5G ITU Standards

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5G and New Sync Standards

ITU-T G.8271 Class level of accuracy

Table 1 – Time and phase requirement classes

Class level of accuracy	Time error requirements (Note 1)	Typical applications (for information)
1	500 ms	Billing, alarms.
2	100 – 500 µs	IP delay monitoring. Synchronization signal block (SSB)-measurement timing configuration (SMTC) window.
3	5 µs	LTE TDD (large cell). Synchronous Dual Connectivity (for up to 7 km propagation difference between eNBs/gNBs in FR1). (Note 2)
4	1.5 µs	UTRA-TDD, LTE-TDD (small cell), NR TDD, WiMAX-TDD (some configurations). Synchronous dual connectivity (for up to 9 km propagation difference between eNBs/gNBs in FR1) (Note 2). New radio (NR) intra-band non-contiguous and inter-band carrier aggregation, with or without multiple input multiple output (MIMO) or transmit (TX) diversity.
5	1 µs	WiMAX-TDD (some configurations).
6	x ns (Note 4)	Various applications, including location based services and some coordination features. (Note 3)

NOTE 1 – The requirement is expressed in terms of time error with respect to a common reference. Some of the original requirements were expressed in terms of relative time error.

NOTE 2 – FR1: 410 MHz – 7.125 GHz; FR2: 24.25 – 52.6 GHz

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

NOTE 4 – For the value x, refer to Table 2 and Table II.2 of Appendix II.

Table 2 – Time and phase requirements for cluster based synchronisation

Class level of accuracy	Maximum relative time error requirements (Note 1)	Typical applications (for information)
3A	5 µs	LTE MBSFN.
4A	3 µs	NR intra-band non-contiguous (FR1 only) and inter-band carrier aggregation; with or without MIMO or TX diversity.
6A	260 ns	LTE 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. NR intra-band contiguous (FR1 only) and Intra-band non-contiguous (FR2 only) carrier aggregation, with or without MIMO or TX diversity.
6B	130 ns	LTE intra-band contiguous carrier aggregation, with or without MIMO or TX diversity. NR (FR2) intra-band contiguous carrier aggregation, with or without MIMO or TX diversity.
6C (Note 2)	65 ns	LTE and NR MIMO or TX diversity transmissions, at each carrier frequency.

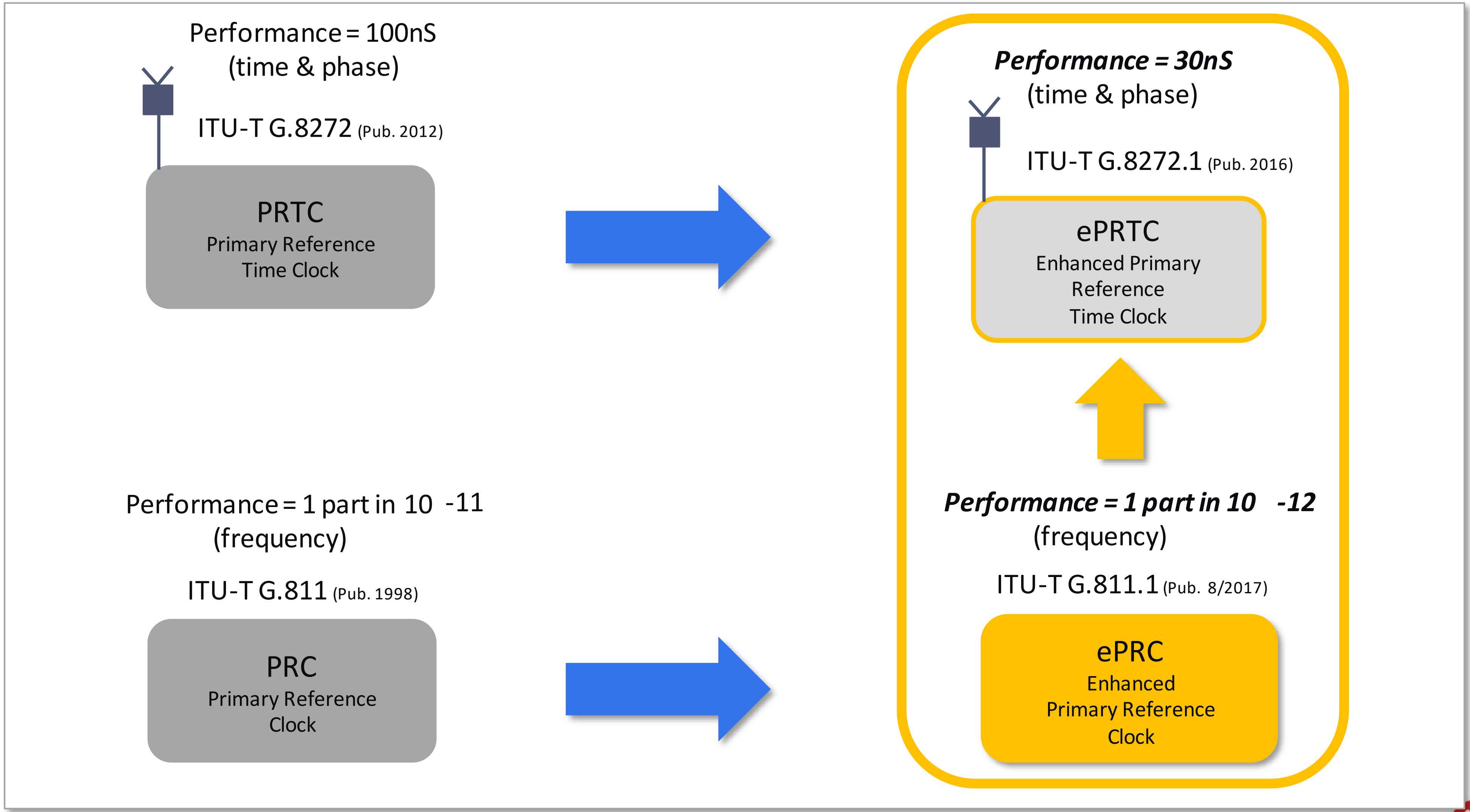
NOTE 1 – The maximum relative time error requirements represent the largest timing difference measured between any two elements of the cluster. See Appendix VII of [b-ITU-T G.8271.1] for illustration of how requirements are specified in a cluster. In 3GPP terminology this is equivalent to time alignment error (TAE).

NOTE 2 – Level 6C is an internal equipment specification, and does not result in a synchronization requirement on the transport network.

