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Distribution of Timing: Sync over the Packet Layer of Networks

WSTS Tutorial – March 2023

Contents

Note: actions are being taken in various Standardization bodies to revise the Master/Slave terminology («inclusive terminology»).
This process is expected to be completed by 2023 in most of the concerned bodies.
This slide set is planned to be updated based on the outcome of these initiatives

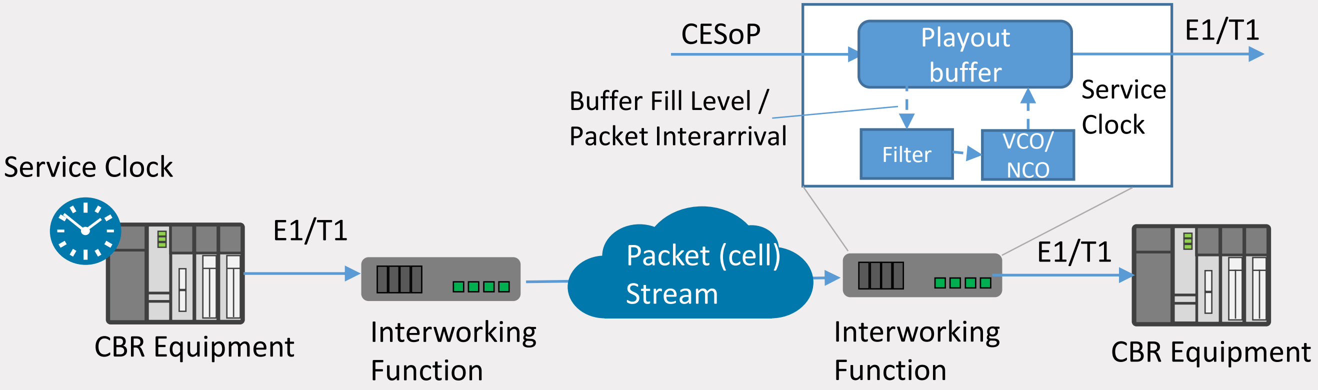
The use of Inclusive Terminology

- P1588g – Amendment to IEEE 1588 for inclusive terminology
  - Scope – “This amendment adds an optional alternative suitable and inclusive terminology to the terms: “master” and “slave”, but it does not replace the terms “master” and “slave”.”
  - timeTransmitter and timeReceiver were selected as an alternative nomenclature for master and slave, and it has been used as a basis for the draft amendment
  - The approved draft of this amendment is available through IEEE SA as **IEEE Std 1588g-2022**, and it is in the process of being published.
- IEEE 802.1 TSN is working on an amendment to IEEE Std 802.1AS to replace offensive words in the standard, it is based on IEEE Std 1588g-2022
- IEEE P3400 WG
  - IEEE P3400 Standard for Use of Inclusive Language in Technical Terminology and Communications
- ITU-T is planning to revise terminology of active Recommendations
  - Revising terminology of Physical Layer (SyncPHY) is also planned
- Master and Slave are still used in this presentation

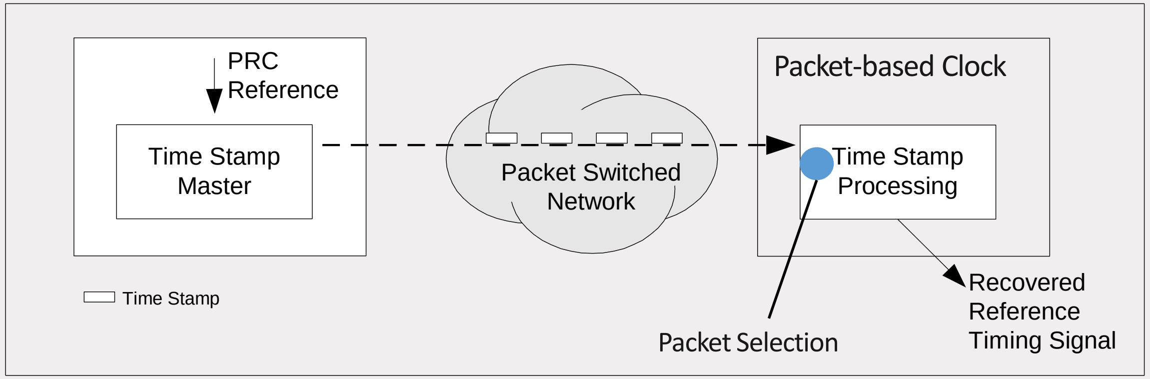
Contents

Introduction

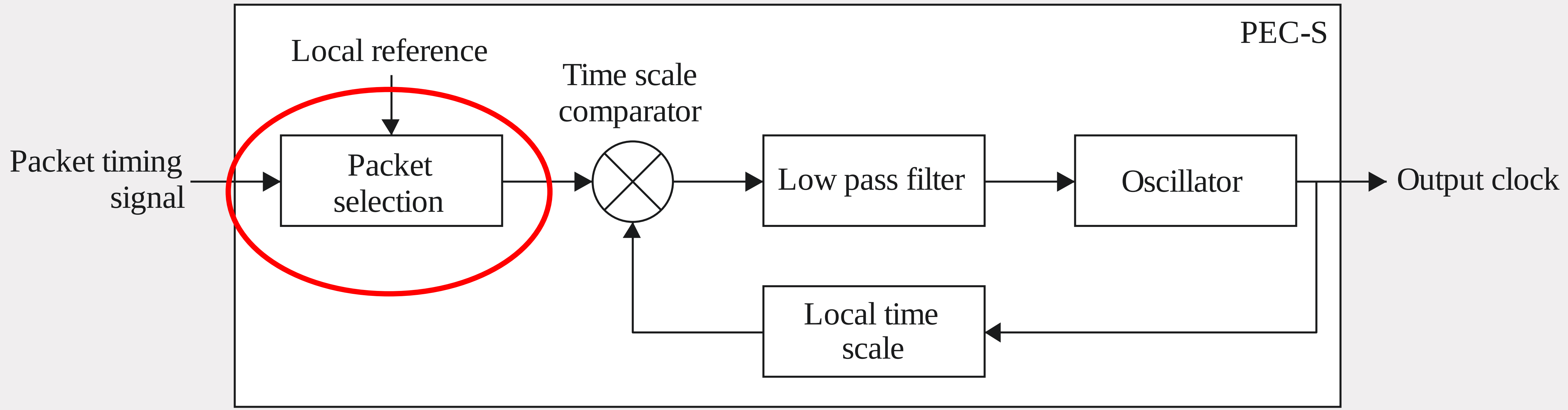
- Timing carried via packets was originally used to recover the service timing (e.g., 2 Mbit/s service carried over packet networks); known as “Circuit Emulation”
    - Service clock adjusts based on buffer fill level / packet arrival rate, **PDV** influences wander at the network output



- Similar principle applied replacing traffic data with dedicated timing packets (NTP or PTP)
    - Packets may not arrive regularly, but **timestamps** mean time information can be extracted
    - Timing information contained in the arrival/departure time of the packets
    - **Two-way or one-way** protocols
    - Timing recovery process requires **PDV filtering**

