Deutsche Telekom

Accurate and Precise Time and Timing in Telecommunication

[Metrology and Telecommunication overlapping and co-operating more and more ...]

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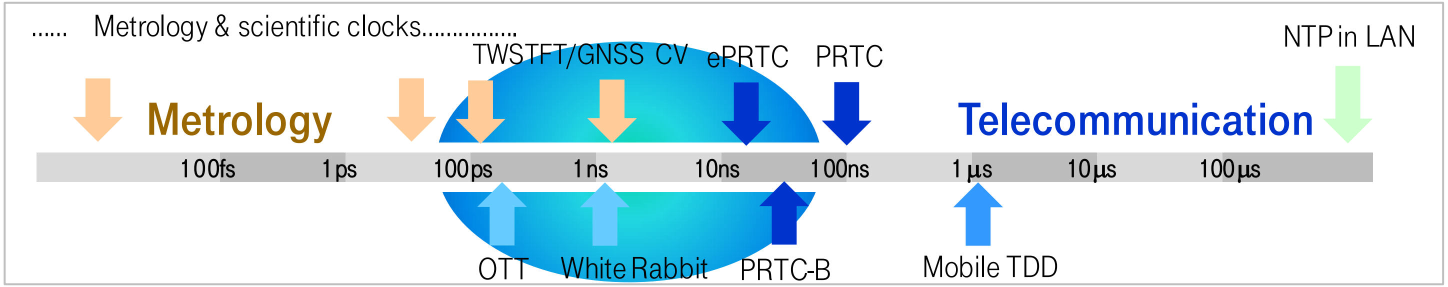
Accurate & Precise Time and Timing in Telecommunication Networks

In the past
- Metrology was in a order of << several ns
- Telecommunication was in a order of >100 ns

Now
- Both do overlap more and more and learning from each other, several co-operations as reported at WSTS and ITSF
- Network operators trying better Time Transfer (Optical or "White Rabbit") coming from Metrology, now considered for telecommunication
- Metrology need telco networks to transfer time to compare clocks and UTC
- New enhanced ITU-T clock coming closer to metrology clocks



CV = Common View

OTT = Optical Time Transfer

ePRTC = enhanced PRTC

NTP = Network Time Protocol

PRTC = Primary Reference Clock

PRTC-B = PRTC Class B

TDD = Time Division Duplex

White Rabbit ≈ IEEE1588 High Accuracy

Accurate & Precise Time and Timing in Telecommunication Networks
Agenda

1. The wording - from Metrology .... to Telecommunication PTP based ITU-T Solutions:

❶ Good accuracy with good precision	▪ Full Timing Support from Network - FTS	⇨ enhanced Clocks
❷ Good accuracy w/o good precision		⇨ "first generation" Clocks
❸ Low accuracy and good precision		⇨ Cluster synchronization
❹ Low accuracy and low precision	▪ Assisted Partial Timing Support -A-PTS	⇨ GNSS at slave clock
	▪ Partial Timing Support -PTS	⇨ Worst case

2. Need for enhanced clocks
   - (1) Application driven – Mobile
   - (2) Application driven – Business customers
   - (3) Synchronization network driven
   - (4) Synchronization network supervision driven

3. Scaling and new enhanced clocks under study at ITU-T SG15/Q13

PTP =
Precision Time Protocol
acc. to IEEE1588-2008

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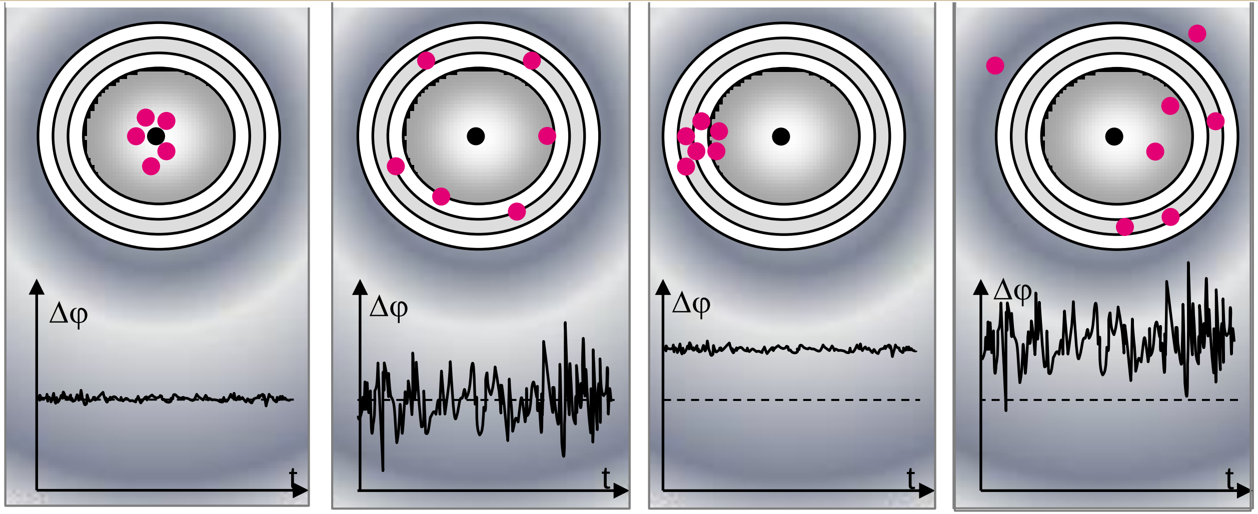
The wording - from Metrology to Telecommunication

TE = Time Error

		❶	❷	❸	❹
Metrology	Precision	☺	☹	☺	☹
	Accuracy	☺	☺	☹	☹
Telecom-munication	dynamic TE	☺	☹	☺	☹
	constant TE	☺	☺	☹	☹