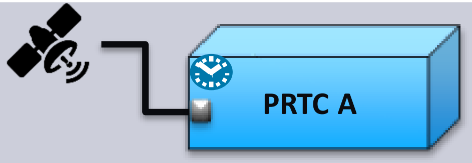
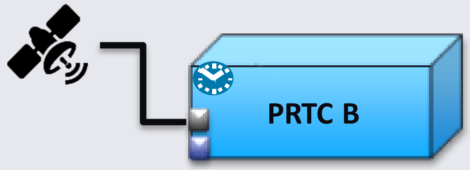
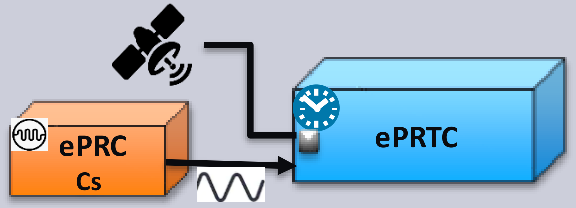
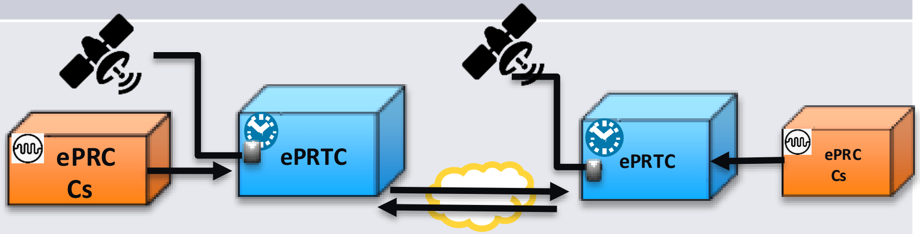
Transport and Clocks new ITU-T needs

G.8272.1 - ePRTC
G.8262.1 - ePRC
G.8272 – PRTC Class A and B
G.8273.2 – Network Element T-BC and T-TSC
G.8271.1 - Clock Holdover

ePRTC and ePRC



New Standard Clocks for 5G and so on

PRTC Type	Performance	Device Configuration
PRTC class A (G.8272)	**Maximum time error 100ns from UTC** Single band GNSS	
PRTC class B (G.8272)	**Maximum time error 40ns from UTC** Dual band GNSS - Error reduction of GNSS signal reception by multi-band receiver	
Enhanced PRTC (ePRTC) (G.8272.1)	**Maximum time error 30ns from UTC** Time synchronization is maintained when GNSS reception is impossible by frequency reference device ePRC (within 100ns over 14 days)	
Coherent network PRTC (cnPRTC) (G.8275 et al.) under discussion	**Maximum time error ?** Reliability improved by mutual monitoring and comparison through the network High precision achieved by mutual synchronization	

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Standard Background – ITU-T G.8273.2 Amendment 2 (01-2019)

- For class D, the maximum time error measured through a **first-order low-pass filter with a bandwidth of 0.1 Hz**, max|TEL|, is shown in Table D.2.

Table D.2 – Maximum absolute time error low-pass filtered (max|TE_L|)

T-BC/T-TSC Class	Maximum absolute time error – max|TE_L| (ns)
D	5 ns

- The noise generation is divided into two components, the cTE and the dTE noise generation.
- D.2.1.1 Constant time error generation (cTE):

At the precision time protocol (PTP) and 1 pulse per second (PPS) outputs, the cTE generation for classes C and D is shown in Table D.3

Table D.3 – T-BC/T-TSC permissible range of constant time error

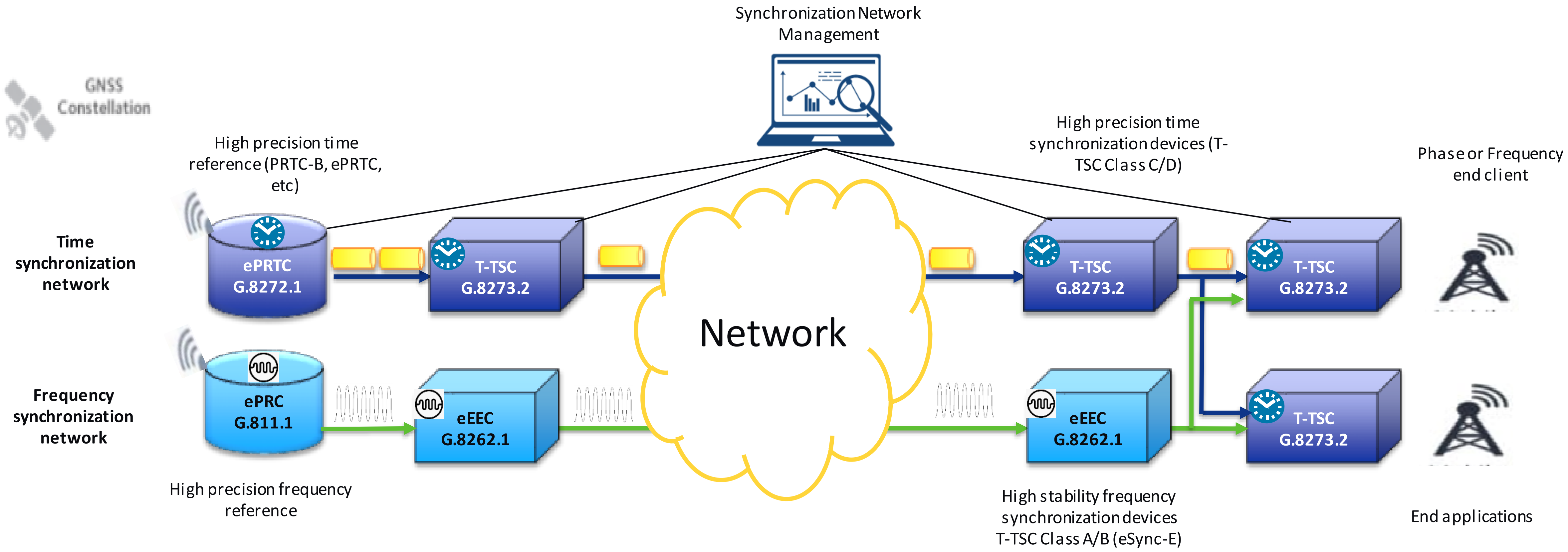
T-BC/T-TSC Class	Permissible range of constant time error – cTE(ns))
C	±10
D	For further study

NOTE 2 – Constant time error definition and the method to estimate constant time error are defined in [ITU-T G.8260]. For the purpose of testing the limits in Table D.3, an estimate of constant time error should be obtained by **averaging the time error sequence over 1,000 sec.**

T-BC Classes

Parameters	Conditions	Class A	Class B	Class C	Class D
Max |TE|	Unfiltered 1000s.	100ns	70ns	30ns	FFS
Max $\|TE\|_L$	0.1Hz LPF 1000s measurement	-	-	-	5ns
cTE	Averaged over 1000	50ns	20ns	10ns	FFS
dTE_L MTIE	0.1Hz LPF const temp 1000s	40ns	40ns	10ns	FFS
dTE_L TDEV	0.1Hz LPF const temp 1000s	4ns	4ns	2ns	FFS
dTE_H	0.1Hz HPF const temp 1000s	70ns	70ns	FFS	FFS

4.5G & 5G Synchronization Architecture: High Precision Core Clocks and new transport elements class



ePRTC – Enhanced Primary Reference Time Clock
ePRC – Enhanced Primary Reference Clock
T-TSC – Telecom Time Slave Clock
T-BC – Telecom Boundary Clock
eEEC – Enhanced Synchronous Ethernet Equipment Clock
cTE – Constant Time Error

