Quantum time sync in telecoms
  - Secure quantum clock synchronization
  - A quantum network of entangled clocks
- Time sync needs and solutions to support QKDN:
  - e.g. absolute time distribution in ms, **point-to-point rTE sub-ns**

Summary

- Synchronization continues to be a fundamental function as networks and applications evolve
- We expect increasing focus in the next 2 years on:
  - Telecom supporting connected applications: Industrial Automation, Data centres, etc.
  - New interfaces carrying timing
  - Increased resiliency (GNSS protection, PTP security, sync monitoring, holdover, HA links from Metrology labs, etc.)
  - Emerging needs in mobile networks: e.g. 5G Advanced, NTN integration
- We won't stop there!:
  - 6G (local timing / higher stability); Sync over radio
  - New applications with particularly stringent timing requirements, e.g. quantum key distribution (QKD)

Deployments are becoming increasingly varied. The impact of bad sync can increasingly result in disruptions in critical infrastructure:
Verification of the various technologies and scenarios remains key to prevent issues

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