DEUTSCHE TELEKOM
RESILIENCE FOR TIMING & SYNCHRONISATION NETWORKS

ITSF2021, Helmut Imlau, 4.11.2021

RESILIENCE FOR TIMING & SYNCHRONISATION NETWORKS
Agenda.

1. Requirements: Accuracy & stability, Cost efficiency, Resilience

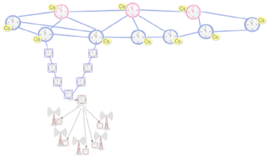
2. GNSS for telecommunication synchronization networks and related risks

3. The toolbox: ITU-T specified primary reference time clock functions with GNSS usage
   (1) GNSS Receiver … … … … … … … … … … … … … PRTC ITU-T G.8272
   (2) Additional source: Remote cesium clock via network … … PRTC ITU-T G.8272
   (3) Additional source: Local cesium clocks … … … … … … ePRTC ITU-T G.8272.1
   (4) Meshed clock combiner architecture … … … …. … … cnPRTC ITU-T G.8275 / G.8272.2

   PRTC = Primary Reference Time Clock, ePRTC = enhanced PRTC, cnPRTC = coherent network PRTC

4. Resilience level: New IEEE project P1952 and 'Resilient PNT Conformance Framework (CF)'
   Ideas for mapping between ITU-T primary clock concepts and CF resilience level 1 … 4

5. Example for synchronization network architecture at resilience level 4



Summary

RESILIENCE FOR TIMING & SYNCHRONISATION NETWORKS

1 - Requirements for synchronization networks

Accuracy and stability:

- Currently, ≤1.500 ns (UTC) are needed for mobile Time Division Duplex (TDD) at base station air interface.
- 3GPP has Time Alignment Error (TAE) specifications, e. g. TAE ≤ 260ns (peak-peak) for inter-site carrier aggregation. Depending on specific architecture, a UTC related maximum time error (max|TE|) ≤ 130ns could apply.
- ITU-T specifies related clock and network requirements including accuracy and stability as MTIE and TDEV.

MTIE – Maximum Time Interval Error, TDEV – Time Deviation

Cost efficiency:

- Technology already known from scientific & UTC(k) time lab community, is going to be used for telecommunication on 'industrial' greater (mass) market product level, with a related lower pricing.
  Examples: clock combiner (atomic clocks with GNSS) as ITU-T enhanced Primary Reference Time Clock (ePRTC), high-accuracy time transfer methods, or multi-band GNSS.

Resilience (scope of this talk):

- Importance: Phase/time synchronization is basic for spectrum efficiency and for services to be provided, e. g. a TDD base station out of specified performance ➔ has to go out of service, in order not to interfere other.
- To overcome GNSS problems or any interference problems (e. g. by jamming) and spoofing issues
  ➔ Resilient network architecture with strongly limited GNSS usage is recommended.

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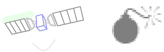
2 - GNSS for synchronization networks



- GNSS is very often used for mobile base station and network synchronization.
- GNSS based technology can fulfill all timing and synchronization performance requirements, examples are: single-band (PRTC-A) $\leq$ 100ns, multi-band (PRTC-B) $\leq$ 40ns acc. to ITU-T G.8272, ePRTC $\leq$ 30ns acc. G.8272.1.

PRTC = Primary Reference Time Clock, ePRTC = enhanced PRTC

- GNSS time is technically UTC based, e. g. GPS system time is related to UTC(USNO), Galileo system time is related to 4 European UTC(k) labs.
- GNSS usage need a strong risk management to guarantee 24/7 operation e. g. due to following risks:

- Local risks:
  (a) Local antennas with internal amplifier on top of building, may long cabling, any repair (3rd party) needs time,
  (b) intentional interference: Jammer *), e. g. for manipulation of fleet tracking or games (Pokémon),
  (c) non-intentional interference: shared radio spectrum (very low GNSS signal power, others often with much more),
  (b) spoofing, (c) meaconing (e. g. GNSS repeater is wrong **) or mis-used)
- Regional risks: region-wide degradation due to political of military conflicts ***)
- Global risks: GNSS system or satellite failures, or space weather due to sun activity ****)

*) Airport Newark Liberty International, U. S. : Motorway close to airport, Trucker with jammer, 2011
**) Airport Hannover, Germany, 2010: Defect GPS repeater
***) Numerous reports from Finland and Black Sea
****) Growing probability of an new "Carrington event"