❶ Best case ☺☺

❷ Noisy, but a good oscillator / PLL helps ☺☹

❸ High cTE ☺☹
Telco: A-PTS + cluster sync

❹ Worst case ☹☹
Telco: No solution

Accuracy /cTE is most critical

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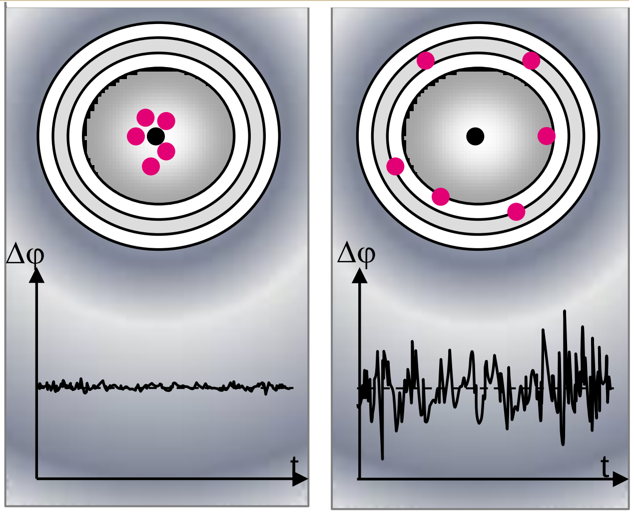
(1) Good accuracy with ❶ and w/o ❷ good precision: FTS solution

	❶	❷
Precision	☺	☹
Accuracy	☺	☺
dynamic TE	☺	☹
constant TE	☺	☺



Application:

❶ UTC based high precision requirements with enhanced clocks
e . g. as backup for GNSS time & timing (<100 ns)

❷ UTC traceable hierarchical synchronization network
UTC as customer requirement
Mobile base station sync e. g. Time Division Duplex
(<±1,1/1,5 µs)

Network implementation:

- Maximum noise accumulation acc. to ITU-T supply chain specification to fulfill the related requirements
- ITU-T clocks:
  - ❶ ePRTC, PRTC Class B, T-BC Class C, eEEC
  - ❷ PRTC / T-BC Class A/B / T-TSC / EEC

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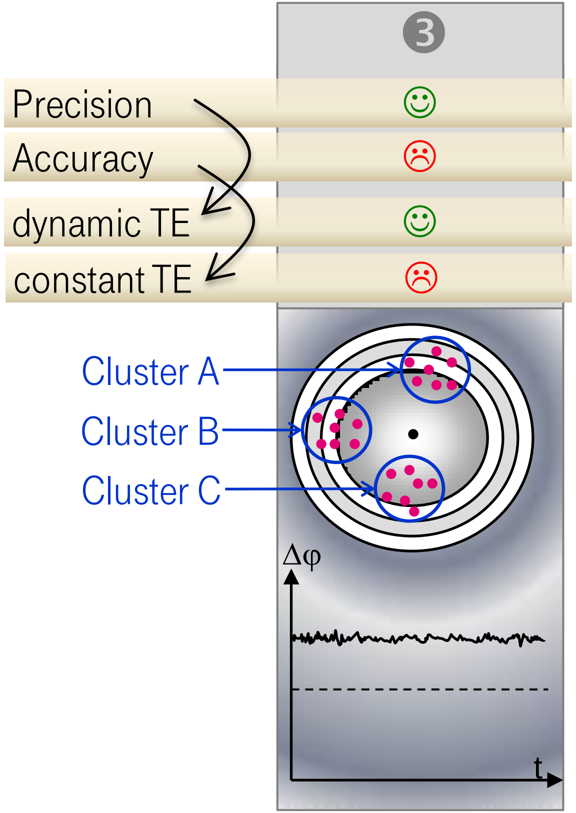
(2) Low accuracy and good precision: Cluster synchronization



Application:

Mobile base station cooperation cluster synchronization (e. g. up to ±65 ns)
The requirement is not related to UTC, relative Time Error inside cluster only

Network implementation acc. to ITU-T:

- enhanced clocks like enhanced EEC acc. to G.8262.1 (under development) inside the cluster and T-BC Class B/C (Class C is under development)