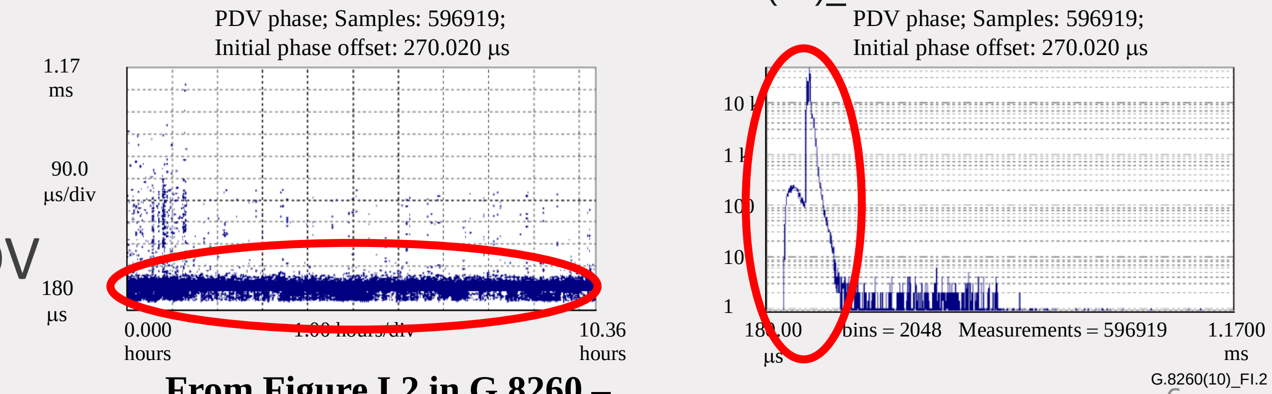


Packet-based Equipment Clock



G.8263-Y.1363(12)_FA.1

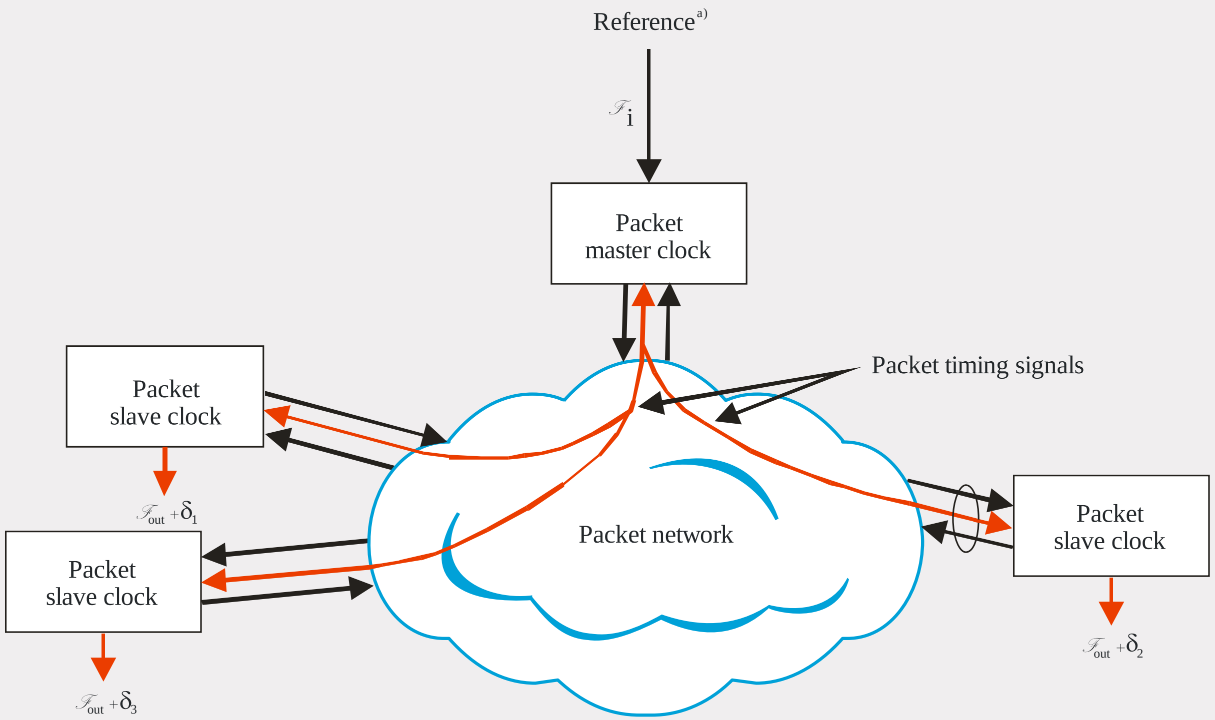
- Concept of «**Packet Selection**»:
    - Pre-processing of packets before use in a traditional clock to handle PDV



From Figure I.2 in G.8260 –
Measured packet delay and corresponding PDV histogram

ITU-T G.8265.1 Frequency Profile – IEEE-1588 without support from Network

- Profile targeted for applications that need only frequency synchronization
- Packet delay variation (PDV) will impact the performance of the clock (PDV filtering is needed in the slave clocks)
- Several ITU-T Recommendations, G.826x series, G.781.1, have been developed to support this profile



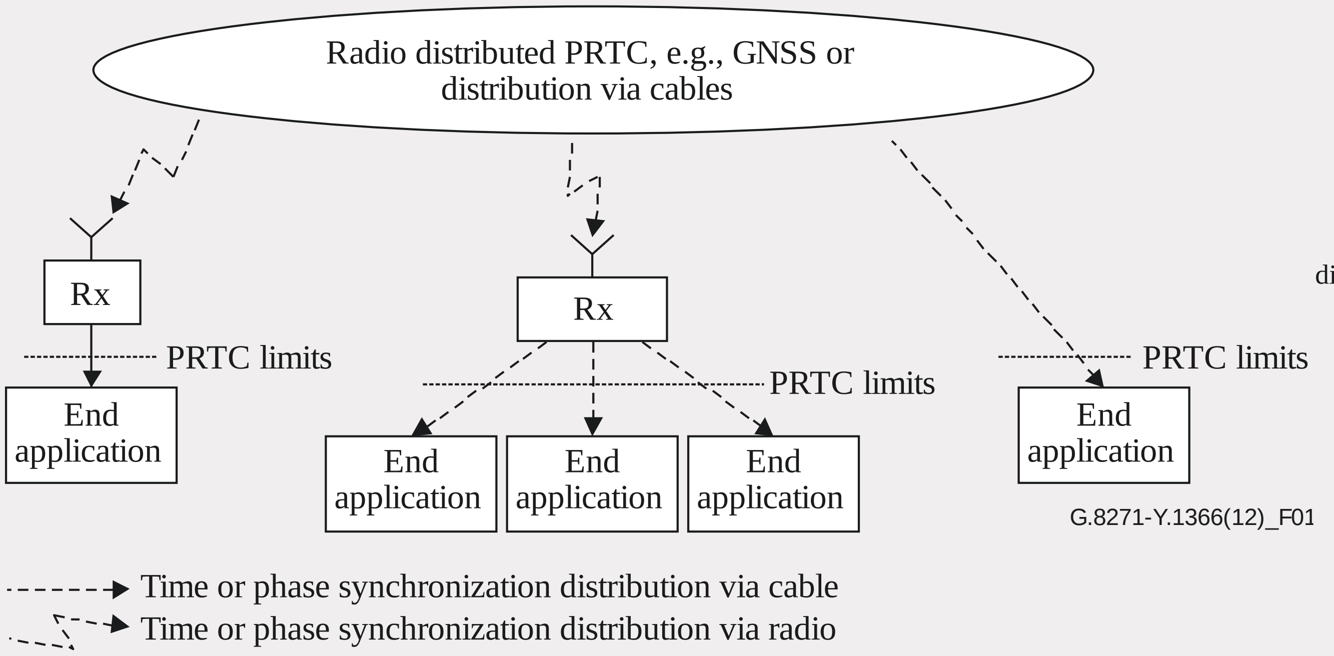
[a)] The reference may be from a PRC directly, from a GNSS or via a synchronization network