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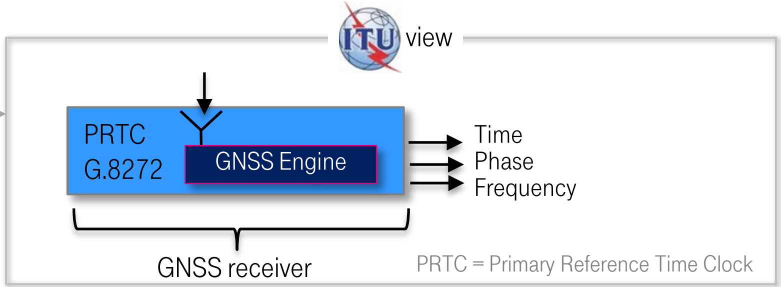
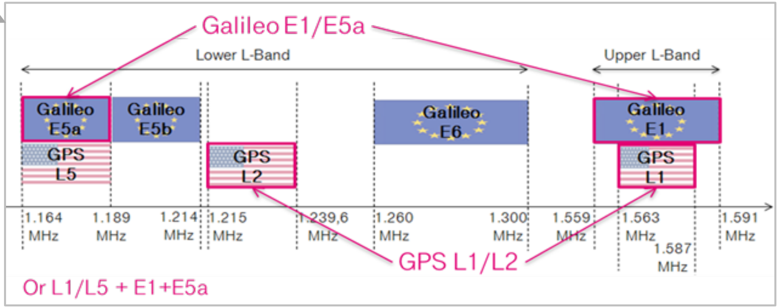
3 - Toolbox (1): GNSS Receiver ➔ Primary Reference Time Clock (G.8272)

Technology view:

- Multi-constellation, e. g. GPS and Galileo
- Multi-band e. g. L1/E1 (higher band around 1,5GHz) combined with L2/E5 (lower band around 1,2GHz)
- Navigation message authentication (NMA) (e. g. as planned for GPS and Galileo OS-NMA or PRS)
- Improved antenna technology, e. g. choke-ring antennas





Methods above are strongly recommended, but ...

- Cannot fully overcome many GNSS antenna risks, interference, spoofing and space weather risks.

Performance during threat (e. g. broad-band jamming or antenna defect):

- After limited hold-over time, depending on internal oscillator ➔ output must be quelched, system is off-line
- After threat: system will come back with original performance

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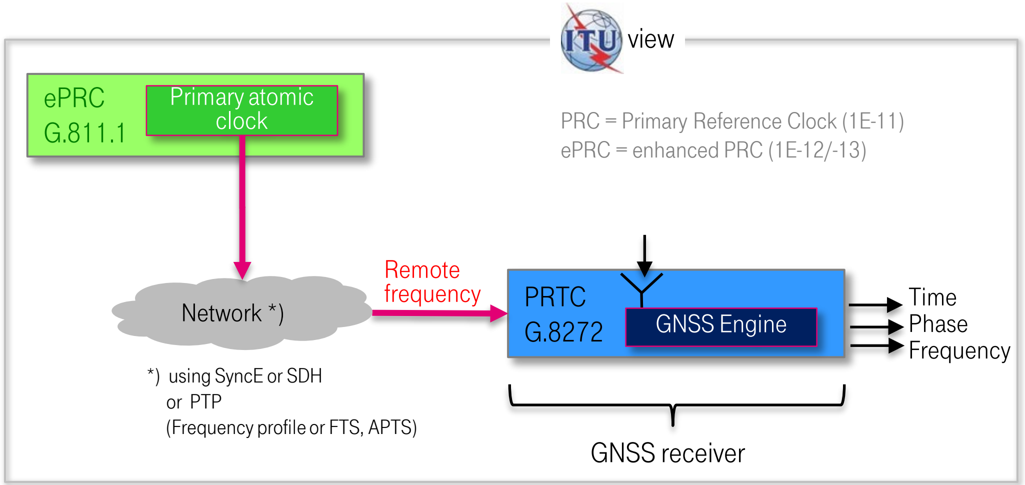
3 - Toolbox (2): PRTC + Additional source: Remote cesium clock via network

Technology view:

- To combine local GNSS receiver with stable external frequency from remote location, via a frequency synchronization network.
- Allows frequency measurements during locked mode & plausibility checks to detect threats.
- Primary remote frequency source could be UTC traceable.
- Providing the 'ticking' for the clock like a balance wheel if GNSS fails:
  ➔ time hold-over based on external frequency.