MaxTE (ns)	Class A	Class B	Class C
T-TSC	100	70	30
T-BC	100	70	30

*Class D for future study (Max|TE| = 5ns)

Holdover

Time Error Budget based on G.8271.1

Recommendation

ITU-T G.8271.1/Y.1366.1 (11/2022)

Network limits for time synchronization in packet networks

Table V.1 – Example of time error allocation

Budget component	Failure scenario (a) *(T-GM rearrangement)*	Failure scenario (b) *(Short GNSS interruption)*	Failure scenario (c) *(Long holdover periods, e.g., 1 day)*
PRTC (ce_{ref})	100 ns	100 ns	100 ns

V.3 Failure scenarios

There are three main failure scenarios considered here.

a) Failures in the synchronization network that cause the end application clock to enter holdover for a short period. This is denoted TE_{REA} (rearrangement TE), which is provided by end application, and is normally considered to be less than 250 ns.

– As an example, this might be triggered by a loss of PRTC traceability of one of the redundant T-GMs in the network. The loss of traceability is indicated by the clockClass field carried in the Announce messages indicating a degraded quality level, and triggers the BMCA to run. If the clockClass is set to a value that is unacceptable to the end application, then the clock will enter holdover for a short period (e.g., 1 min) prior to synchronizing to another T-GM.

b) Failures in the synchronization network that do not cause the end application clock to enter holdover. This is denoted TE_{HO} (holdover TE), which is provided by PRTC, and is normally considered to be less than 400 ns.

– As an example, this might be related to a short interruption of the GNSS signal (e.g., 5 min), causing the PRTC to go into holdover for a short period. During this period, either a PRC-traceable synchronous Ethernet signal or a stable internal oscillator might be used as a back-up to the PRTC. In this case, the clockClass field continues to indicate an acceptable quality level so that the end application clock stays locked to the PTP reference.

c) Long interruption to the GNSS signal, with no alternative UTC-traceable T-GM available. The long-term holdover condition is handled as a special case where the 1.5 µs limit is exceeded. This is assumed to be a particularly rare event.

The TE due to the holdover in this case, provided by PRTC, is assumed to be, in the worst case, 2 400 ns.

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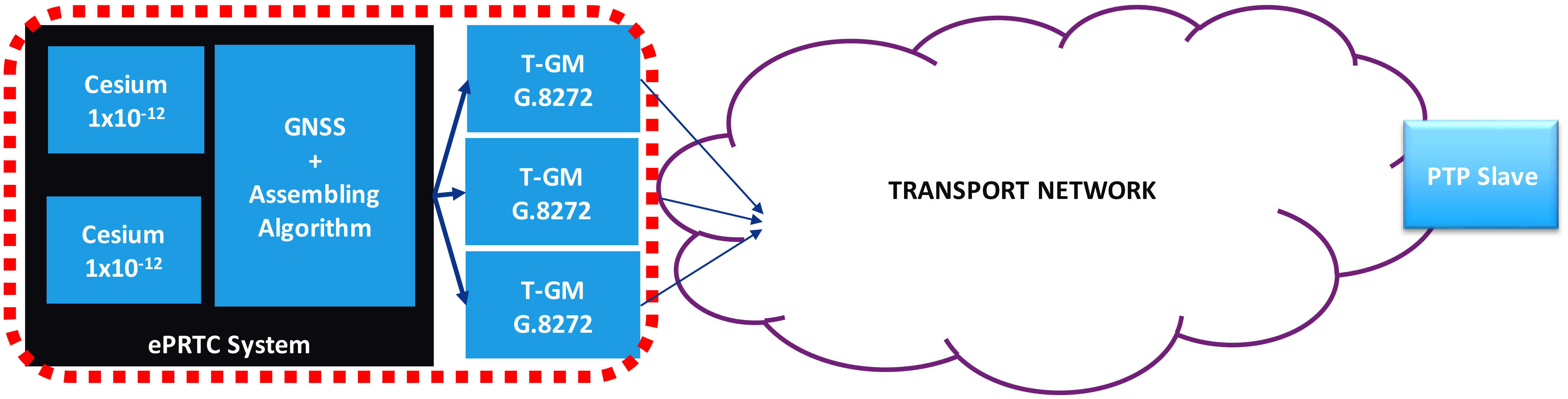
Time Error Budget End to End

Budget Component	PRTC (G.8272)	Holdover and Network Rearrangements	Random Error + NEs error + Link Asymmetries	End Application
Time Budget	±100 ns	±400 ns	±850 ns	±150 ns

← ± 1.5 µs →



Comparison Rubidium vs. High Quality OCXO (Qz) Time/Phase Holdover

Oscillator Type	200 ns	400 ns	1100 ns	1500 ns	5000 ns	10000 ns
OCXO ++ (other vendors) (zero temp variation & Phase/Freq Error ZERO)	---	15 hours	1.3 days	2 days	4 days	6 days
Rubidium (Microsemi) (no restrictions on initial phase and freq error, regular temp variation of ±5˚C)	1 day	1.8 days	3.5 days	4.3 days	8.5 days	12.5 days

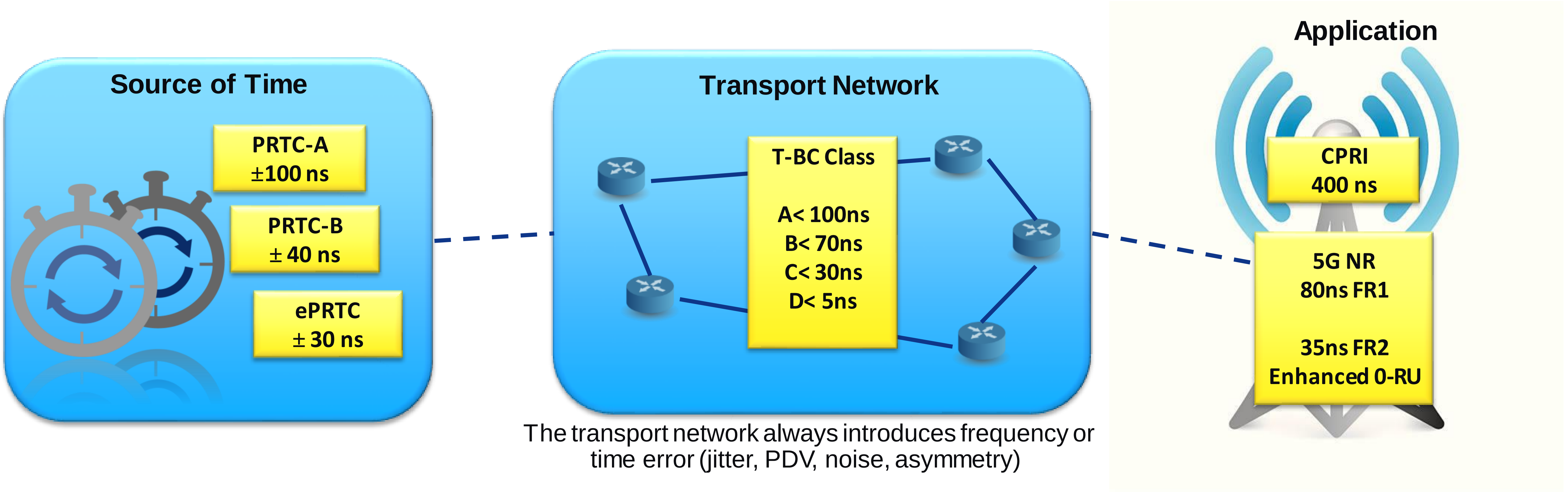
New Architectures for 5G

IEEE802.1 CM – Time Error
G.8275.2 – Unicast profile
G.8275.1 – Multicast profile
G.8273.4 – APTS