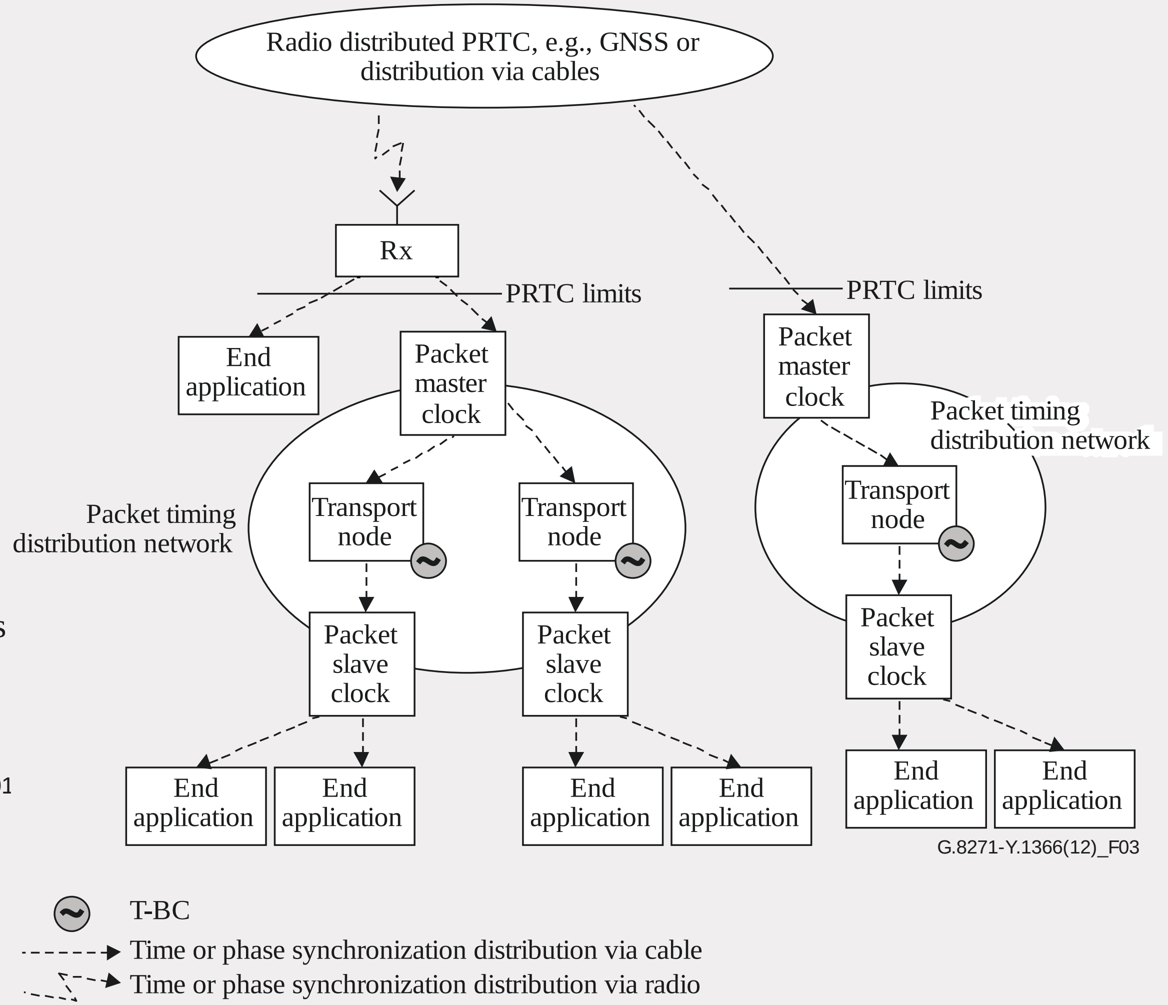
G.8265/Y.1365(10)_F01

Contents

Introduction

- Distributed vs. packet-based

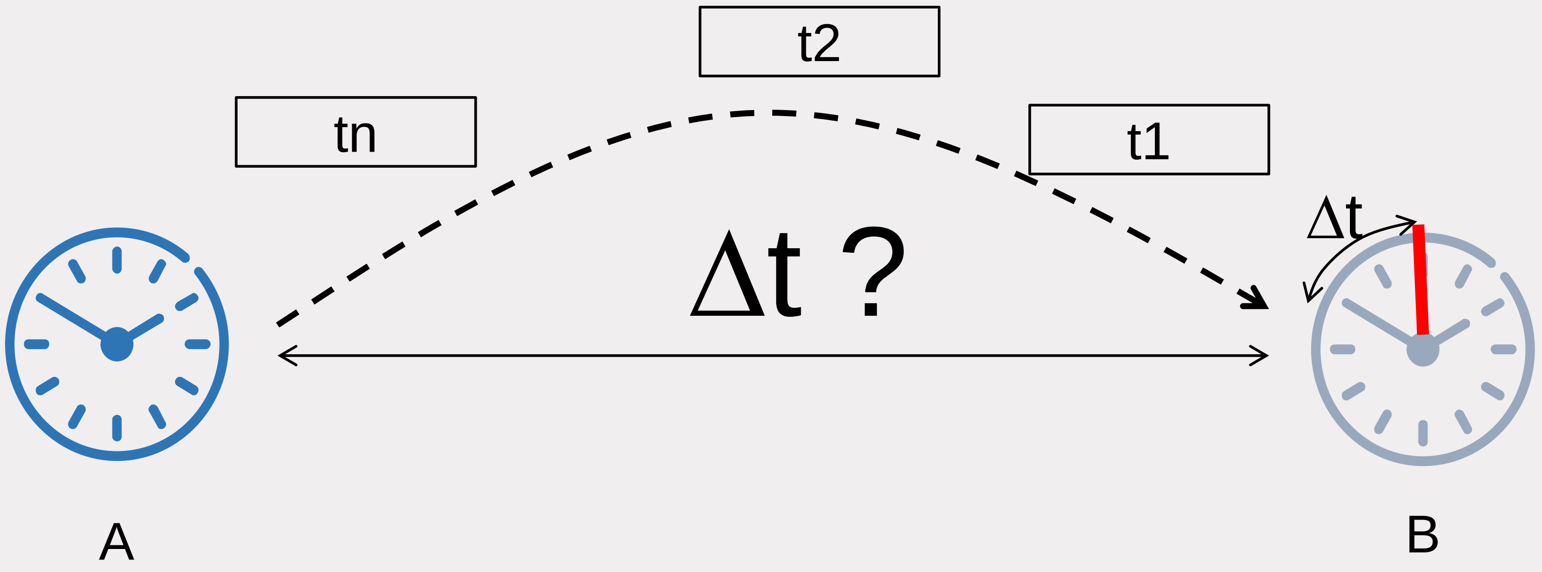




(From ITU-T G.8271)

Two-ways time transfer

- Delivery of Time synchronization requires also the knowledge of «transit delay» from A to B



- Two-ways timing protocols (round trip delay)
- Assumption for symmetric channel

Time Synchronization Architecture (Telecom perspective)

