Deutsche Telekom

Enhanced Primary Clocks and Time Transfer

Helmut Imlau

ITSF 2017, November 8th

Enhanced Primary Clocks and Time Transfer
Agenda (a)

Enhanced Primary Clocks

Why enhanced primary clocks?

1. Primary Reference Clock: PRC and ePRC
2. Primary Reference Time Clock (PRTC) Class A and B
3. Clock combiner: enhanced PRTC (ePRTC)
4. New cnPRTC concept

For abbreviations, please refer next page.

High accuracy Time Transfer

Why high-accuracy time transfer? Methods:

1. PTP-FTS over dedicated wave length
2. IEEE1588 High Accuracy (CERN “White Rabbit”)
3. OTT/ELSTAB

Standards view

Enhanced Primary Clocks and Time Transfer
Agenda (b)

Enhanced Primary Clocks

Why?

1. Primary Reference Clock: PRC and ePRC
2. Primary Reference Time Clock (PRTC) Class A and B
3. Clock combiner: enhanced PRTC (ePRTC)
4. New cnPRTC concept

PRC =Primary Reference Clock, **ePRC** = enhanced PRC
- autonomous Cesium atomic clock(s), ITU-T: G.811, G.811.1

PRTC = Primary Reference Time Clock
- basically a GNSS timing receiver, ITU-T: G.8272

ePRTC = enhanced PRTC
- basically clock combiner: PRC + PRTC , ITU-T: G.8272.1

cnPRTC = coherent network PRTC
- combines ePRTC with PTP-FTS/SyncE links, ITU-T: planned

High accuracy Time Transfer

Why? Methods:

1. PTP-FTS over dedicated wave length
2. IEEE1588 High Accuracy (CERN “White Rabbit”)
3. OTT/ELSTAB

PTP-FTS = Precision Time Protocol with Full Timing Support from the network
- ITU-T: G.8271.1, G.8273.2, G.8575 (based on IEEE1588-2008)

CERN = European Organization for Nuclear Research, Geneva
- High-accuracy time transfer, now in IEEE1588 High-accuracy group

OTT = Optical Time transfer, **ELSTAB** = Electronic STABilized
- Developed by AGH University Krakow

Standards view

Enhanced Primary Clocks and Time Transfer

ePRTC = ePRC + PRTC   ePRTC Class A = ePRC Class A + PRTC Class A   enhanced Primary Reference Time Clock

(Clock combiner)   ePRTC Class B = ePRC Class A + PRTC Class B

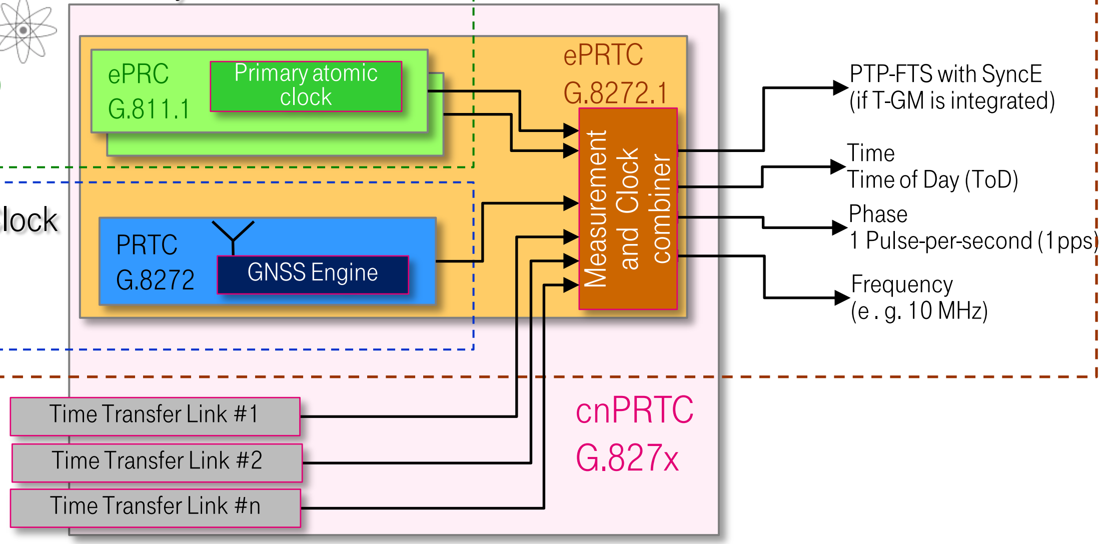
PRC = Atomic clock (e. g. Cs 1988) for frequency   Primary Reference Clock

ePRC = better PRC

- ePRC Class A = better / combined PRC (2017)
- ePRC Class B = much better PRC (2018)

PRTC = GNSS receiver Primary Reference Time Clock

- PRTC-A = single-band GNSS receiver (<100ns)
- PRTC-B = multi-band GNSS receiver (<40ns)



cnPRTC = ePRTC + Time Transfer links

- Class A with ePRTC Class A
- Class B = with ePRTC Class B

coherent network Primary Reference Time Clock (name to be confirmed by ITU-T)