Time Error (IEEE 802.1 CM)

- **Category A** (relative requirement)
  - Maximum relative Time Alignment Error is **130 ns**
  - (T-GM or T-BC is nearest common master)
- **Category B** (relative requirement)
  - Maximum relative Time Alignment Error is **260 ns**
  - (T-GM or T-BC is nearest common master)
- **Category C** (absolute requirement)
  - Maximum absolute Time Alignment Error is **1.1 us**

Time Error Budget Allocation 5G



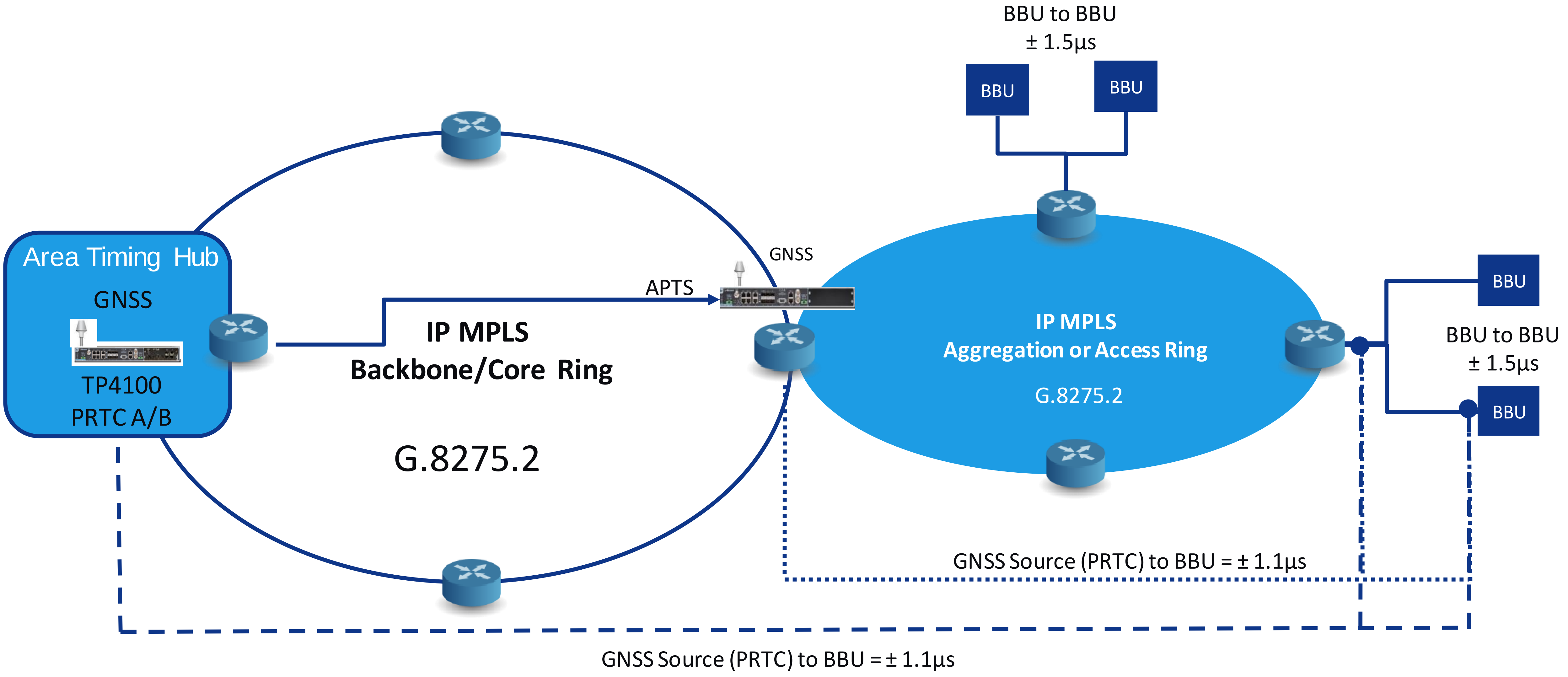
The transport network always introduces frequency or time error (jitter, PDV, noise, asymmetry)