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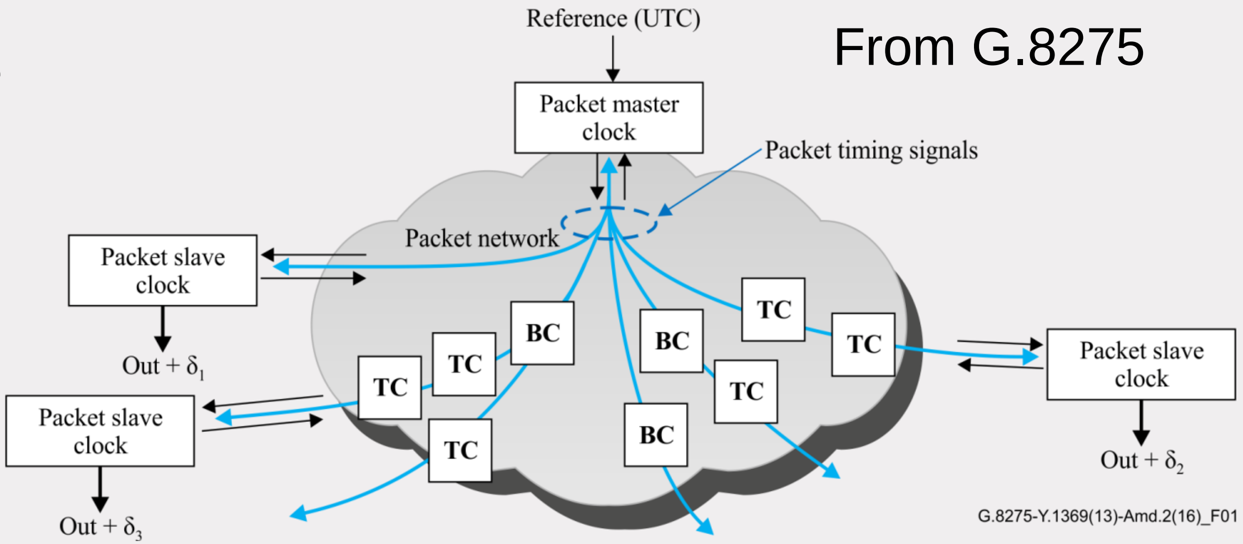
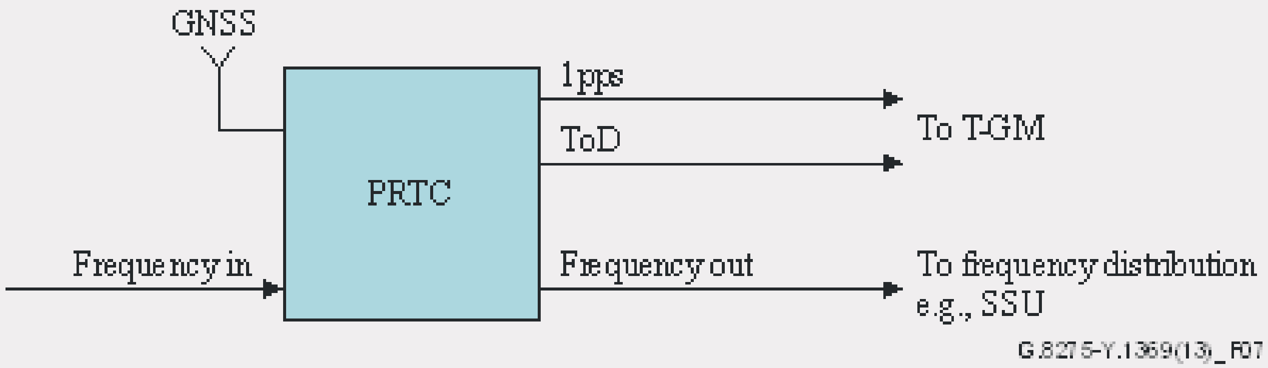
- General network topology for time/phase distribution from a packet master clock PRTC to a telecom time slave clock (T-TSC)
- The synchronization flow is from the master to slave, although the timing messages will flow in both directions.
- Individual nodes are T-BCs or T-TCs in the case of full support from the network