Why enhanced clocks

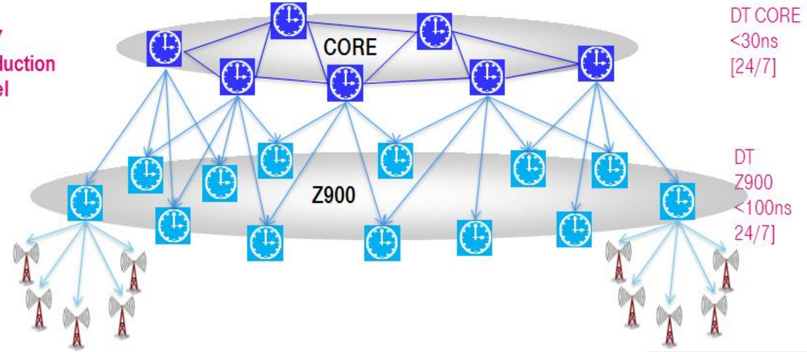
Enhanced Primary Clocks and Time Transfer
Why enhanced primary clocks ?

Customer required accuracy: ITU-T G.8271 defines accuracy level 1 - 6

- Accuracy level 4 (1.5μs) is basis for current clock specifications
  ➔ acc. to basic mobile requirements like TDD (Time Division Duplex)
- Accuracy level 5 and 6 (values lower than 200/500 ns are under discussion, e .g. 130 ns are proposed) require better primary clocks
  ➔ Drivers are: Mobile 5G and products for business customers
  e. g. PTP-FTS to backup GNSS based timing and synchronization solutions (<100 ns)

Network operation view, for 24/7 synchronization dissemination:
Based on the needed maximum time error of end-application

- a hierarchical synchronization network is needed: better clocks at top level of the network
- GNSS related risks to be minimized



next: PRC

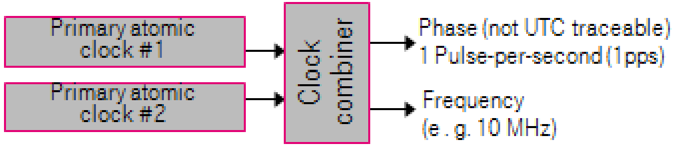
Enhanced Primary Clocks and Time Transfer
1. PRC and ePRC (for frequency)

<u>PRC (as specified 1988/97)</u>

- Based on standard Cs at technology level 1988
- Used as basis for all TDM specifications (with 8000 Hz frame rate / one frame per 125 ms):
  $1*10^{-11}$ => max. 1 frame slip in 72 days between different PRCs ($125ms/2*10^{-11}$=72d)

<u>From PRC to enhanced PRC (ePRC):</u>

- Cs technology now allows better than $1*10^{-11}$ as specified for PRC
- Clock combiner using more than one Cs allow much better performance than single clocks
  ➔ ePRC Class A is already specified ($1*10^{-12}$)

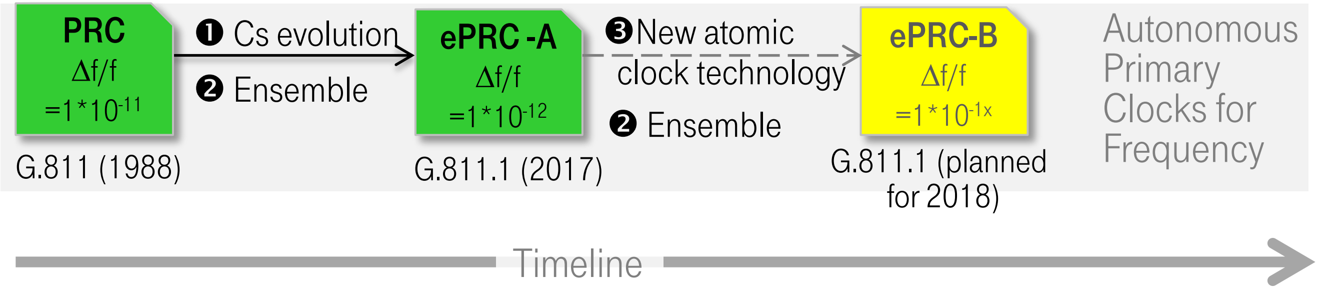


- Further technology steps can be expected soon
  ➔ ePRC Class B

Enhanced Primary Clocks and Time Transfer
1. PRC and ePRC (for frequency)

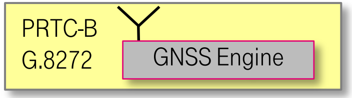
Specification view: ePRC specification (2017):

- ePRC are basis for ePRTC (to filter diurnal GNSS depending wander and to overcome any GNSS related issues)
- Two classes: Class A with $1*10^{-12}$, class B (ffs, shall take future technology steps into account)



next: PRTC

Enhanced Primary Clocks and Time Transfer
2. Primary Reference Time Clock (PRTC): Class A and B