GNSS + Cesium

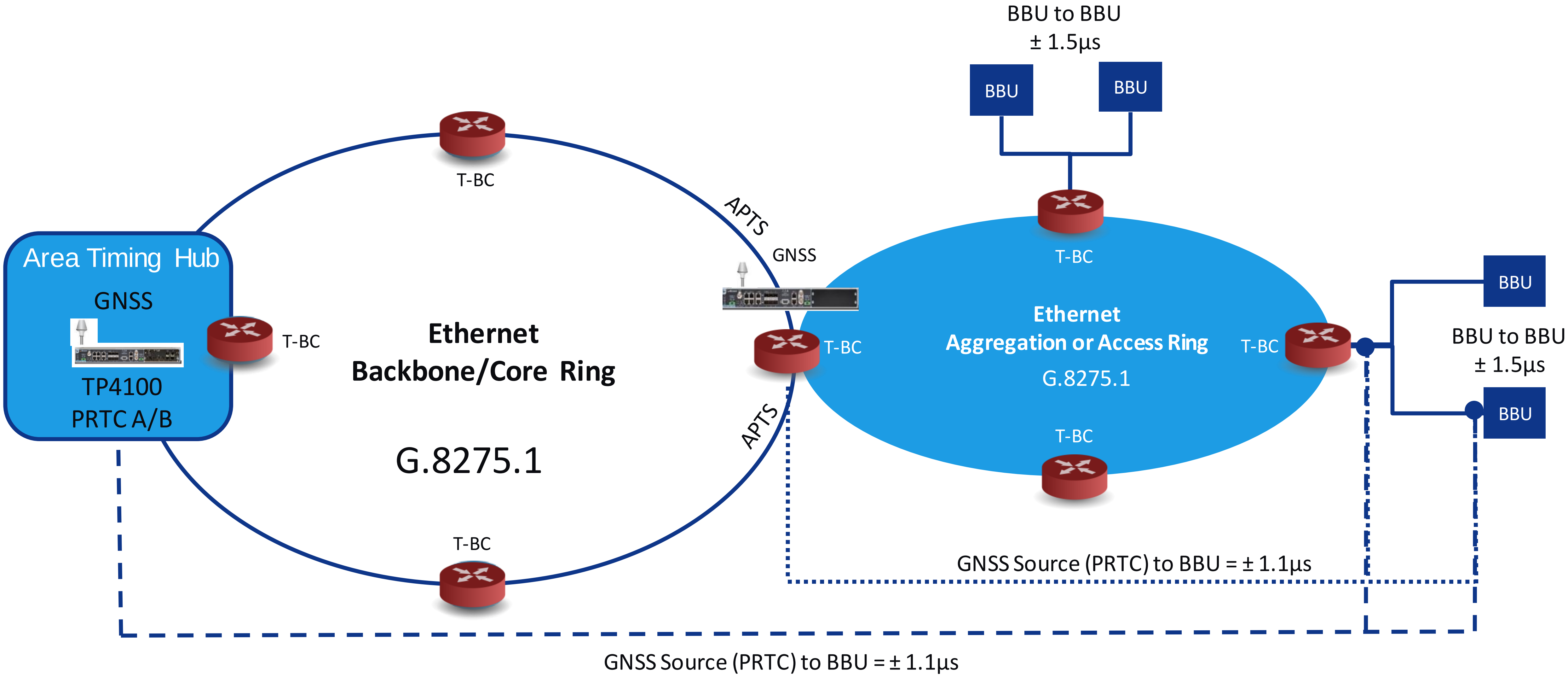
Fiber

RU

Transport IP-MPLS (Layer 3) – Unicast G.8275.2

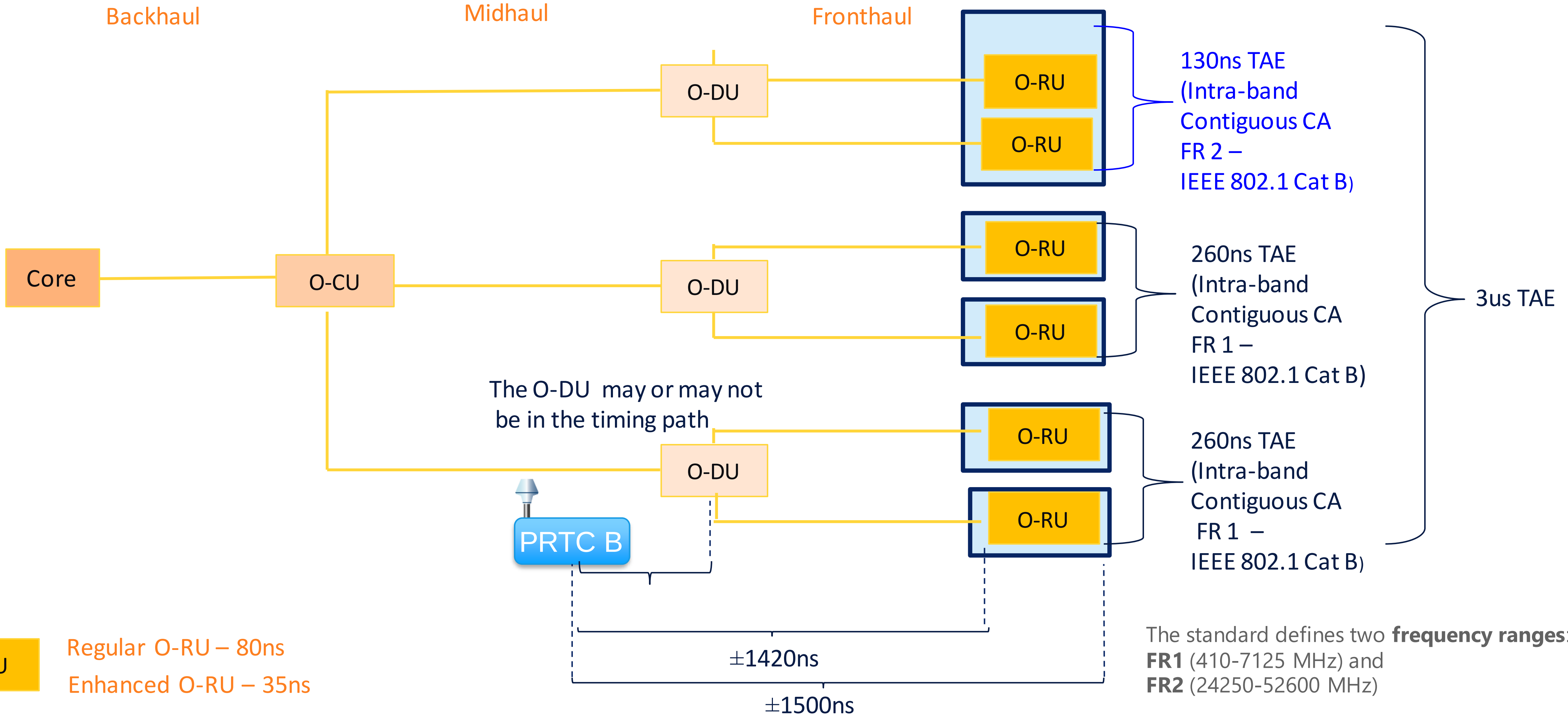


Transport Ethernet (Layer 2) – Multicast G.8275.1



Fronthaul – 5G NR

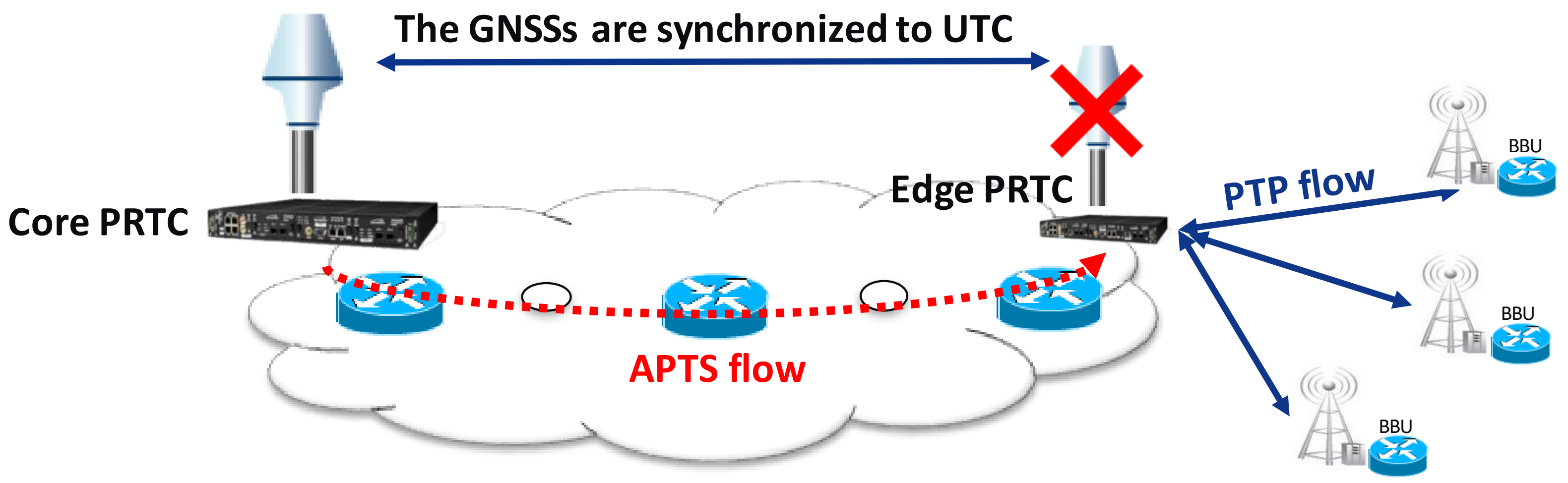
TE Budget for O-RU
is 80 Nanoseconds

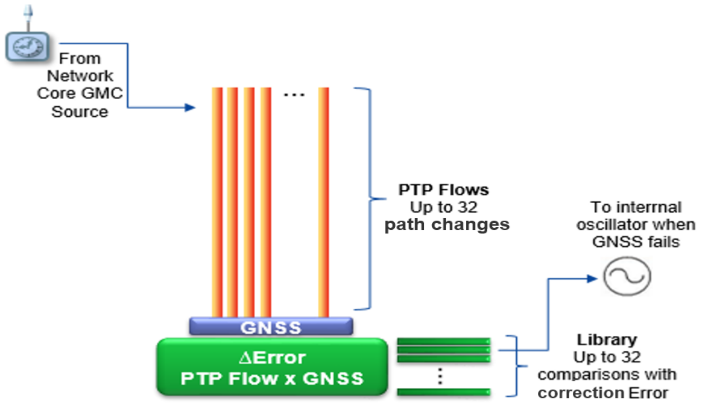


Regular O-RU – 80ns
Enhanced O-RU – 35ns

The standard defines two **frequency ranges**:
FR1 (410-7125 MHz) and
FR2 (24250-52600 MHz)

APTS G.8273.4 (enhanced version from Microchip)