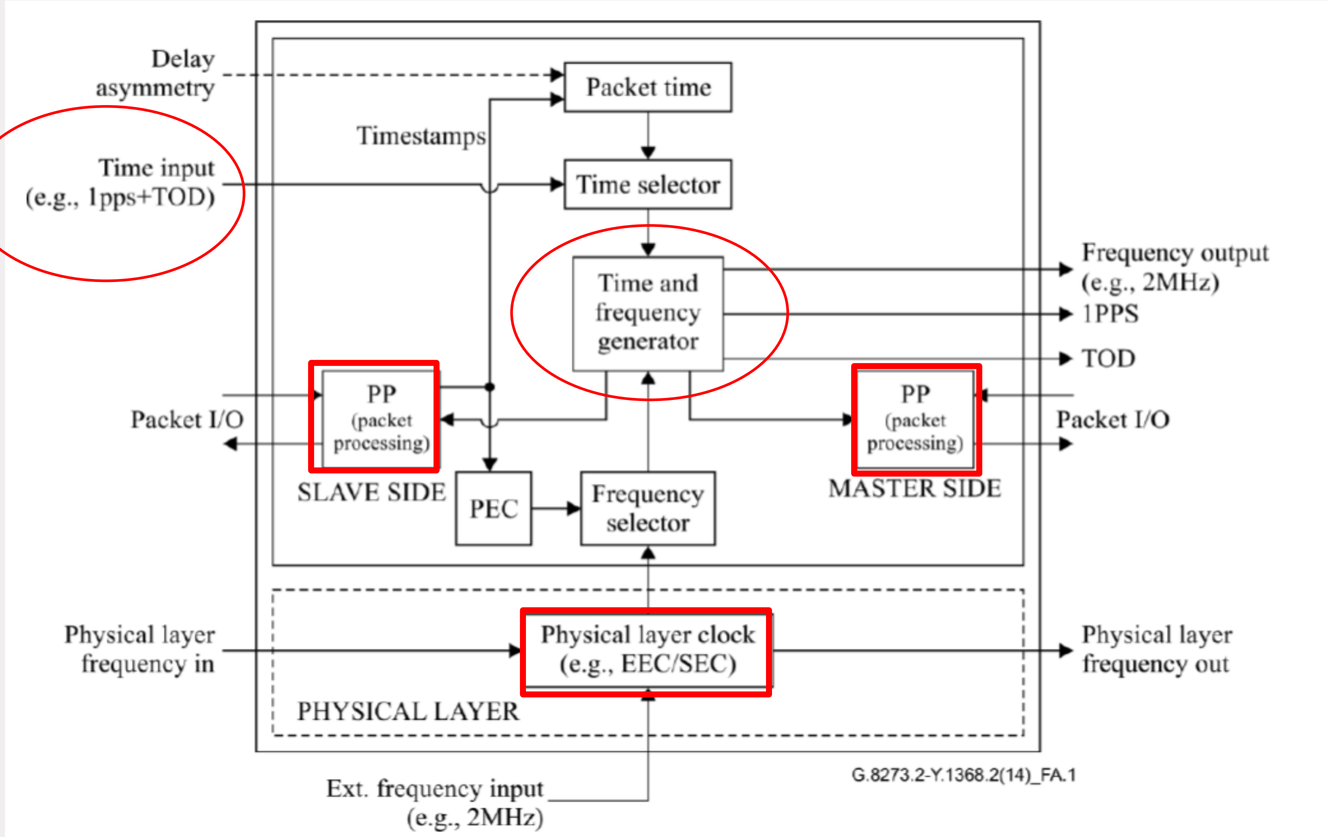
From G.8275

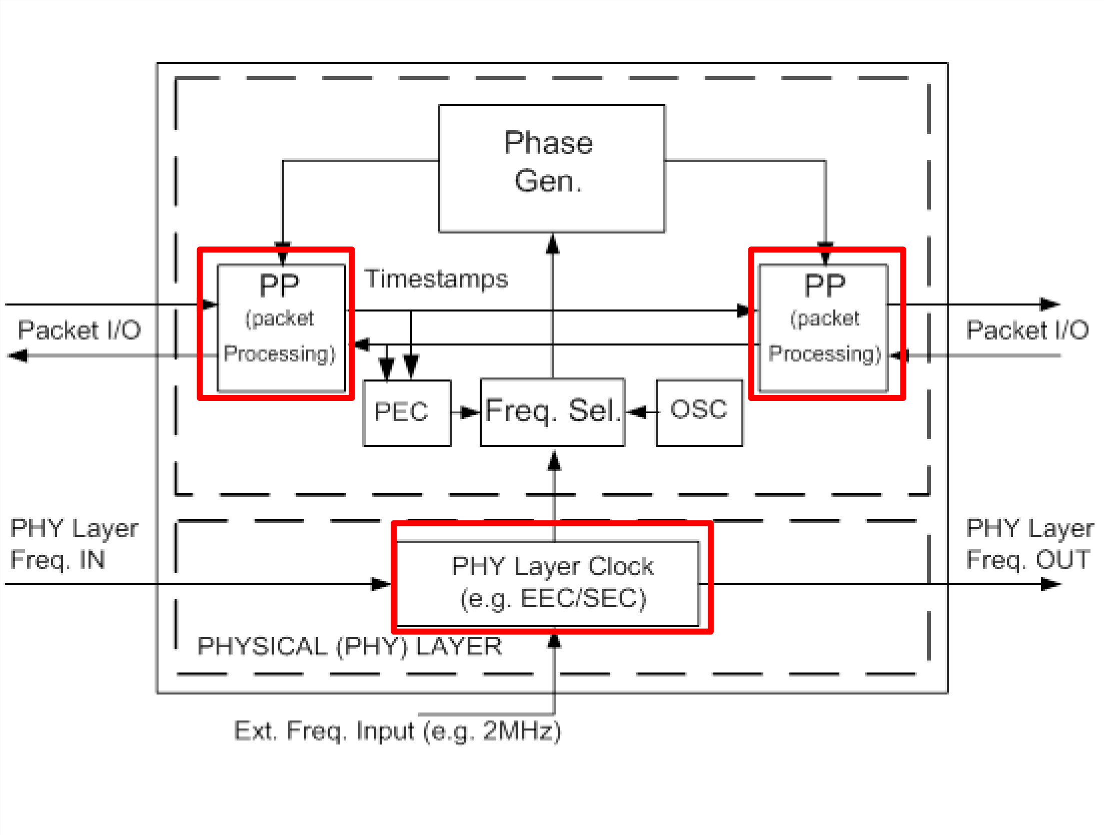




- Primary Reference Time Clock (PRTC) is the master of the time synchronization network (G.8272).
- Optional Holdover (as per G.812) (recent agreement)
- ePRTC (enhanced PRTC) defined in G.8272.1, with 14 days Holdover (100 ns)

T-BC and T-TC clock models for full timing support

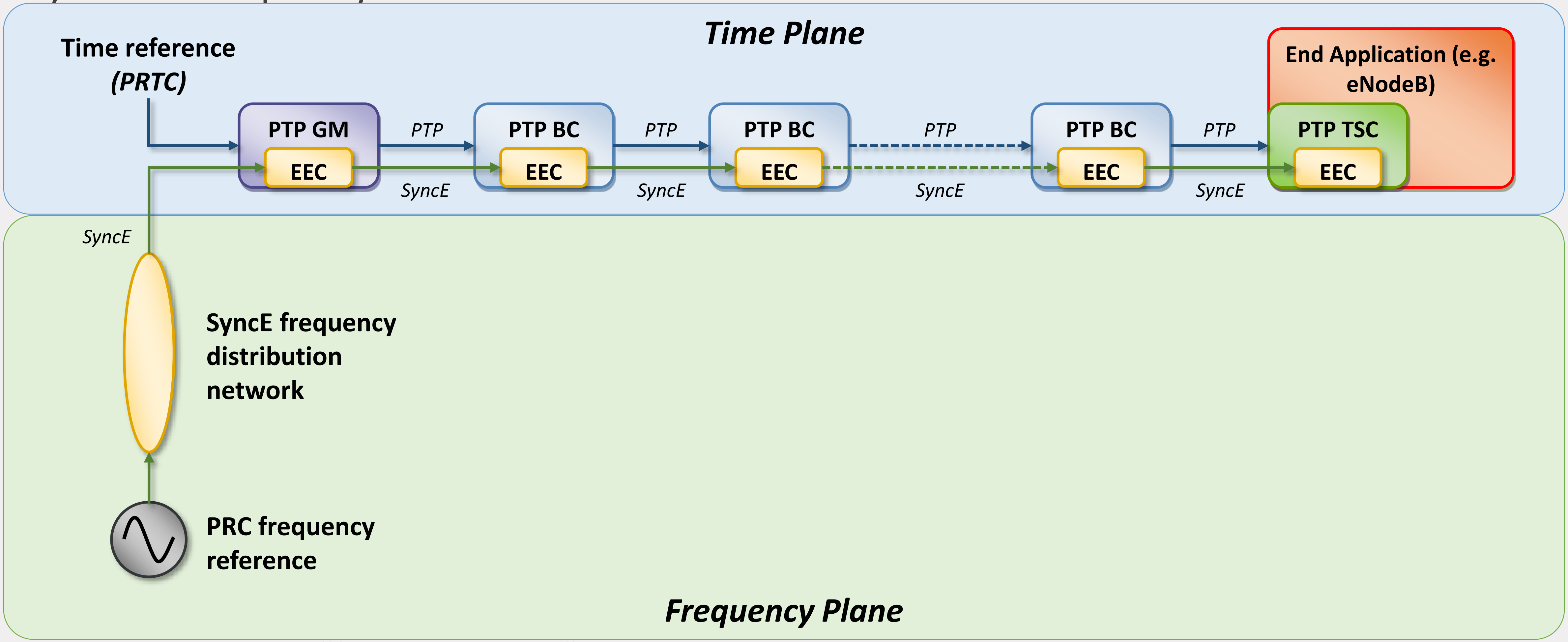




- G.8273.2 and G.8273.3 provide models for the Telecom Boundary and Transparent Clocks
- Frequency sync via physical layer
  - Option without physical layer did not get much traction, but recent studies shows that it may be feasible (Physical layer used only for “time holdover”?)

Combined PTP-SyncE

- SyncE as "frequency assistance" to PTP



- Gives immediate "frequency lock" to the PTP client
- SyncE & PTP functionality may be in the same node/element
- SyncE might be used for "Time sync holdover"

G.8275.1- ITU-T Time/Phase Profile – IEEE-1588 with full timing support (FTS) from Network

- Profile for applications that need accurate phase/time synchronization
- Based on the full timing support from the network (i.e., T-BCs and T-TCs are used in every node)

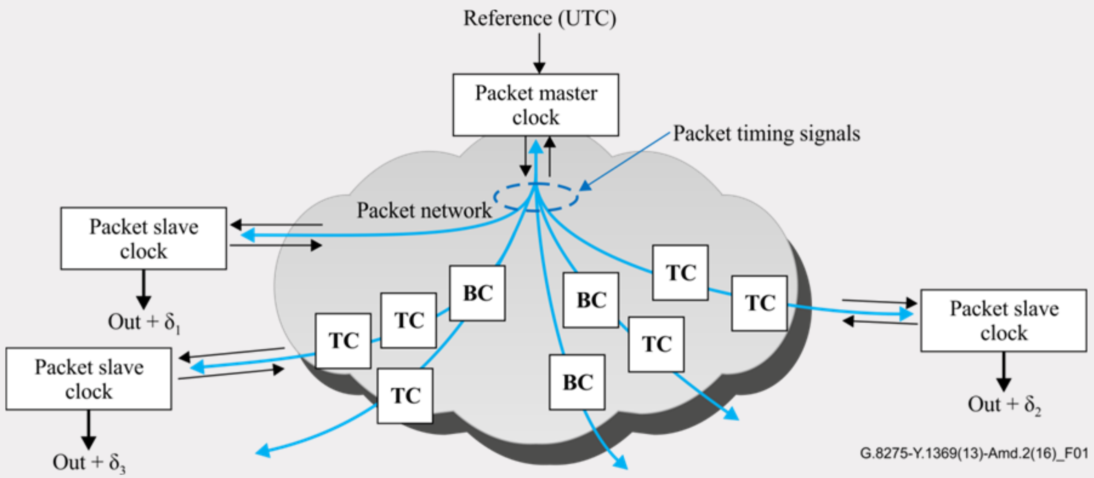


Figure 1 from ITU-T G.8275

BC – Boundary Clock
TC – Transparent Clock
T-BC – Telecom Boundary Clock
T-TC – Telecom Transparent Clock