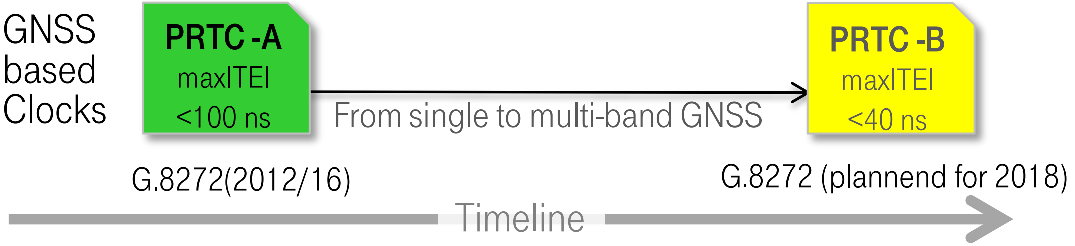


PRTC (specified 2012)

- To derive UTC traceable frequency, phase and time from GNSS
- Based on standard GNSS technology level 2012, using single-band GNSS (GPS L1 /1.5 GHz) timing receiver
- 100 ns max absolute Time Error to satisfy supply chains at accuracy level 4 (with 1.5 µs for customer application)
- will be re-named as PRTC Class A (PRTC-A)

PRTC Class B under specification:

- ITU-T SG15Q13 has decided to develop a second more stronger PRTC class
- 40 ns max absolute Time Error (value is provisionally agreed 10-2017) by using multi-band GNSS receivers
- Planned to be consented 02-2018



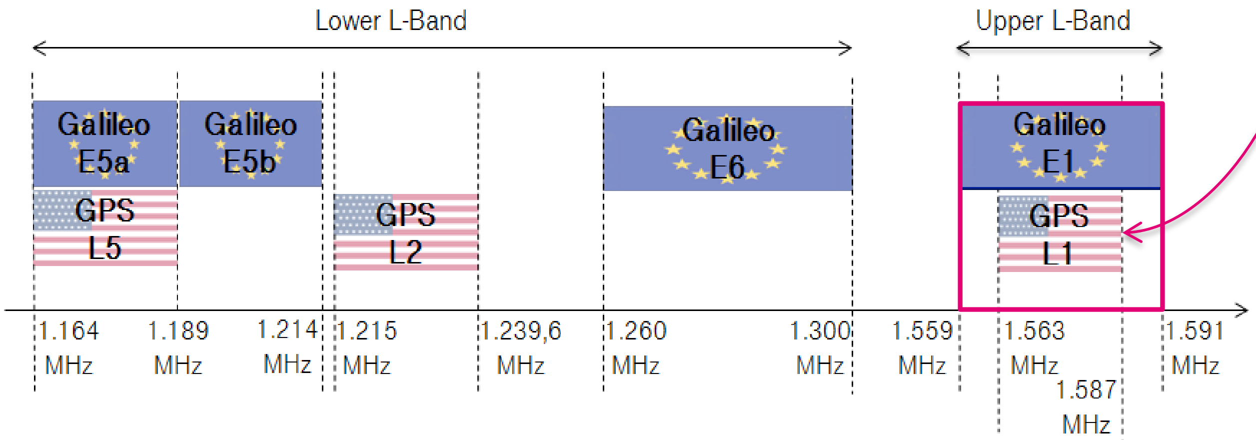
Enhanced Primary Clocks and Time Transfer
2. Primary Reference Time Clock (PRTC): Class A and B [2/5]

The problem:

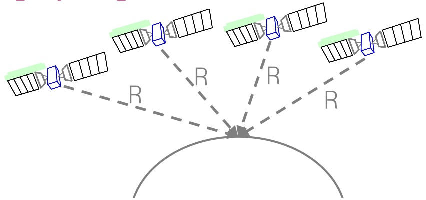
Largest source of time error in GNSS timing receivers is signal delay though the ionosphere, which ...

- depends on space weather, e. g. influenced by sun activity (11 years cycle),
- has 24 hours diurnal cycle, depending on the rotation of earth, with minimum delay at night

Maximum diurnal peak-peak value measured by DT several years ago was **48 ns**, measured with single-band receiver (GPS L1 =1,5 GHz) receiver using a Rb oscillator



Enhanced Primary Clocks and Time Transfer
2. Primary Reference Time Clock (PRTC): Class A and B [3/5]



GNSS basics:

The distance between satellites and GNSS receiver is an essential parameter for position and time calculation. The uncorrected distance is called ”pseudo range” R.

$$R = r + c\Delta t_s + c\Delta t_R + \Delta R_i$$ with c= speed of light

r = actual distance

ΔR_i = error due to ionsphare

ΔR_R = error of receiver clock

ΔR_S = error of satellite clock

ΔR_i is inversely proportional to the signal frequency squared

so, it is a known relationship, which is important for the solution

$\Delta R_i \sim 1/(f_c)^2$ with f_c = carrier frequency

next: the solution

Enhanced Primary Clocks and Time Transfer
2. Primary Reference Time Clock (PRTC): Class A and B [4/5]