FTS – Full Timing Support from network, APTS – Assisted Partial Timing Support

Performance during threat (e. g. jamming):

- Time hold-over with limited output performance, mainly depending on stability of network, used for frequency transfer.

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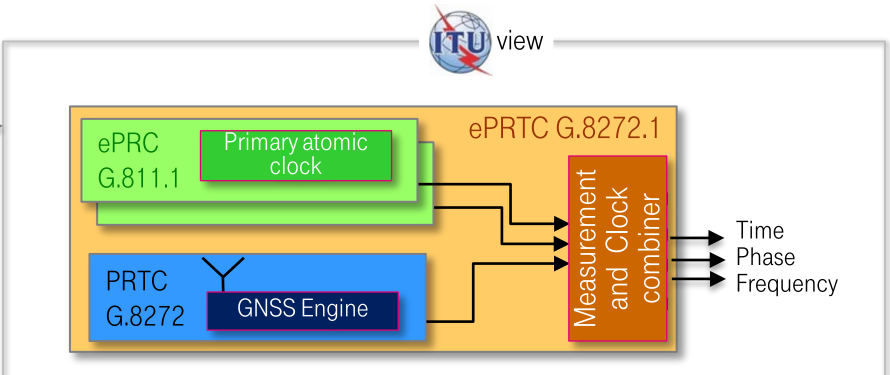
3 - Toolbox (3): PRTC + Local cesium clocks as additional source = ePRTC

Technology view:

- To combine local GNSS receiver with local cesium clocks e. g. at core network level.
- During GNSS locked mode:
  ➔ Cesium to improve stability for low-pass functionality.
  ➔ Specific cesium frequency deviation can be measured.
- During threat:
  ➔ Time hold-over based on known cesium(s) frequency.



ePRTC = enhanced PRTC (Clock combiner, using GNSS and local cesium)

Performance during threat (e. g. jamming):

- Time hold-over with defined output performance, depending cesium clock stability.

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3 - Toolbox (4): ePRTC in a meshed clock combiner architecture = cnPRTC

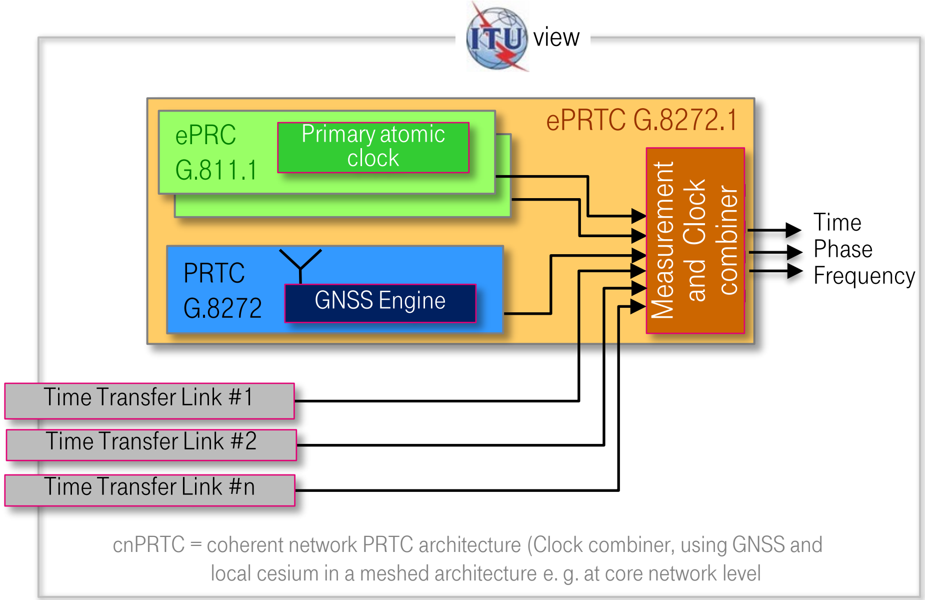
Technology view:

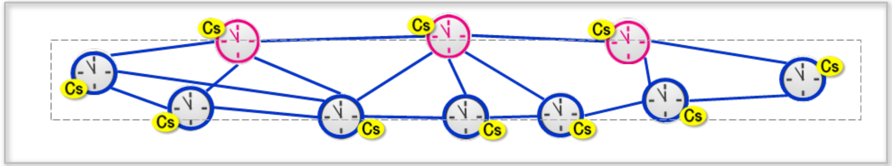
- To mesh ePRTC clock combiner at core network level.
- cnPRTC = ePRTC clock combiner
  + network connections
- Architectural concept and functional block diagram is descript in ITU-T G.8275.
- Clock specification development of new G.8272.2 is going to start 12/2021.