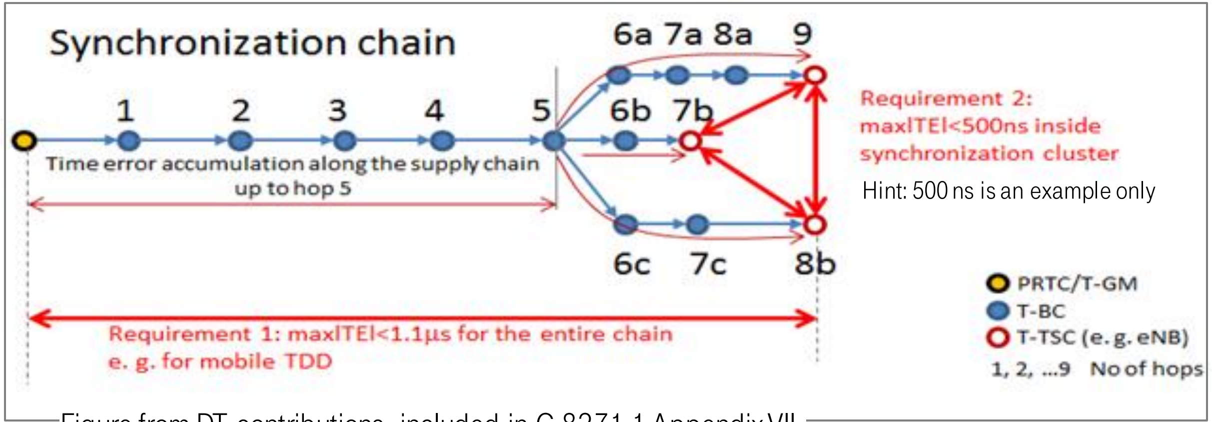


Figure from DT contributions, included in G.8271.1 Appendix VII

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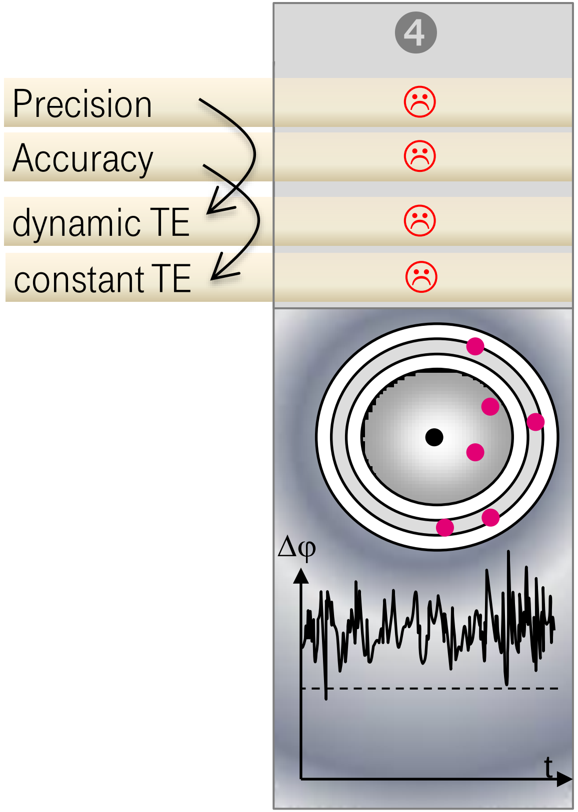
(3) Low accuracy and low precision - but with GNSS assistance => A-PTS

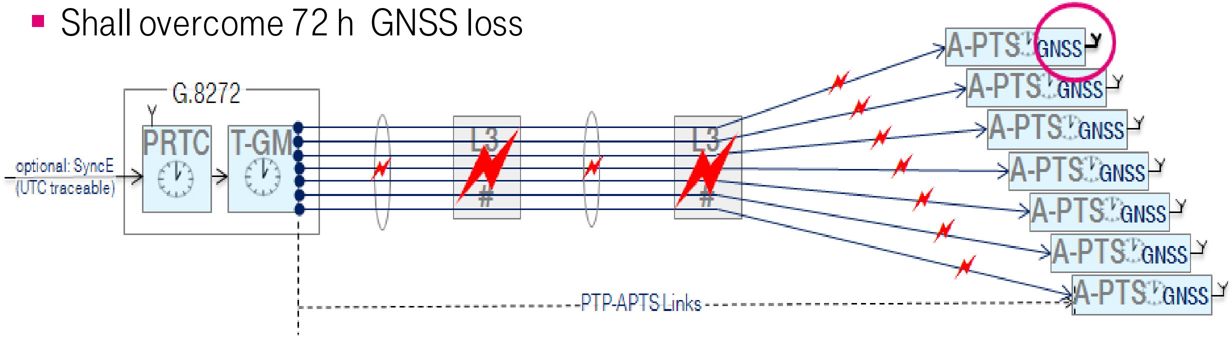


<u>Application:</u>

④ Mobile telecommunication features like Time Division Duplex (±1,5 µs)

<u>Network implementation acc. to ITU-T:</u>

- (GNSS) **A**ssisted **P**artial **T**iming **S**upport (from the network) profile: **A-PTS**
- Noise to be limited by (a) packet selection and
  (b) filtered by a good A-PTS clock
- Constant Time Error to be calculated and compensation with help by GNSS
- Shall overcome 72 h GNSS loss



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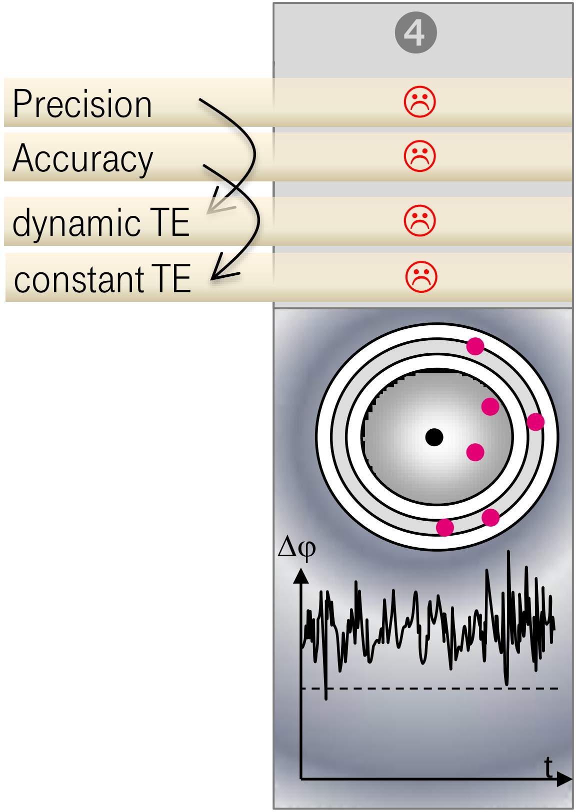
(4) Low accuracy and low precision / worst case (PTS)



Application would be:

❹ Existing networks w/o on-path support from network

Network implementation:

- ITU-T has a work item for a Partial Timing Support (PTS) solution, it is open
- Unsolved issue: ⇨ constant Time Error, no solution for compensation
  Reachable quality depends on
  - ⇨ network behavior
  - ⇨ degree of over provisioning
  - ⇨ symmetry of the traffic (e. g. impact of video streaming)
  - ⇨ symmetry of the link (e. g. impact of xDSL)
  - ⇨ frame size (e. g. impact of jumbo frames)
- Network operator would need permanent asymmetry monitoring
  One initial measurement does not help (e. g. traffic changes with new services)