- Several ITU-T Recommendations, G.827x series, G.781.1, have been developed to support FTS phase/time synchronization

ITU-T G.8271.1 Sync Network Architecture

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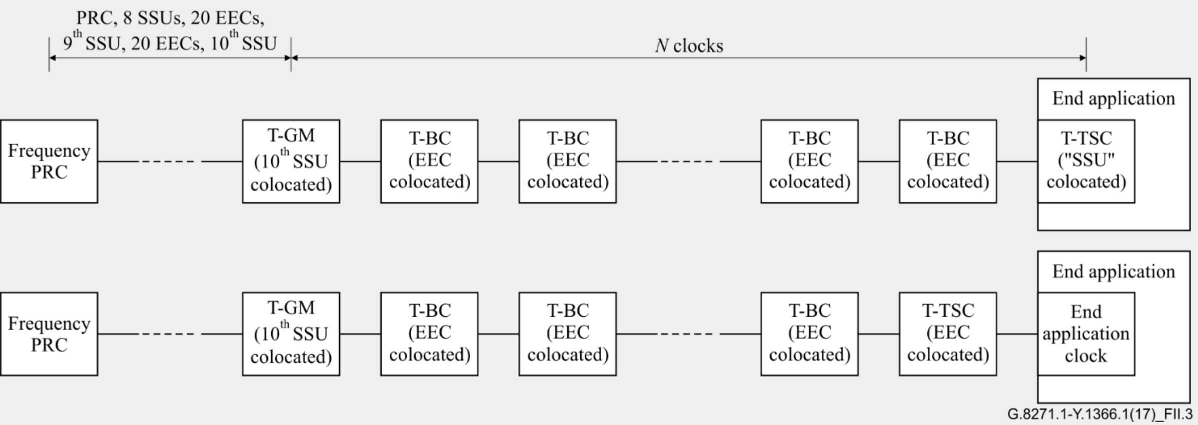
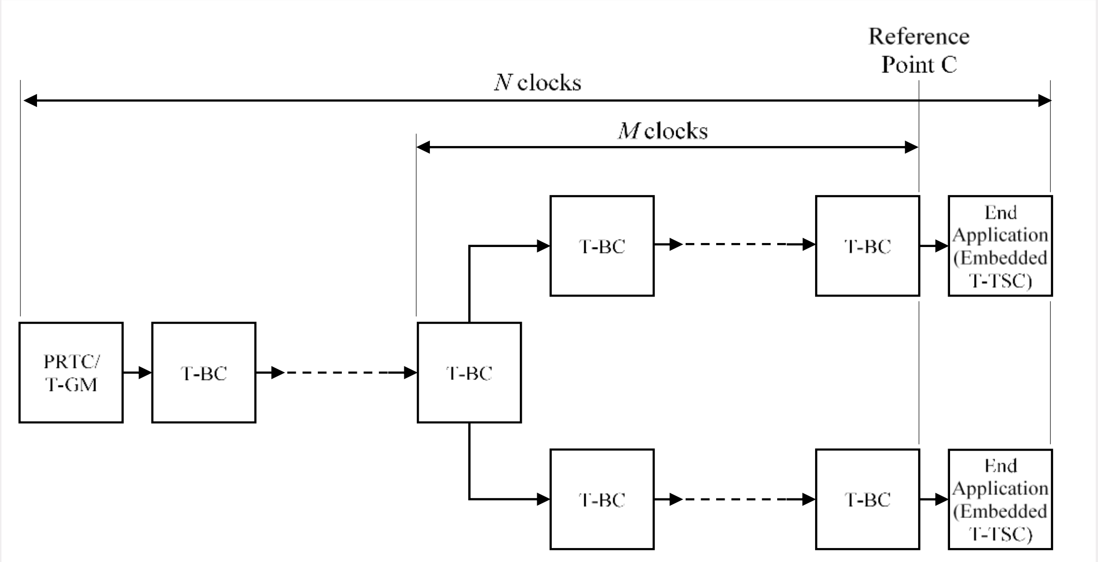




PRC = Primary Reference Clock
PRTC = Primary Reference Time Clock
T-GM = Telecom Grand Master
T-BC = Telecom Boundary Clock
T-TC = Telecom Transparent Clock

- G.8273.2 and G.8273.3 define several classes of T-BCs and T-TCs to be used in G.8271.1 architecture. Reference chains with class A and B have been fully studied for telecom backhaul
  - For a shorter chain N=12 (uses T-BC/T-TC class A)
  - For longer chain N=22 (uses T-BC/T-TC class B or C)
- Guidelines for network dimensioning for fronthaul
- Use of G.8273.2 Clock Class C (enhanced Synchronous Ethernet is required) or T-BC class B
- Short clock chain (M ≤ 4 with class C and M= 1 for class B)

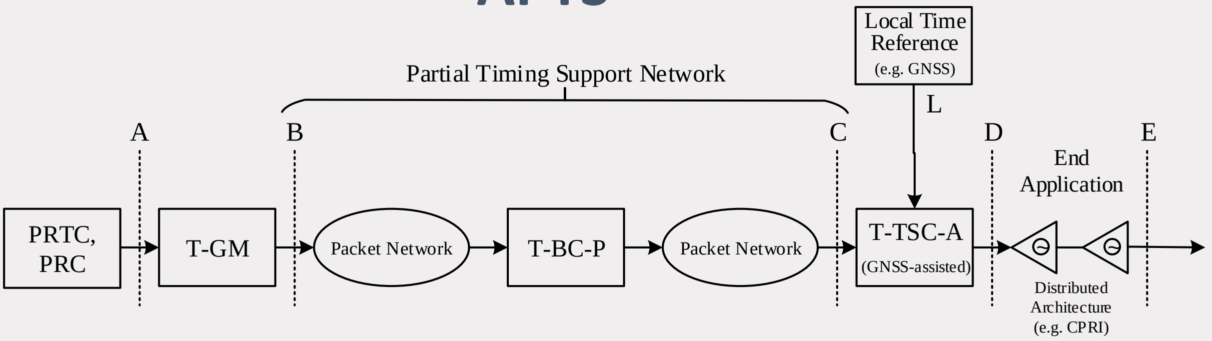
T-BC/T-TSC/T-TC	cTE	dTE (MTIE)	max|TE|	dTE (High-Pass filtered)
Class A (with SyncE)	+/-50ns	40 ns	100 ns	70ns
Class B (with SyncE)	+/-20ns	40ns	70ns	70ns
Class C (with eSyncE)	+/-10ns	10ns	30 ns (T-BC) Under Study for T-TC	Under Study
Class D(with eSyncE) Only T-BC/T-TSC	Under Study	Under Study	5 ns *	Under Study