The solution:

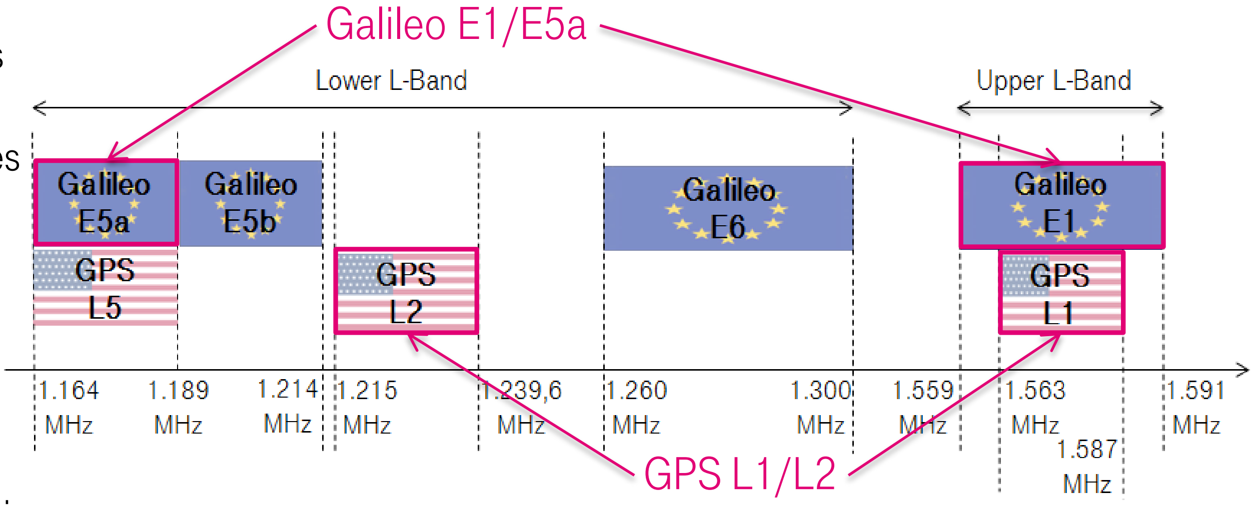
Impact of ionosphere behavior depends on used frequency:

- 1.5 GHz GNSS band (GPS L1 / Galileo E1) delay differs from 1.2 GHz GNSS band (GPS L2 / Galileo E5a) delay
- Phase shift between both carriers can be measured and used for estimation and compensation of absolute ionosphere delay:

➔ Multi-band GNSS receivers

➔ can use measurement results of the same satellites for both frequencies at the same time

➔ to have an additional 'known' factor at the receiver system of equations to eliminate the ionosphere delay variation



Enhanced Primary Clocks and Time Transfer
2. Primary Reference Time Clock (PRTC): Class A and B [5/5]

The multi-band method is well known for

- geodetic ‘SmartRTK’ solutions (Real-Time-Kinematic reference station) and
- metrology UTC timing receivers used by UTC time labs for UTC measurement purpose,

but seldom used for telecommunication application, where usage of single-band GNSS receivers for PRTC functions is state of the art (11-2017).

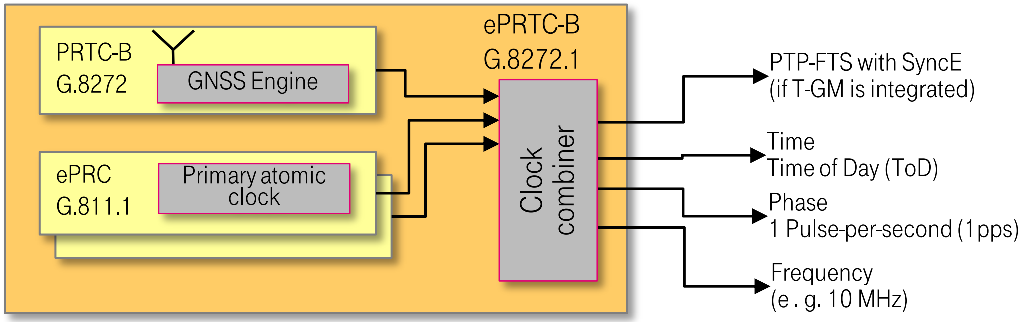
With PRTC Class B standardization by ITU-T, a new market for multi-band GNSS systems is created.

next: Clock Combiner ePRTC

Enhanced Primary Clocks and Time Transfer
3. Clock Combiner: enhanced PRTC [1/2]

Technology view:

- PRTC acc. to G.8272/8272.1 has no relevant hold-over and is fully GNSS dependant
- ePRTC = Clock combiner for GNSS plus primary atomic clock (like ePRC)
- GNSS is used for UTC traceability