Still no engineered solution to reach accuracy class 4 with <±1.1/1.5 µs

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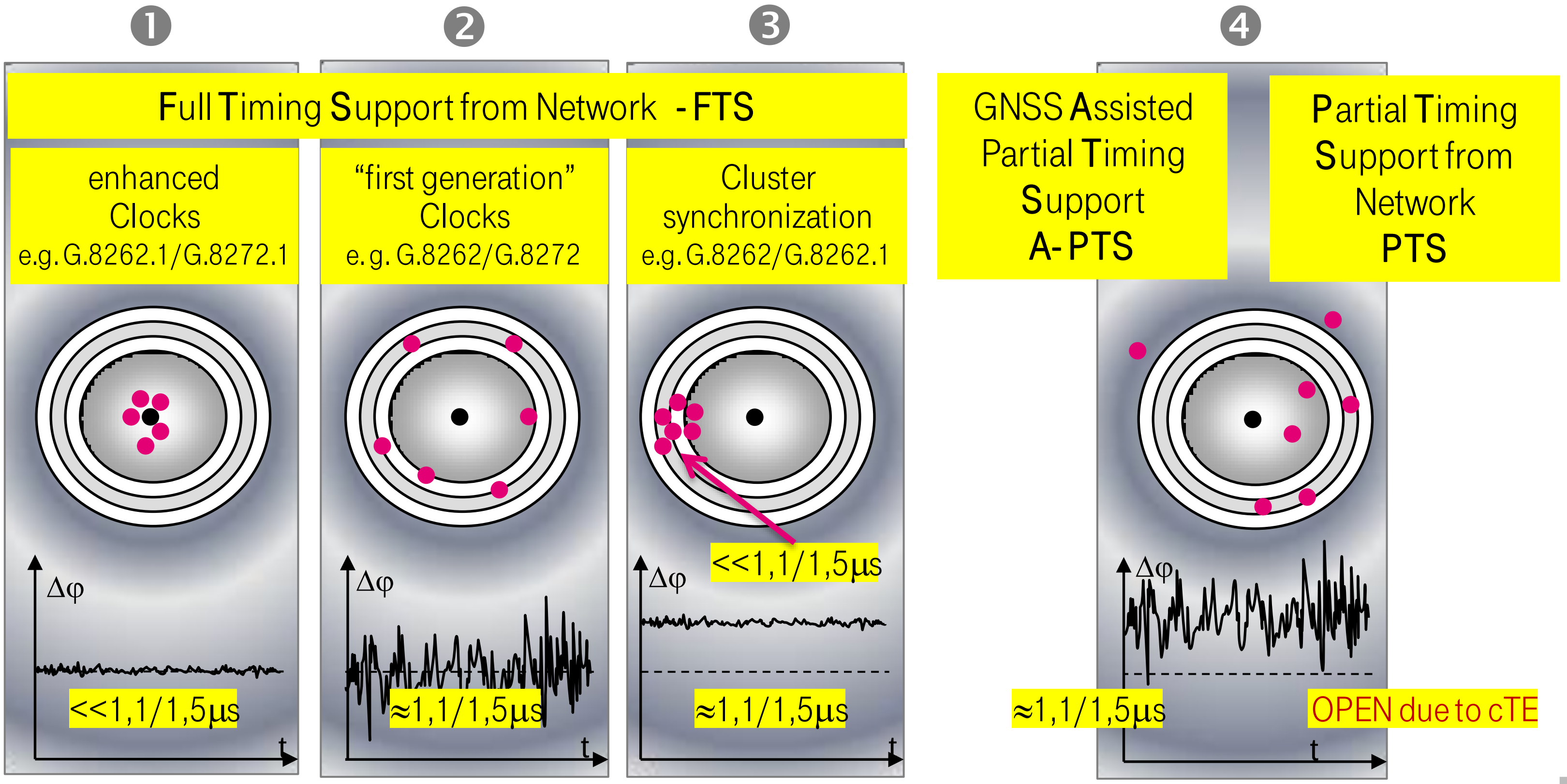
Summary: Solutions acc. to ITU-T



Accurate & Precise Time and Timing in Telecommunication Networks
Need for enhanced clocks: (1) Application driven - Mobile

Application:

- Current ITU-T clock specifications are related to G.8271 accuracy level 4.
- Level 5 and 6 require better clocks

Tables from G.8271

Level of accuracy	Time error requirements (Note 1)	Typical applications (for information)
1	500 ms	Billing, alarms
2	100 μs	IP Delay monitoring
3	5 μs	LTE TDD (large cell)
4	1.5 μs	UTRA-TDD, LTE-TDD (small cell) Wimax-TDD (some configurations)
5	**1 μs**	**Wimax-TDD (some configurations)**
6	**x ns (Note 3)**	**Various applications, including Location based services and some LTE-A features (Note 2)**

NOTE 1 – The requirement is expressed in terms of error with respect to a common reference.

NOTE 2 – The performance requirements of the LTE-A features are under study. For information purposes only, **values between 500 ns and 1.5 μs** have been mentioned for some LTE-A features. Depending on the final specifications developed by 3GPP, LTE-A applications may be handled in a different level of accuracy.

NOTE 3 – For the value x, refer to Table 2 below and Table II.2 of Appendix II.

Level of accuracy	Max Relative TE (Note 1)	Typical applications (for information)
6A	260 ns	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
6B	130 ns	Intra-band contiguous carrier aggregation, with or without MIMO or TX diversity
6C	65 ns	MIMO or TX diversity transmissions, at each carrier frequency

NOTE 1 – The maximum relative time error requirements represent the peak-to-peak time difference measured between the elements in the cluster only.
In 3GPP terminology this is equivalent to time alignment error (TAE), which is defined as the largest timing difference between any two signals.