*measured with a first order filter of 0.1Hz bandwidth

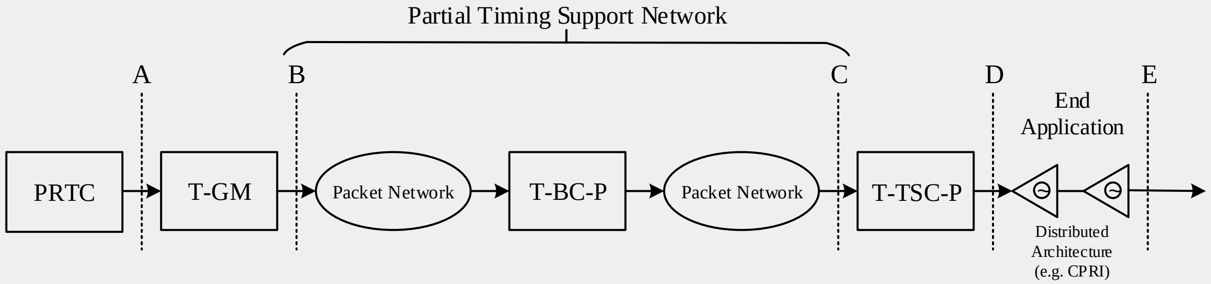
G.8275.2- ITU-T Time/Phase Profile – IEEE-1588 without timing support from Network

GNSS= Global Navigation Satellite System
T-TSC-A – Telecom Time Slave Clock – Assisted
T-TSC-P – Telecom Time Slave Clock – Partial support

APTS



PTS

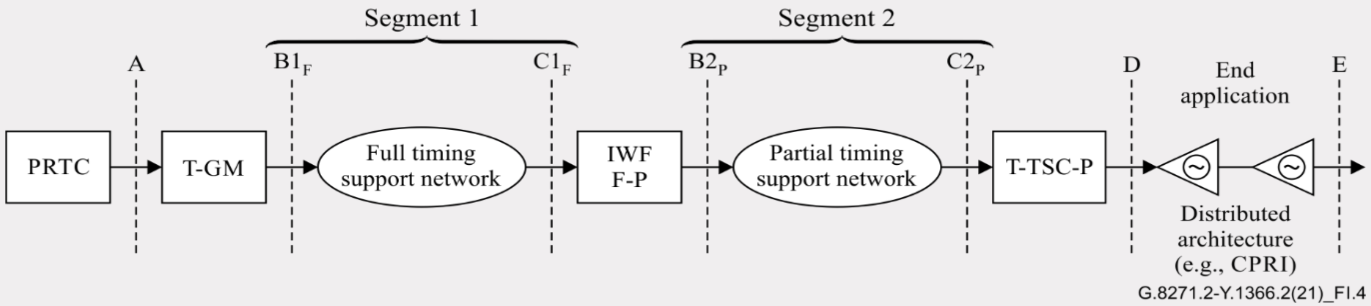


- Assisted Partial Timing Support (APTS) – GNSS is co-located with the T-TSC-A
  - PTP is used as a backup for GNSS failures
- Partial Timing Support (PTS) – without the GNSS co-located with T-TSC-P
  - Only PTP is used for timing

- Several ITU-T Recommendations, G.827x series, G.781.1, have been developed to support PTS phase/time synchronization (PTS)

IWF Between PTP Profiles (G.8275)

- In some deployment scenarios an inter-working function (IWF) may be used to connect synchronization network segments that are running different PTP profiles.



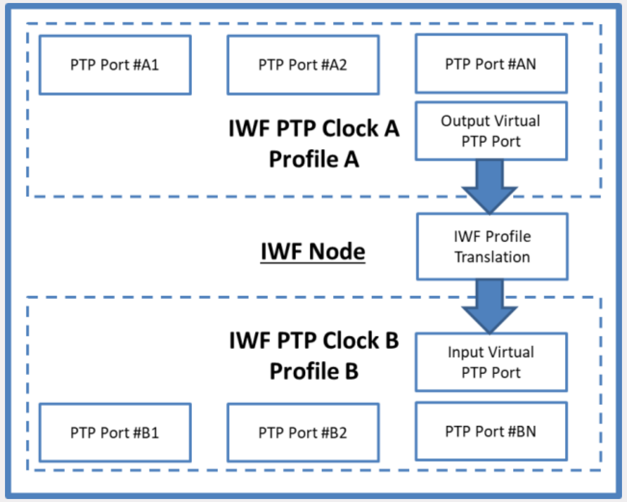
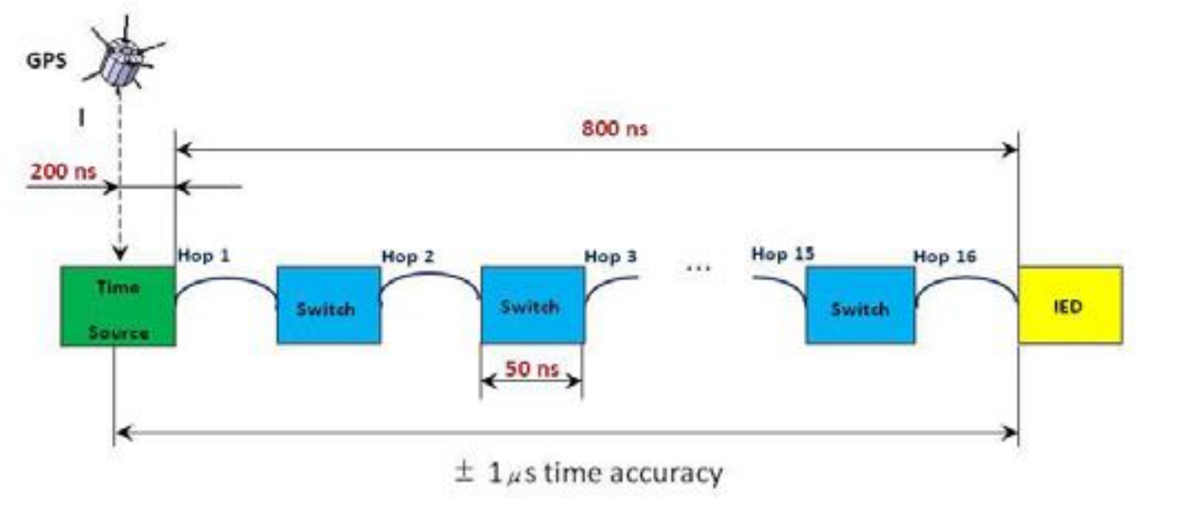


Table 1 – Mapping between IWF, ITU-T G.8275.1, ITU-T G.8275.2 and PTP clock types

IWF Node Type	PTP Profile	Clock type from [G.8275.1] & [G.8725.2]	Clock type from [IEEE 1588]
IWF F-P	A (G.8275.1)	T-TSC or T-BC	OC or BC
	B (G.8275.2)	T-GM	OC or BC
IWF P-F	A (G.8275.2)	T-TSC-P or T-TSC-A	OC or BC
	B (G.8275.1)	T-GM	OC or BC

Power Profile Architecture and Profile

- IEC/IEEE 61850-9-3:2016, Communication networks and systems for power utility automation – Part 9-3: Precision time protocol profile for power utility automation
  - to deliver time to clients with an accuracy of one microsecond or better over a network comprising up to 15 TCs or 3 BCs.
  - A TC shall introduce less than 50 ns time inaccuracy; A BC shall introduce less than 200 ns time inaccuracy
  - Layer 2, peer-to-peer profile of based on J.4 of IEEE Std 1588-2008.