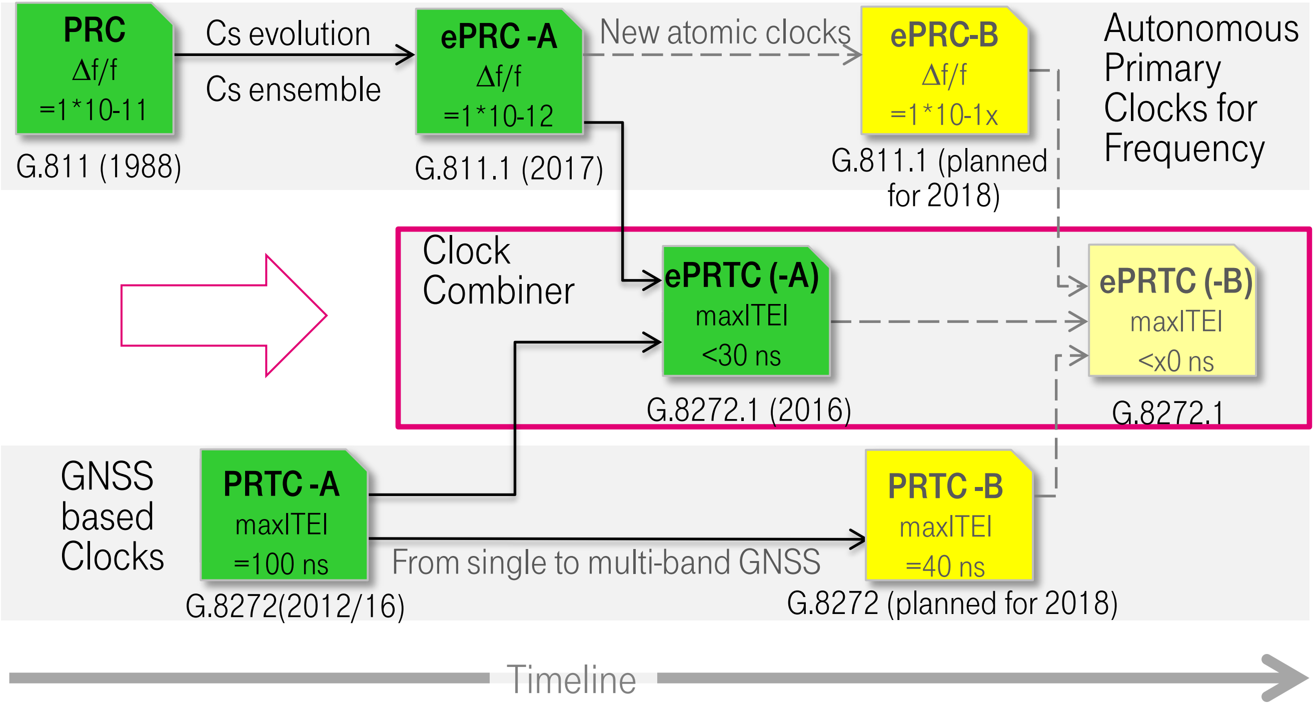
- ePRC is used for stability (low-pass function) and hold-over to overcome GNSS problems

Enhanced Primary Clocks and Time Transfer
3. Clock Combiner: enhanced PRTC [2/2]

Specification view:

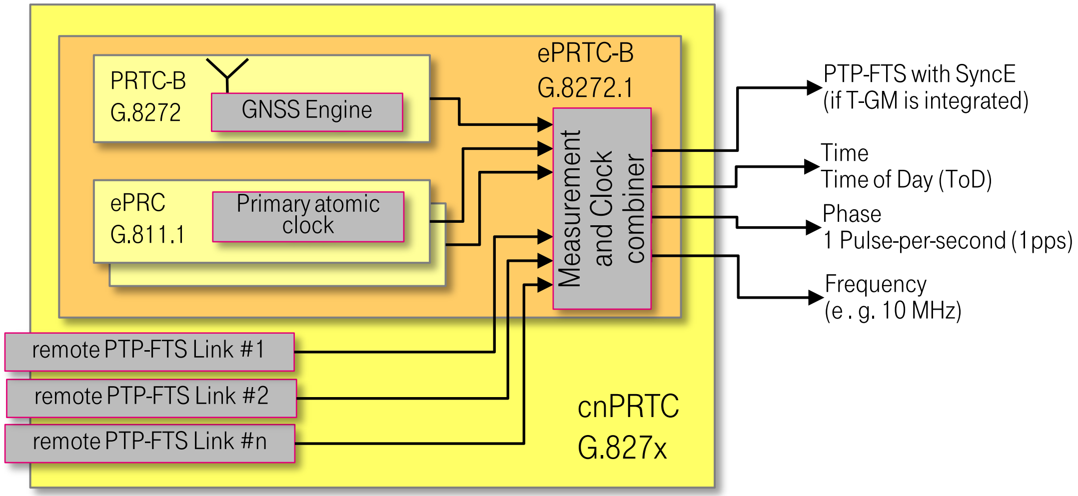
Two classes:

- Class A based on ePRC-A and PRTC-A is already specified in G.82721.1
- Class B (ffs), shall take future technology steps into account, will be based on ePRC-B and PRTC-B, will be added to G.8272.1