Performance during threat (e. g. jamming):

- Time hold-over based on meshed network, derived from many known cesium, can overcome threats for weeks or month w/o any performance degradation.

cnPRTC Clock combiner





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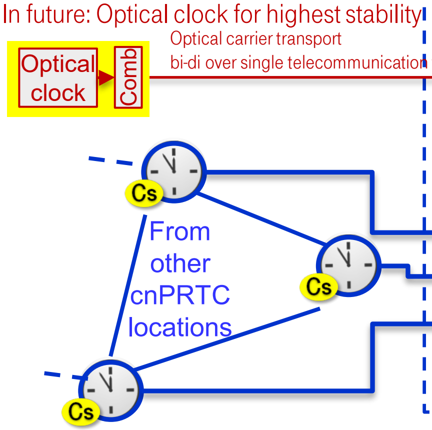
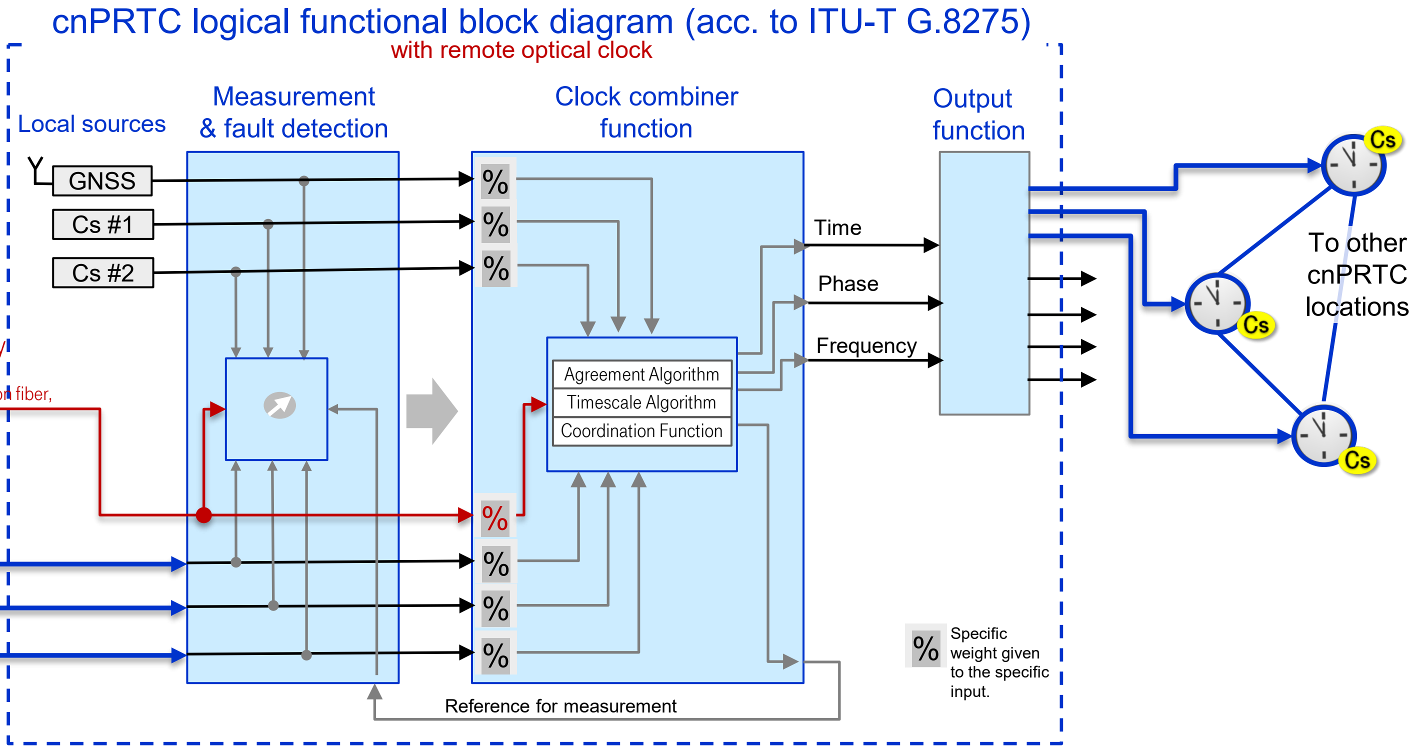
3 - Toolbox (4): Meshed clock combiner architecture