- APTS synchronizes the Core PRTC with the Edge PRTC using PTP
- The PTP flow into the Edge PRTC is calibrated using the local GNSS which is the same as the Core GNSS
- Edge PRTC can store up to 32 variation flows (link asymmetry, congestion, route change, etc.)
- *This Advanced Asymmetry Compensation Algorithm can hold around 200ns for a week
- GNSS Proxy license allowing the Edge PRTCs to point up to 3x different APTS sources

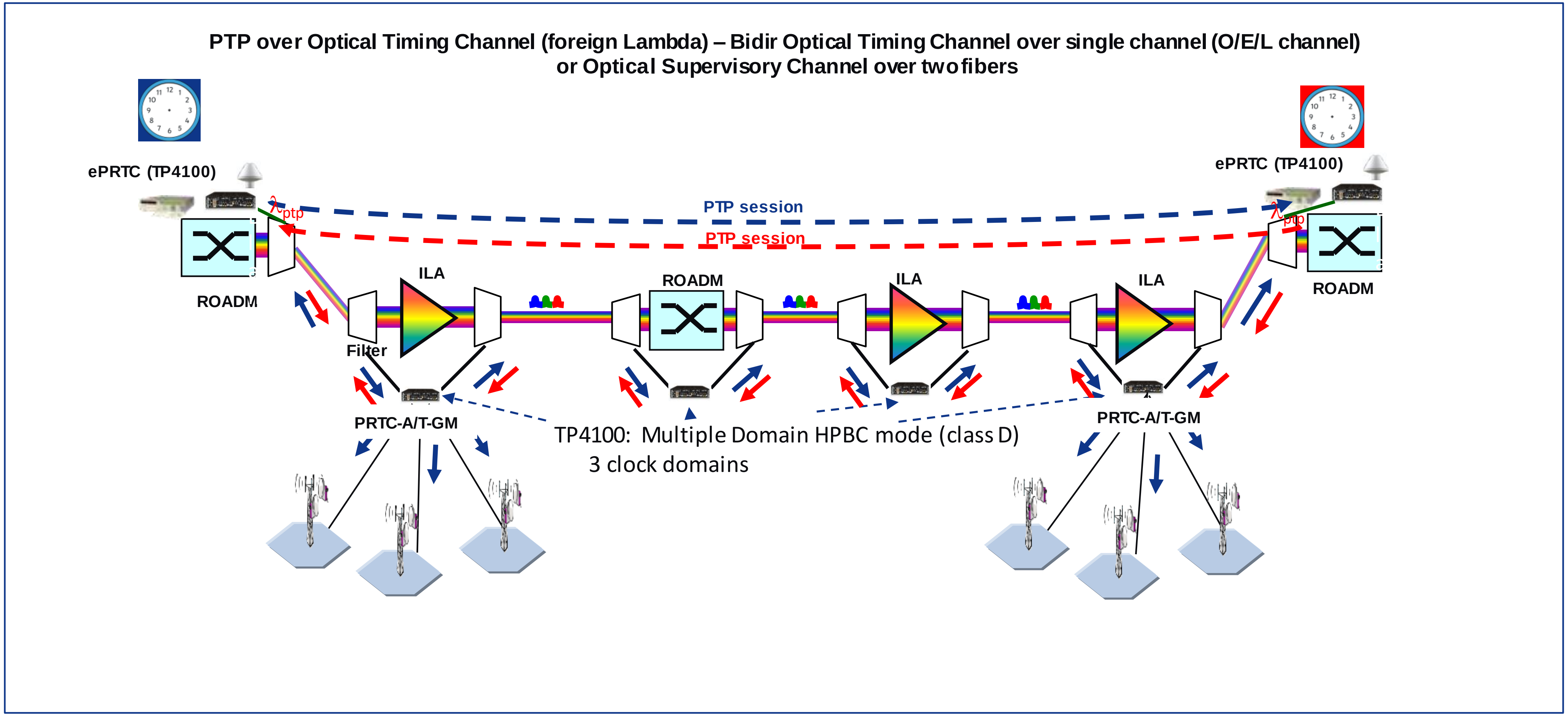
**Expected based on stable transport networks with low PDV and Asymmetry besides all nodes synchronized*