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Need for enhanced clocks: (2) Application driven – Business customers

Application:

- Any customer application with stronger accuracy & precision need (than 1,1/1,5 µs)
- E. g. PTP-FTS to backup GNSS based timing and synchronization solutions (<100 ns)

Requirements:

- Reliability to overcome GNSS outages and jamming
- Customer wants to have performance similar to GNSS
- like A-PTS but for 100 ns instead of 1,1 µs

Technical options:

- Using packet selection from A-PTS for FTS
- Better system internal calibration “by design” for lower constant time error
- Better internal oscillators / PLLs for noise filtering
- Using higher PTP packet rate: 128 /s instead of 16 /s
- Using ePRC / ePRTC / PRTC Class B
- Bidirectional single fiber usage

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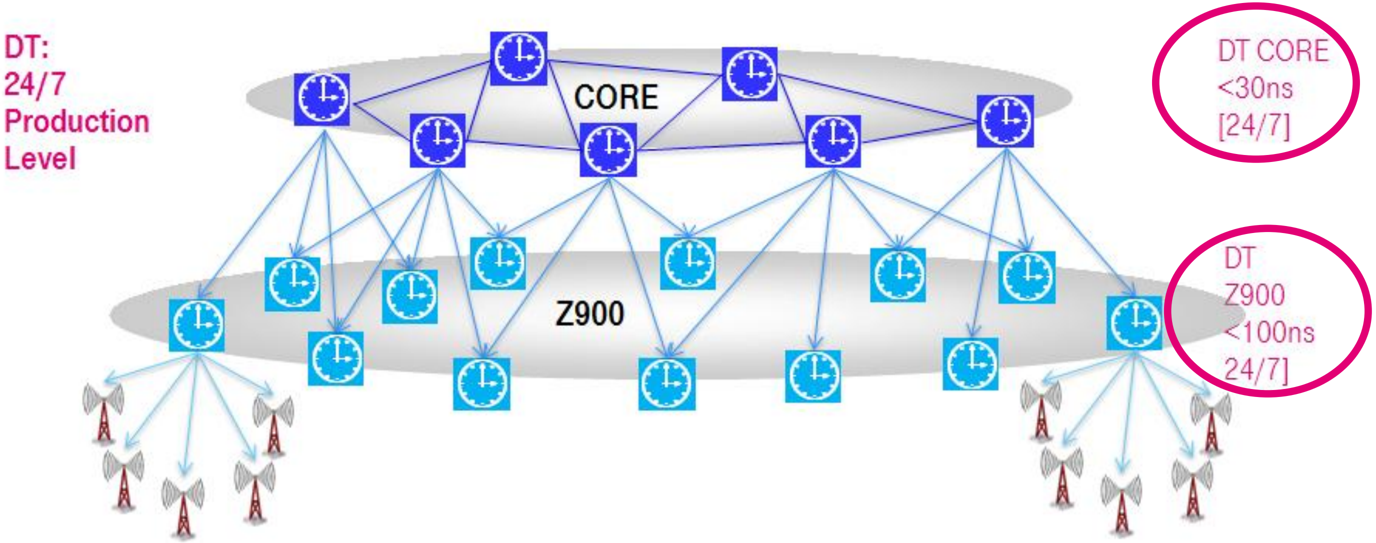
Need for enhanced clocks: (3) Synchronization network “production”

For 24/7 synchronization dissemination:

- Based on the needed maximum time error of end-application, **a hierarchical synchronization network is needed**



Requirements:

- Reliability e. g. to overcome GNSS outages and jamming
  => should be not too much GNSS dependent, if GNSS is used => a backup is needed
- Permanent supervision and measurement => requires better reference clocks and better time transfer

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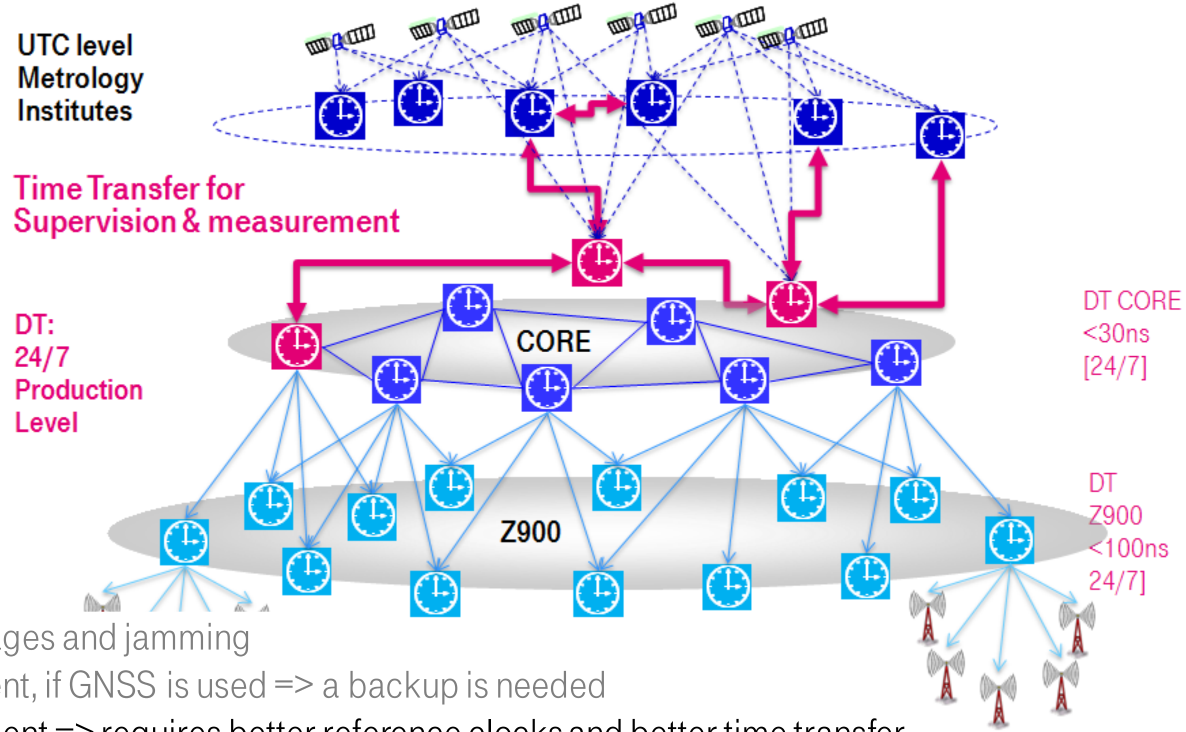
Need for enhanced clocks: (4) Synchronization network supervision