- need Time Transfer for remote connections
- between different cnPRTC locations
- to build up the meshed architecture





cnPRTC = coherent network PRTC

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4 - Resilience level: New IEEE project and Resilient PNT Conformance Framework

Conformance Framework development

- Based on NIST workshops “Assured Access to Accurate Time” 2018/19.
- A work group lead by DHS has developed a ’Resilient PNT Conformance Framework’ published in 2020.
- IEEE has started 2021 a new project P1952 and is going to develop a new ‘Standard for Resilient Positioning, Navigation and Timing (PNT) User Equipment’.

IEEE P1952 5.4 Purpose: This standard defines expected behaviors in resilient PNT UE and facilitates development and adoption of those behaviors through a common framework that enables improved risk management, determination of appropriate mitigations, and decision making by PNT users. The standard allows stakeholders to define and communicate resilient PNT UE needs and evaluate proposed resilience solutions in a consistent, uniform manner.

Conformance Framework content

- Basically, a 4 level model has been developed for resiliency, dealing with how to overcome threats.

Resilience Level	Specification acc. to Conformance Framework
1	System recover to specified performance after threat
2	System provides a (limited) solution during threat, e. g. with restricted performance.
3	System provides defined (still limited) performance during threat.
4	System provides full specified performance during threat.

With following slide, ideas for mapping between ITU-T clock toolbox and resilience level are shown.

RESILIENCE FOR TIMING & SYNCHRONISATION NETWORKS: Mapping

ITU-T solution (primary clock, network)								Resilience evaluation			
Tool-box No.	Name	No.	maxITEI	System / Technology		Support to overcome theat: Local	Support to overcome theat: Remote support from network	Performance during threat	Mapping	Acc. to framework: Resilience Level	Acc. to framework: Specification related to threats
1	Primary Reference Time Clock (PRTC)	G.8272	100ns (PRTC-A) 40ns (PRTC-B)	GNSS	internal OCXO or Rb	internal oscillator for limited time	- none -	After limited hold-over time depending on internal oscillator, output is quelched and comes back after threat		1	After threat: recover back to specified performance
2	Primary Reference Time Clock (PRTC)	G.8272	100ns (PRTC-A) 40ns (PRTC-B)	GNSS	internal OCXO or Rb	internal oscillator for limited time	Frequency synchronization from network 1)	Impacted by network wander at remote frequency received by PRTC (e. g. SyncE or eSyncE)		2	During threat: limited solution e. g. with restricted performance.
3	ePRTC (enhanced PRTC)	G.8272.1	30ns	GNSS	internal OCXO or Rb	local Cesium/s (PRC/ ePRC)	- none - or optional frequency synchronization	Clock combiner has learned about local cesiums during locked state and can supply during threat for days or weeks		3	During threat: defined (still limited) performance
4	cnPRTC (coherent network PRTC)	G.8275 / G.8272.2	30ns	GNSS	internal OCXO or Rb	local Cesium/s (PRC/ ePRC)	Time transfer from neighborhood clock combiner (meshed network)	cnPRTC architecture shall be able to overcome network-wide GNSS problems for weeks to months w/o any degradation		4	During threat: System provides full specified performance

1) SyncE or SDH or PTP frequency profile (G.8265.1) or PTP-FTS (G.8275.1) A-PTS (G.8275.1)