5G – Dedicated Optical Sync Network

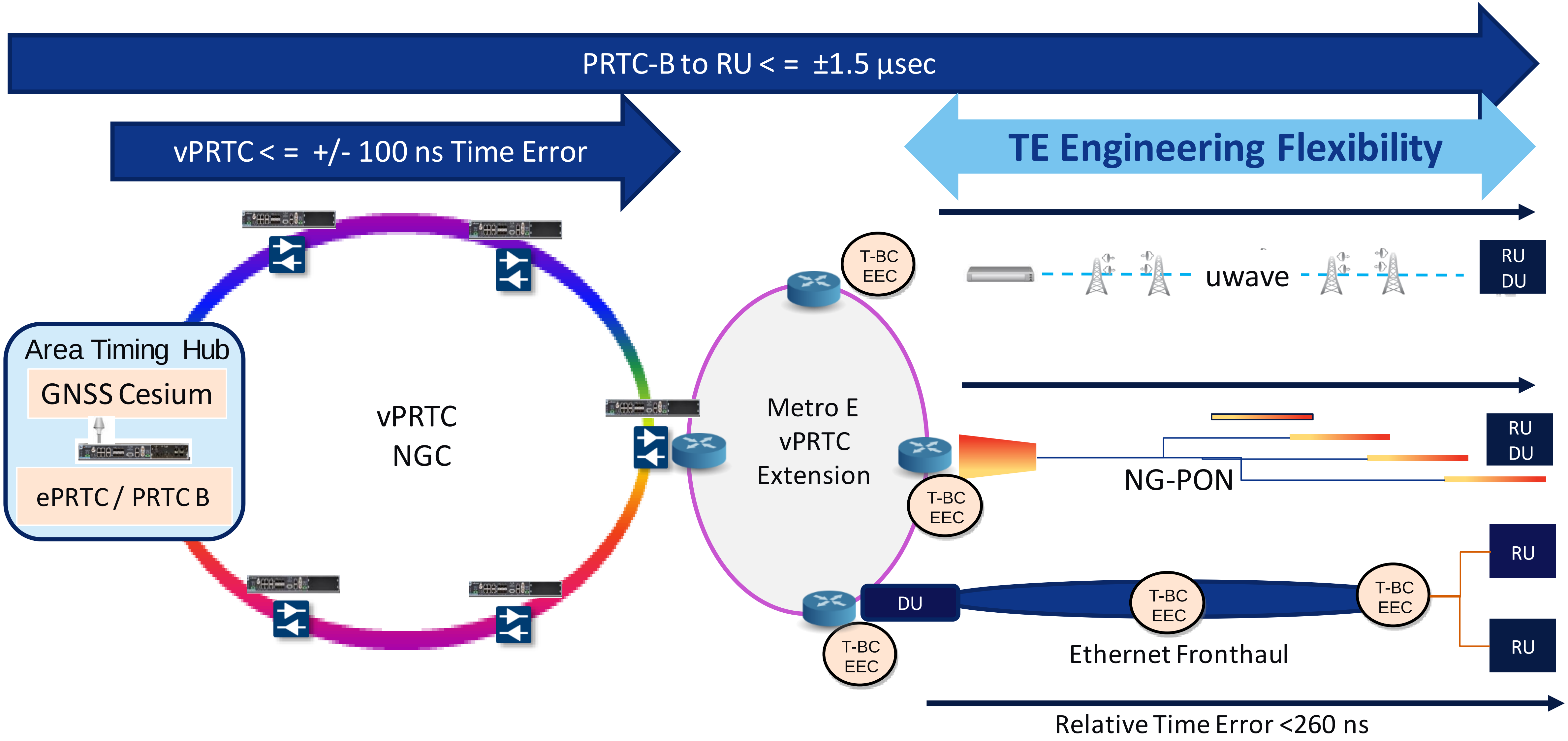
Virtual PRTC (vPRTC)

Ultra stable time transfer over optical fiber

Single fiber bidirectional wavelength to limit asymmetries: Phase noise & asymmetry can be reduced down to fiber temperature fluctuation & use of different wavelengths in each direction, which can be compensated.