Time transfer for network supervision and measurement

Direct measurement method:
- GNSS common view allows < 10 ns

Time Transfer for measurement reference:
(1) IEEE1588 High-accuracy (aka. White Rabbit) allows a few ns
(2) Optical Time Transfer (ELSTAB) allows a few 100 ps



Requirements:
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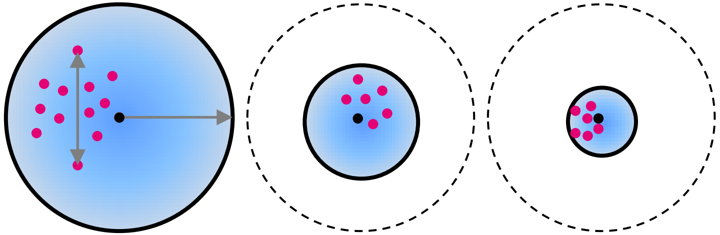
Scaling: Primary Time Sources and Time Transfer Methods

Primary Reference Time Clock functions: UTC related



PRTC-(A):
G.8272
max|TE| ≤100 ns
dTE as MTIE: ≤100 ns

GNSS L1

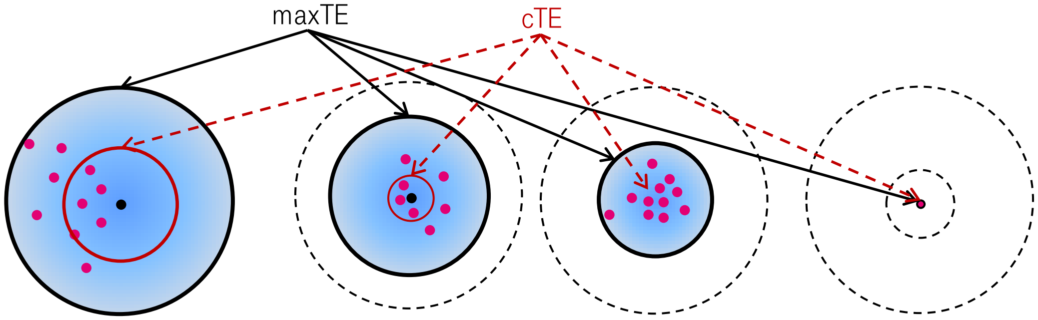
PRTC-B *):
G.8272 *)
max|TE| ≤ 40 ns*)
dTE as MTIE: ≤ 40 ns*)

GNSS L1+L2 (currently for metrology only)

ePRTC:
G.8272.1
max|TE| ≤ 30 ns
dTE as MTIE: ≤ 30 ns

GNSS +atomic clock (e. g. Cs) acc. to G.811/G.811.1 for better stability and better hold-over

Dissemination equipment, output values related to input signal: used in synchronization chains with cTE and noise accumulation



T-BC Class A:
G.8273.2
max|TE| <100 ns
cTE <50 ns
dTE(LP) <40 ns
dTE(HP) <70 ns

T-BC Class B:
G.8273.2
max|TE| <70 ns
cTE <20 ns
dTE(LP) <40 ns
dTE(HP) <70 ns

T-BC Class C *):
G.8273.2
max|TE| <50 ns *)
cTE <10 ns *)
dTE(LP) <20 ns *)
dTE(HP) <50 ns *)

OTT:
G.?? *)
max|TE| <1 ns

*) Not specified or not fully specified by ITU-T

Accurate & Precise Time and Timing in Telecommunication Networks
New Clocks under study at ITU-T SG15/Q13

Name		No.	Scheduled for	Areas for improvement	Examples for related technology
eEEC	enhanced Ethernet Equipment Clock	G.8262.1	2017	Improved EEC for SyncE, e. g. with better reference switching to replace EEC G.8262	Better DPLL /oscillator / phase transient suppression
T-BC-C	Telecom Boundary Clock Class: C	G.8273.2	2018?	Specified are Class A and B, New Class C e.g. with less Time Error, based on eEEC	better cTE calibration and less noise by design
ePRC	enhanced Primary Reference Clock	G.811.1	2017	Specified PRC, e.g. with much better frequency accuracy	New atomic clock technology
PRTC-B	Primary Reference Time Clock Class B	G.8272	2018 ?	Specified PRTC, e. g. with much better max |TE|	Using combined L1/L2 GNSS receivers
ePRTC	enhanced Primary Reference Time Clock	G.8272.1	2016	Less noise (diurnal wander)	Combining new atomic clocks with GNSS

Proposed by ITU-T members for specification at SG15/Q13:

cnPRTC	coherent network Primary Reference Time Clock	new	open	Mashed ePRTC network at core level, less GNSS dependent	Combining PTP-FTS/SyncE with ePRTC
TT	Time Transfer	new	open	Time transfer on metrology level, to connect clocks at highes synchronization level	Optical Time Transfer (ELSTAB), IEEE1588 High Accuracy

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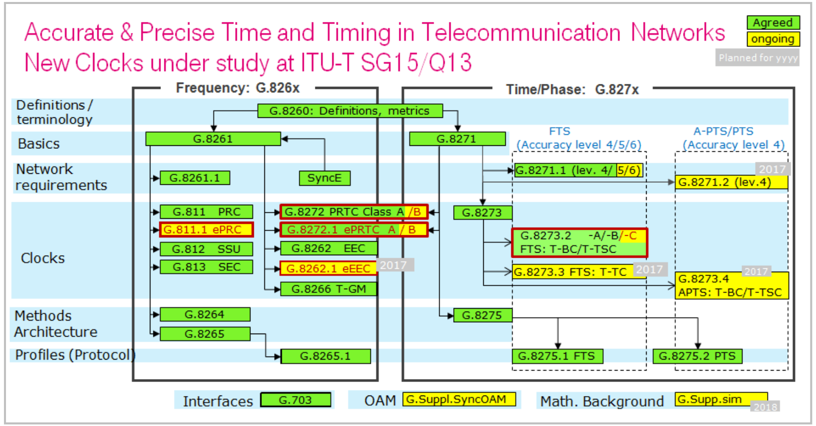
Thank you.