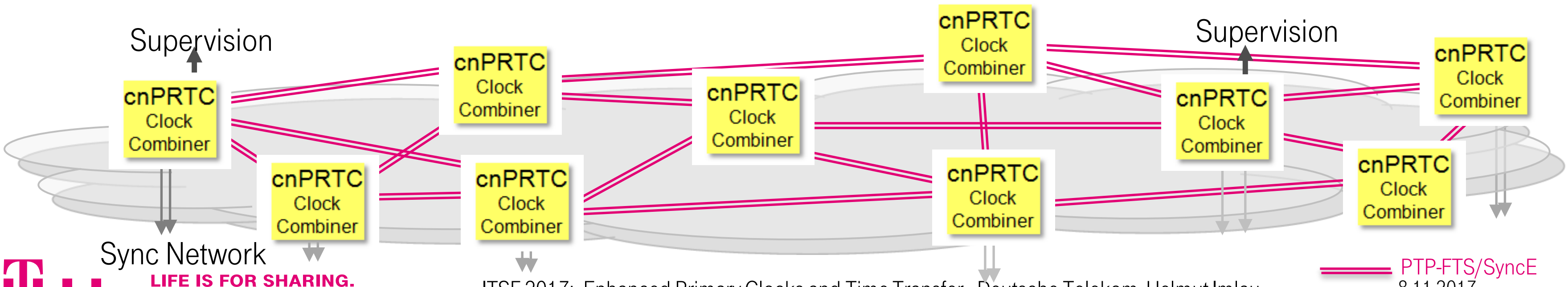
next: cnPRTC

Enhanced Primary Clocks and Time Transfer
4. New cnPRTC concept: coherent network PRTC [1/2]



Technology view:

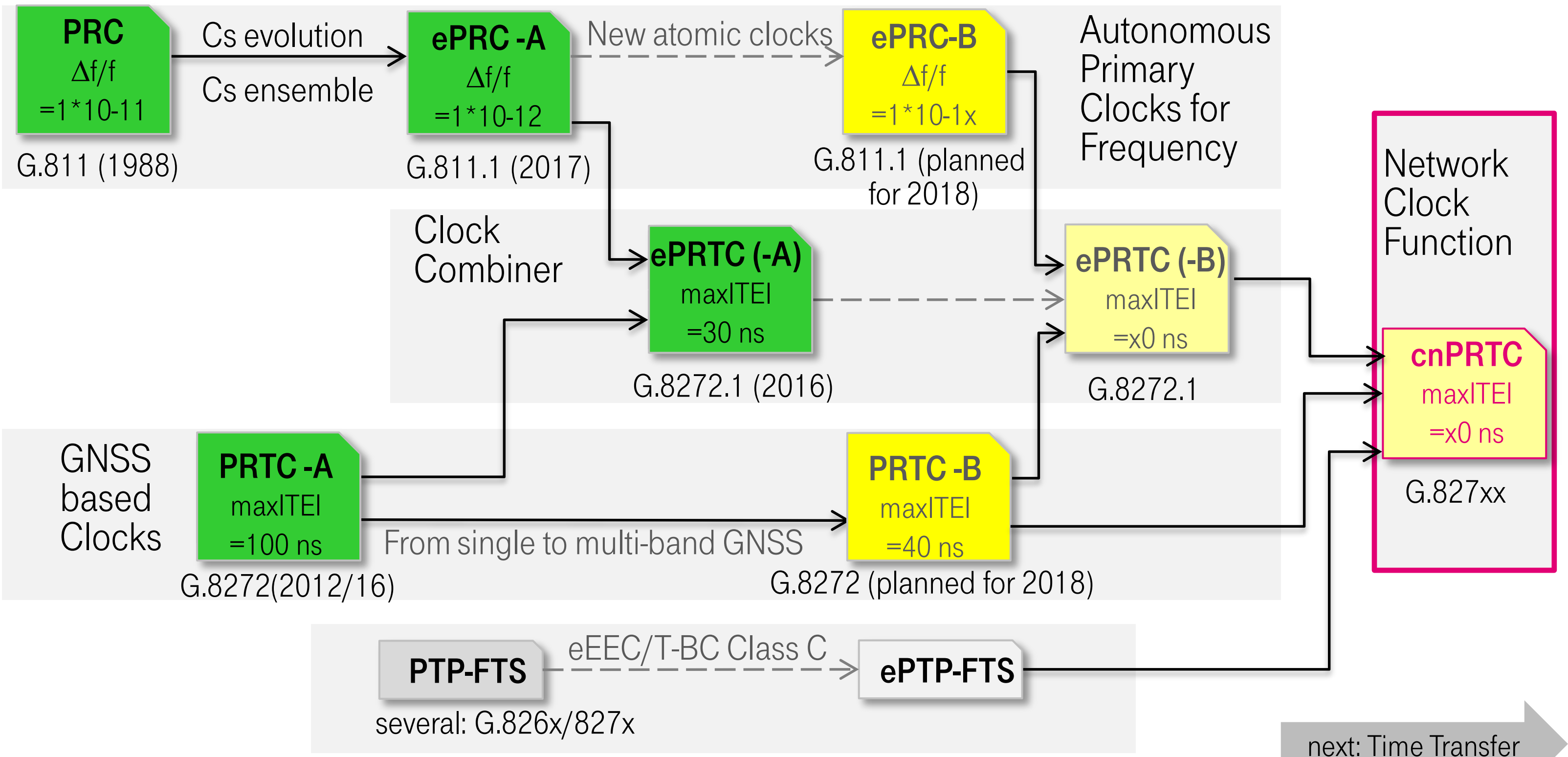
- ePRTC Clock combiner acc. to G.8272.1
  + additional PTP-FTS/SyncE links providing
    time, phase and frequency from and
    to neighborhood locations
- After initial synchronization, it will be GNSS independent to overcome jamming, spoofing and GNSS problems
  (Definition of the second is based on Cs)