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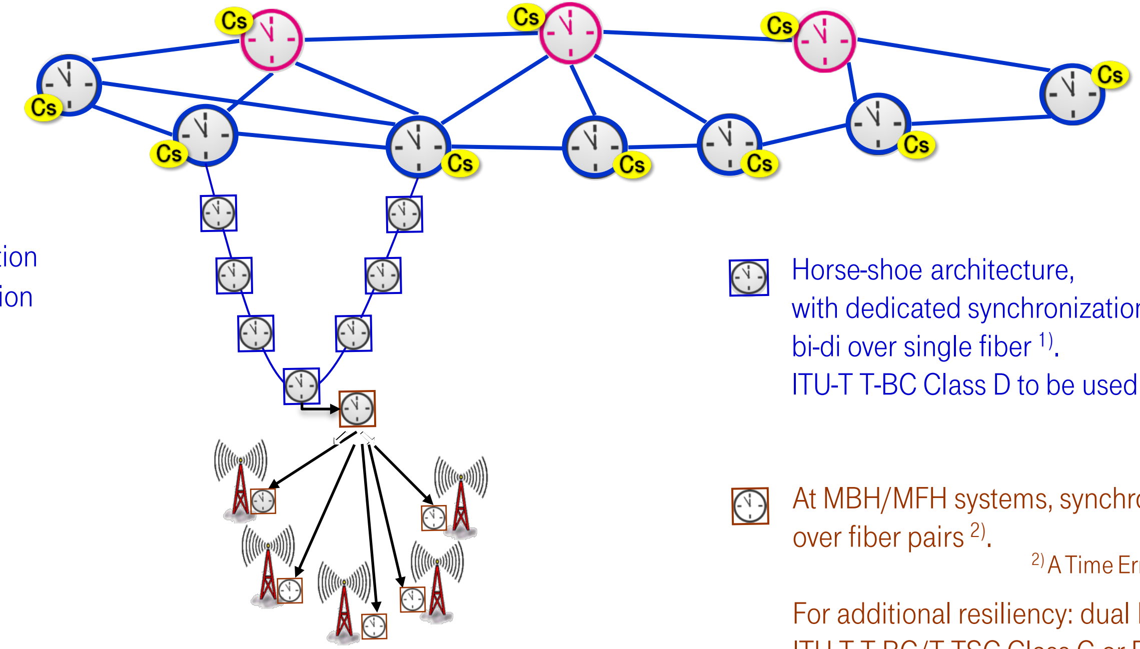
5 - Example for synchronization network architecture at resilience level 4

Core network:
cnPRTC
Architecture

Core to aggregation
synchronization

Access Network



cnPRTC Clock combiner:
GNSS + local cesium(s)
+ network connections
with high-accuracy time transfer,
bi-di over single fiber [1)]

Horse-shoe architecture,
with dedicated synchronization equipment,
bi-di over single fiber [1)].
ITU-T T-BC Class D to be used

[1)] Chromatic dispersion to be compensated

At MBH/MFH systems, synchronization together with traffic,
over fiber pairs [2)].

[2)] A Time Error budget for different fiber length to be considered

For additional resiliency: dual homing of base stations (if needed)
ITU-T T-BC/T-TSC Class C or D to be used

T-BC = Telecom Boundary Clock, T-TSC = Telecom Time Slave Clock, both acc. to G.8273.2

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SUMMARY

- Resilience is one of the most important requirements for synchronization networks.
  24/7 operation must be guaranteed.
  A strong strategy to overcame any GNSS related threats is recommended.

- ITU-T clock and architectural concepts can be mapped at new resilience conformance framework level.

- With coherent network Primary Reference Time Clock architecture acc. to ITU-T,
  the highest resilience level 4 can be reached.
  An example for a level 4 cnPRTC based synchronization network architecture is shown.

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Thank you very much. Questions?

References:

ITU-T G.811.1: Timing characteristics of enhanced primary reference clocks https://www.itu.int/rec/T-REC-G.811.1-201708-I

ITU-T G.8272/Y.1367: Timing characteristics of primary reference time clocks https://www.itu.int/itu-t/recommendations/rec.aspx?rec=13769

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ITU-T G.8273.2: Timing characteristics of telecom boundary clocks and telecom time slave clocks for use with full timing support from the network https://www.itu.int/rec/T-REC-G.8273.2-202010-I

ITU-T G.8275/Y.1369: Architecture and requirements for packet-based time and phase distribution https://www.itu.int/itu-t/recommendations/rec.aspx?rec=14509

T17-SG15-C-2467!!MSW-E, Deutsche Telekom 04-2021 (ITU-T-SG15 Plenary Meeting):
cnPRTC Equipment Specification: G.8272.2 https://www.itu.int/md/T17-SG15-C-2467/en (ITU-T TIES account needed)

T17-SG15-C-2607!!MSW-E, Deutsche Telekom + NTT: Optical Clocks, ePRTC and cnPRTC architecture,
for SG15 plenary meeting December 2021 https://www.itu.int/md/T17-SG15-C-2607/en (ITU-T TIES account needed)

DHS Resilient Positioning, Navigation, and Timing (PNT) Conformance Framework
https://www.dhs.gov/sites/default/files/publications/2020_12_resilient_pnt_conformance_framework.pdf

IEEE Project P1952 Standard for Resilient Positioning, Navigation and Timing (PNT) User Equipment https://standards.ieee.org/project/1952.html