Backup: ITU-T Requirements

References:

[1] L. Śliwczyński, P. Krehlik, J. Kołodziej, H. Imlau, H. Ender, H. Schnatz, D. Piester, and A. Bauch: “Fiber Optic Time Transfer for UTC-Traceable Synchronization for Telecom Networks”, IEEE Communications Standards, March 2017

[2] H. Imlau, "Primary Reference Clocks in Telecommunication Networks: PR(T)C, ePRTC and cnPRTC", WSTS 2015, San Jose / U.S., 11.3.2015

[3] G. Zampetti: “Enhanced PRTC Extended Outage Operation” ITSF2016, Prague/ CZ, 2.11.2016

[4] B. Patrick: Performance results of an optically-pumped cesium beam clock, ITSF2016, Prague/ CZ, 2.11.2016

[5] ITU-T G.8272.1/Y. 1367.1 “Timing characteristics of enhanced primary reference time clocks (ePRTC)” September 2016

[6] P. Krehlik; L. Sliwczynski; L. Buczek; J. Kolodziej; M. Lipinski: "ELSTAB - fiber optic time and frequency distribution technology – a general characterization and fundamental limits,“ IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Year: 2015, Volume: PP, Issue: 99, DOI: 10.1109/TUFFC.2015.2502547

BACKUP

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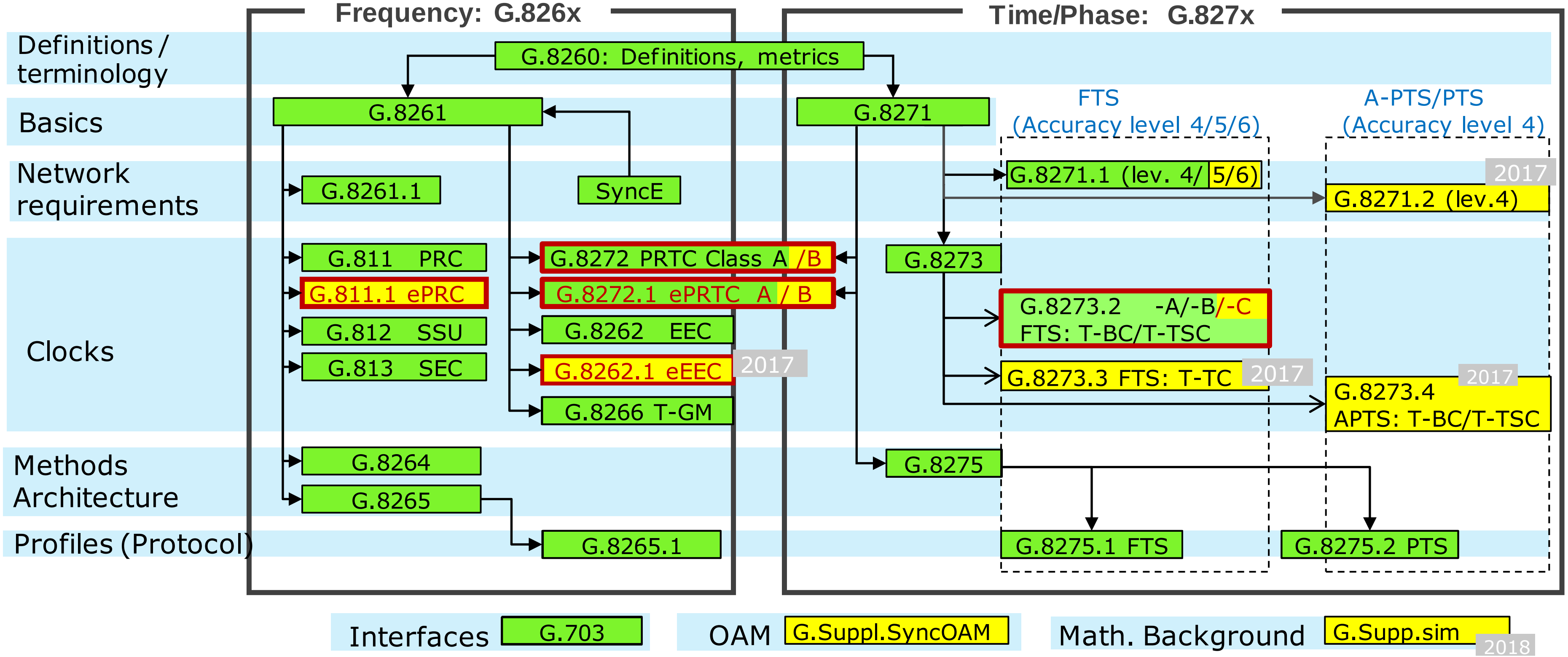
New Clocks under study at ITU-T SG15/Q13