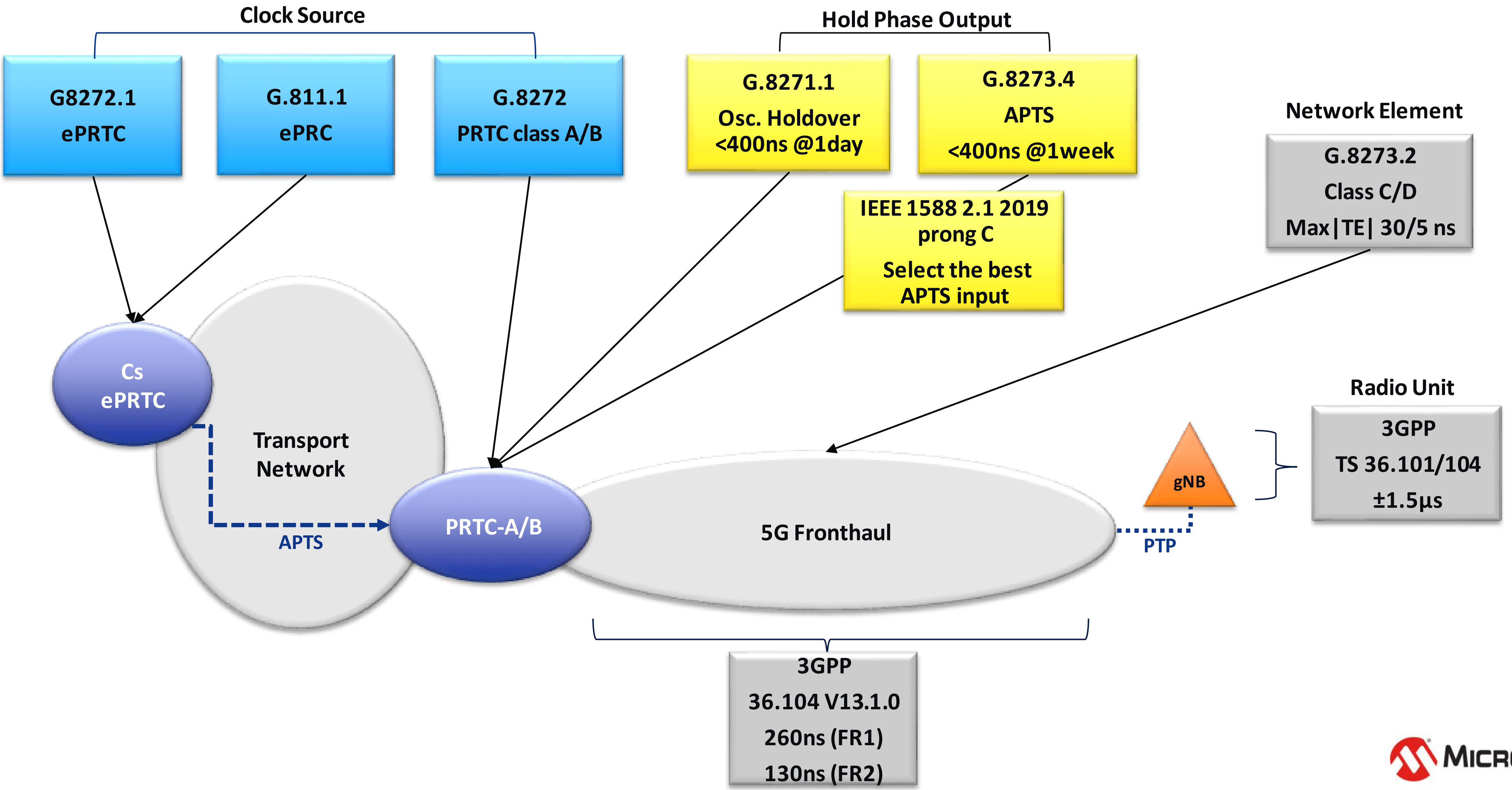


vPRTC Enables Flexible TE Engineering at the Access Edge

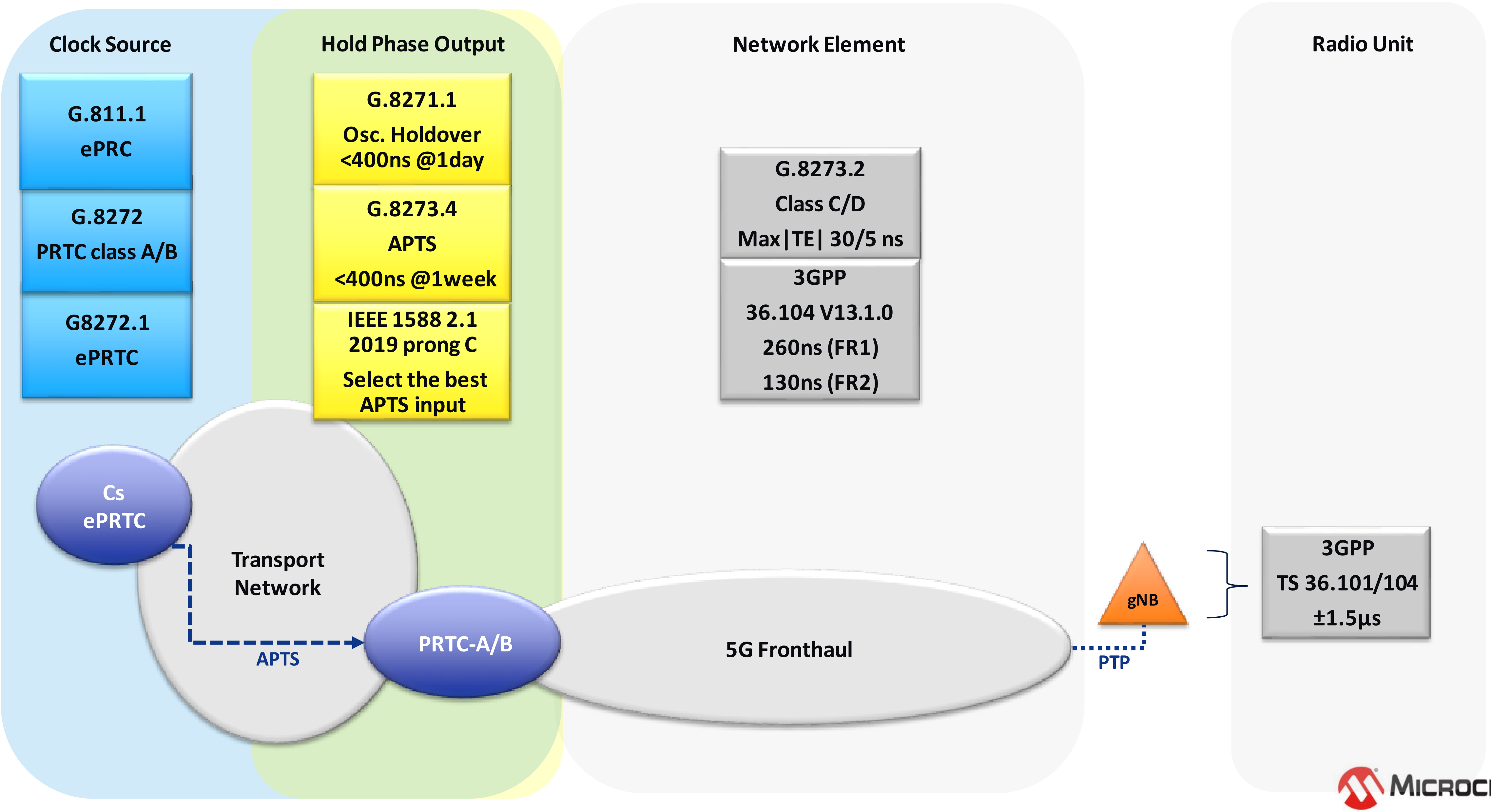


Summary

Summary


Clock Source
G8272.1
ePRTC
G.811.1
ePRC
G.8272
PRTC class A/B
Hold Phase Output
G.8271.1
Osc. Holdover
<400ns @1day
G.8273.4
APTS
<400ns @1week
IEEE 1588 2.1 2019
prong C
Select the best
APTS input
Network Element
G.8273.2
Class C/D
Max|TE| 30/5 ns
Cs
ePRTC
Transport
Network
APTS
PRTC-A/B
5G Fronthaul
gNB
PTP
Radio Unit
3GPP
TS 36.101/104
±1.5µs
3GPP
36.104 V13.1.0
260ns (FR1)
130ns (FR2)

Summary



Clock Source
Hold Phase Output
Network Element
Radio Unit
G.811.1
ePRC
G.8272
PRTC class A/B
G8272.1
ePRTC
G.8271.1
Osc. Holdover
<400ns @1day
G.8273.4
APTS
<400ns @1week
IEEE 1588 2.1
2019 prong C
Select the best
APTS input
G.8273.2
Class C/D
Max|TE| 30/5 ns
3GPP
36.104 V13.1.0
260ns (FR1)
130ns (FR2)
Cs
ePRTC
Transport
Network
APTS
PRTC-A/B
5G Fronthaul
gNB
PTP
3GPP
TS 36.101/104
±1.5µs

Reference Table

ITU-T Standard		Microchip
ePRTC G.8272.1	±30ns	TP4100
PRTC class B G.8272	±40ns	TP4100
PRTC Holdover G.8271.1	<400ns @24hs	TP4100 Rubidium
APTS G.8273.4	<400ns @week	TP4100 up to *96x PTP different flows from TX network
High Performance Boundary Clock G.8273.2	Class D Max|TE| 5ns	TP4100

*GPS Proxy

Reference Table TP4100

Differentiator		Microchip
1G ports	Up to 8 *expansion +4	TP4100
10G ports	Up to 4	TP4100
PTP Capacity @128	1000	TP4100
NTP Capacity *with PTP simultaneous	20.000 rps per port *Up to 160.000 rps in total	TP4100
Redundancy	Full redundancy (1:1) (2xTP4100 as one) ➢ 2x oscillators ➢ 4x power suppliers ➢ 8x1GbE protected ports (8+8) ➢ 2x GNSS receptors ➢ IP Failover (same IP for both boxes to all ports) ➢ *Enhanced redundancy: positioning the 2x boxes in a different rack	TP4100
Rubidium Oscillator	Based on optical engine to control the Rb Gas CPT (coherent population trapping)	TP4100
GNSS Receptor	Multi-Band Receptor	TP4100

Thank You!

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