Enhanced Primary Clocks and Time Transfer
4. New cnPRTC concept: coherent network PRTC [2/2]

Specification view:

- new re-commen-dation proposed
- based on ePRTC
- based on eEEC, T-BC and T-TSC Class C



next: Time Transfer

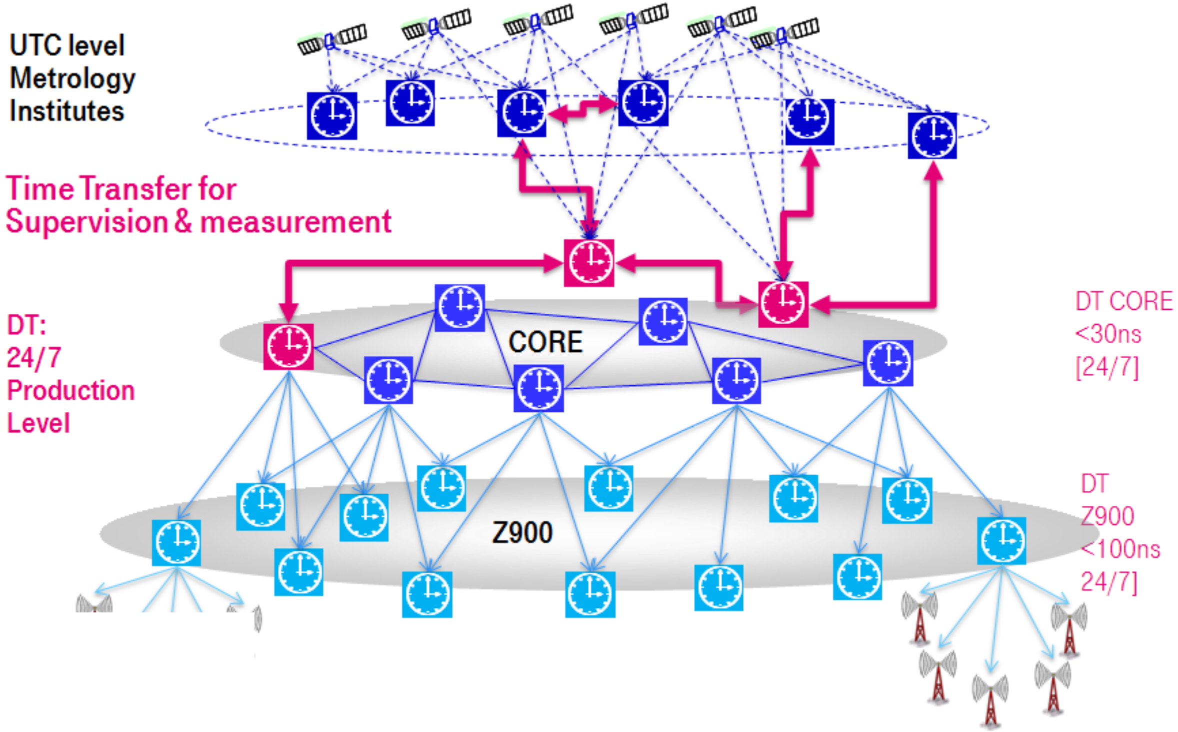
Enhanced Primary Clocks and Time Transfer
Synchronization network supervision need Time Transfer

A cnPRTC based core network needs supervision which should be ...