Agreed
ongoing
Planned for yyyy



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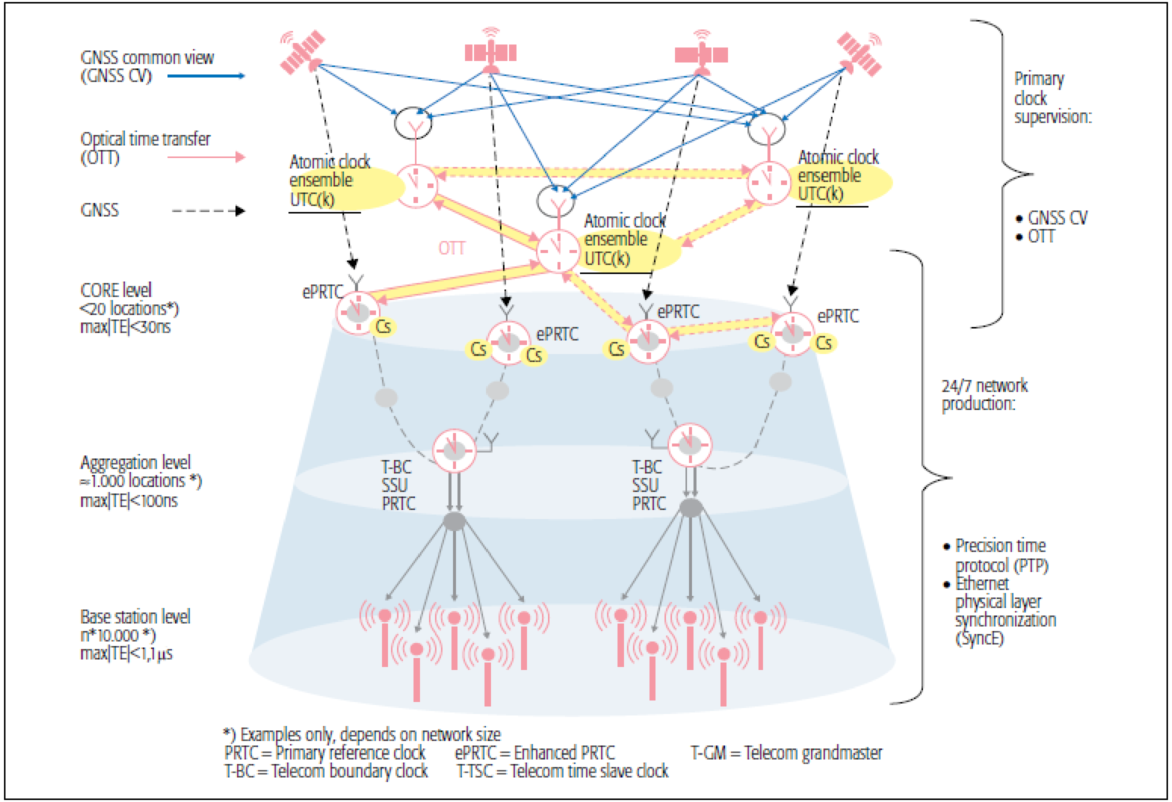

FIGURE 1. An example of a block diagram of a hirarchical telecommunication synchronization network.

References:

[1] L. Śliwczyński, P. Krehlik, J. Kołodziej, H. Imlau, H. Ender, H. Schnatz, D. Piester, and A. Bauch: "Fiber Optic Time Transfer for UTC-Traceable Synchronization for Telecom Networks", IEEE Communications Standards, March 2017

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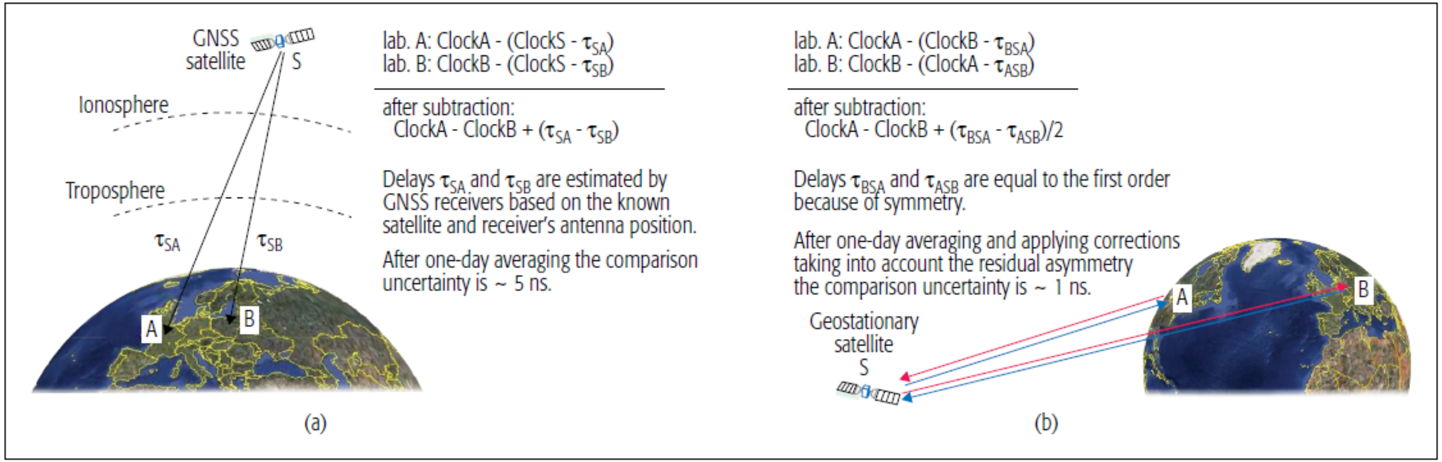

FIGURE 2. Principle of time transfer using standard satellite techniques: a) GNSS common view; b) TWSTFT.

References:

[1] L. Śliwczyński, P. Krehlik, J. Kołodziej, H. Imlau, H. Ender, H. Schnatz, D. Piester, and A. Bauch:
“Fiber Optic Time Transfer for UTC-Traceable Synchronization for Telecom Networks”, IEEE Communications Standards, March 2017