- ... independent from GNSS to be
  able to detect any GNSS anomaly
  or problem
- ... accurate and precise enough
  for ±30 ns network requirement
  at backbone level

Options:

1. GNSS common view allows ≈ 10 ns
2. High accuracy <u>Time Transfer</u>
   for providing remote reference
   to counters



Enhanced Primary Clocks and Time Transfer
Synchronization network supervision need Time Transfer

High-accuracy Time Transfer methods:

(1) Using PTP-FTS with SyncE bi-directional over same fiber

Pro:	Similar to already specified PTP with full timing support from the network make operation easy
Con:	'Lowest' performance of high-accuracy methods
Evaluation by DT:	If T-BC/EEC are used: T-BC determines the quality, Class C and eEEC (G.8262.1) needed

(2) IEEE1588 High-accuracy (aka. White Rabbit acc. to CERN) allows a few ns ... 1 ns

Pro:	Systems are telecommunication-like (based on special PTP and SyncE)
Con:	Calibration needed, special operational requirements, 'Medium' performance
Evaluation by DT:	PoC planned for 2018

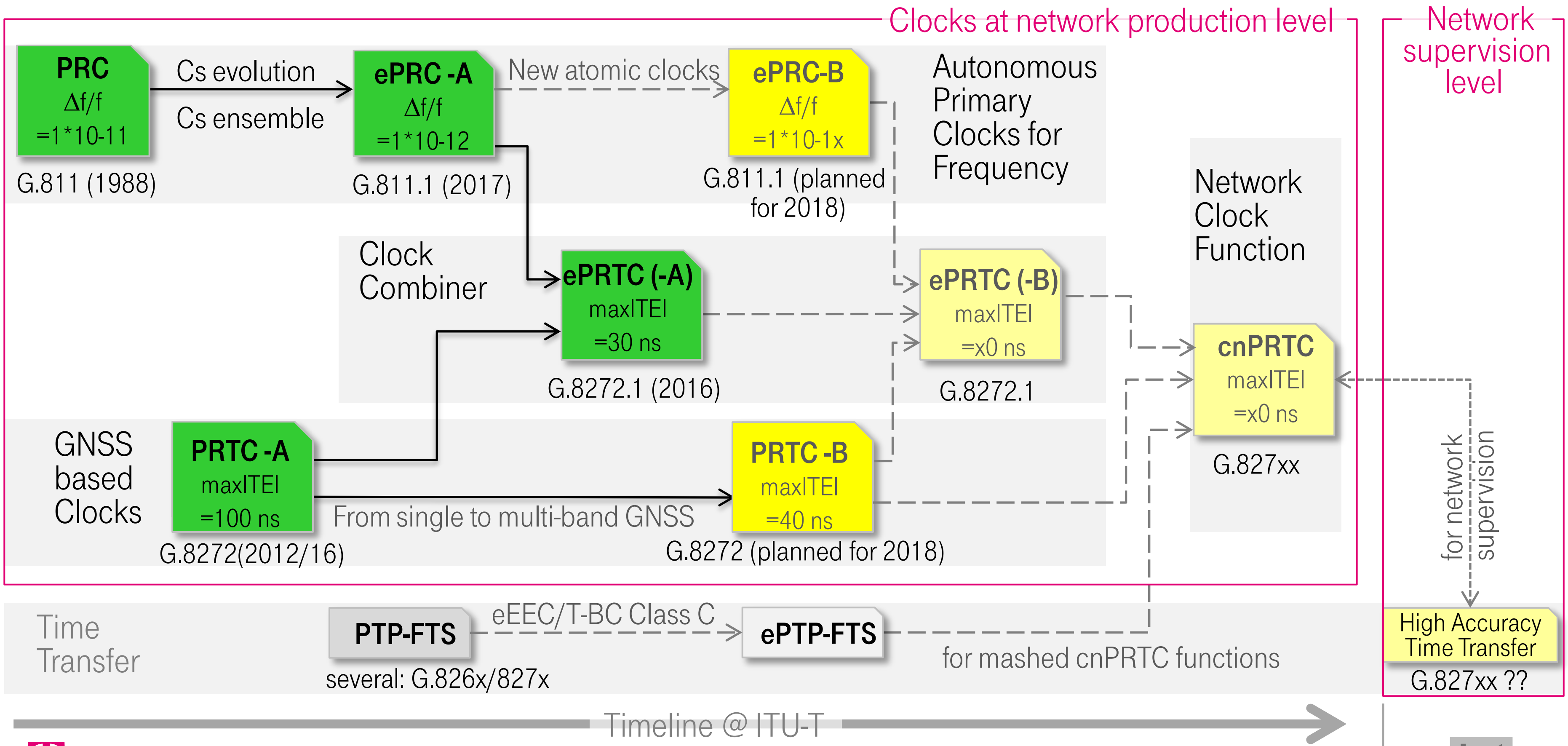
=> Pablo Marín Jiménez
Ultra-accurate time transfer based on the IEEE-1588 High Accuracy Profile standard.

(3) Optical Time Transfer ELSTAB method allows a few 10 ps

Pro:	Highest performance
Con:	Calibration needed, special operational requirements
Evaluation by DT:	Outstanding performance over years, perfect for UTC comparison, (<37 ns, for 9 Month, 500 km) further development needed to simplify calibration and operation

=> Łukasz Śliwczyński, Przemysław Krehlik:
ELSTAB, electronically stabilized fiber optic system for time and frequency distribution with picoseconds accuracy

Enhanced Primary Clocks and Time Transfer: ITU-T Rec. overview



Enhanced Primary Clocks and Time Transfer

Thank you.

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