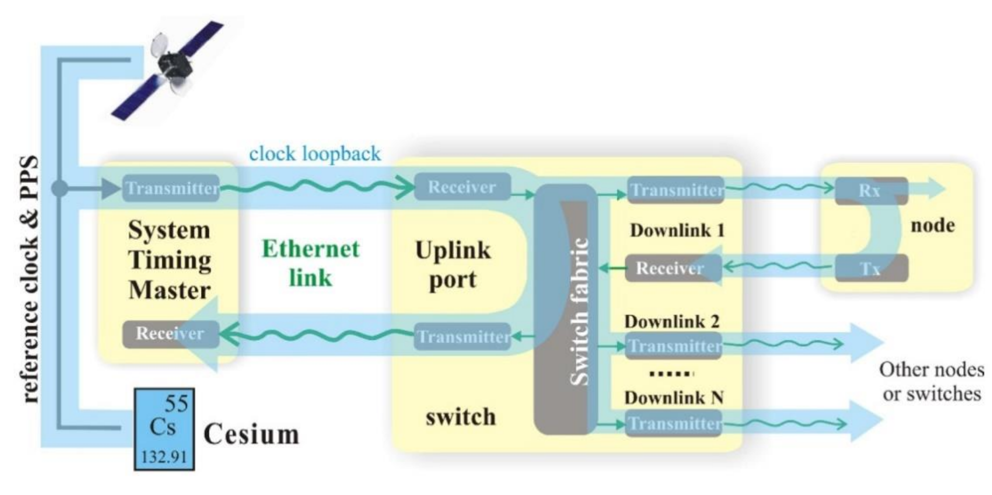


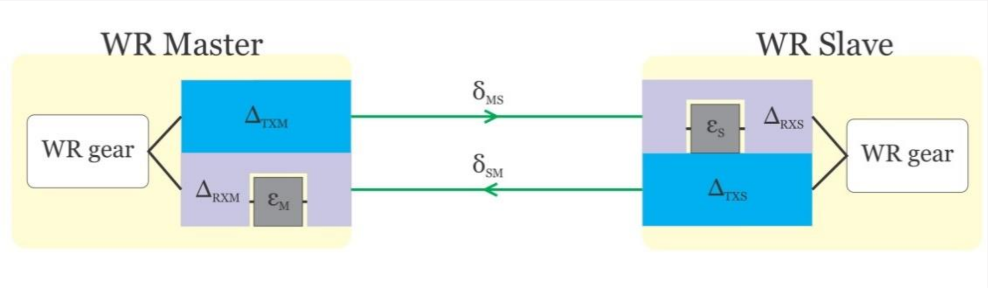
From Standard Profile for Use of IEEE Std 1588-2008 Precision Time Protocol (PTP) in Power System Applications, IEEE PES PSRC Working Group H7/Sub C7 Members and Guests, 2012 IEEE Conference

- IEEE C37-238: IEEE Standard Profile for Use of IEEE 1588™ Precision Time Protocol in Power System Applications (2017)
  - extension of IEC/IEEE 61850-9-3:2016 with two TLVs: one mandatory, providing additional information to monitor clock performance in real time, and an optional TLV, providing local time zone information, to ease transition from IRIG-B systems and for local display applications
  - Clocks claiming conformity with this standard can be used without restriction in an IEC/IEEE 61850-9-3 network

High Accuracy/«White Rabbit» Architecture and Profile

- PTP-based solution originally specified by the CERN targeting sub-ns accuracy, max(|TE|) < 1ns (typically, to support scientific applications); White Rabbit is the name of the project and of the related profile.
- Being specified as High Accuracy Default PTP Profile in IEEE 1588-2019 (Annex J.5)
- Performance is enabled by the following building blocks:
- Clock model in which Layer 1 syntonization cooperates with PTP synchronization
- Phase detection to enhance timestamping precision using Digital Dual Mixer Time Difference (figure in backup slides)
- Compensation of hardware & link asymmetries using "link delay model" and calibration

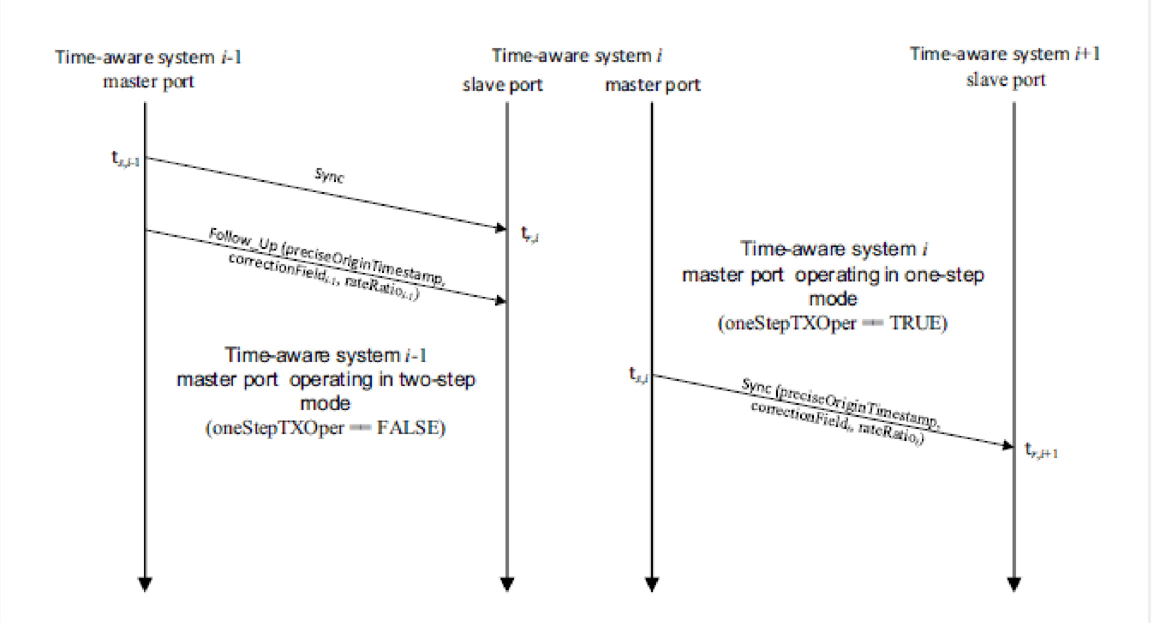




courtesy by Maciej Lipinski

Timing and Synchronization for Time-Sensitive Applications : IEEE802.1AS

- To support time-sensitive applications, such as audio, video, automotive, and Industrial Automation, across networks
- First released in 2011; Latest revision: 802.1AS Std. 2020 (Timing and Synchronization for Time-Sensitive Applications).
- Target Performance:
  - Any two nodes separated by six or fewer PTP instances (i.e., seven or fewer hops) will be synchronized to within 1 µs peak-to-peak of each other during steady-state operation.
- Make use of a "hybrid TC/BC" (Clocks participate in the Best Master Clock Algorithm, but are not required to recover the GM time).
- Based on peer-delay mechanism. Use of "rateRatio" parameter (to correct for frequency differences between local clock and grandmaster clock).
- One of the main objectives of the latest revision was to address other applications besides audio and video.



Copy of figure 11-2 from IEEE 802.1AS:
Transport of time-synchronization information

Time-Sensitive Networking (TSN) Industrial Automation Profile (IEC/IEEE 60802)

- IEC/IEEE 60802 profile is a joint project between IEC SC65C/WG18 and IEEE 802
- It address bridges and end stations for industrial automation
- Time synchronization is based on IEEE 802.1AS
- Typically, Industrial automation contains multiple tasks that are based on time or cycles
- The data flow needs to operate continuously and relies on regular updates based on a local or network time base
- Latency and time delays are critical and needs to be minimized and bounded
- Two types of clocks are being defined: Global Time (synchronized to TAI (International Atomic Time)), and Working Clock (synchronized to an arbitrary time (ARB)
- The Working Clock, a network of at least 64 nodes must be supported, and it is desirable to support up to 100 nodes between the grandmaster and the end application
  - Need to meet a maximum absolute Time Error of 1us
  - Simulations are being run to define key parameters that will be specified in the profile (e.g. residence time, Sync and Pdelay message rates)

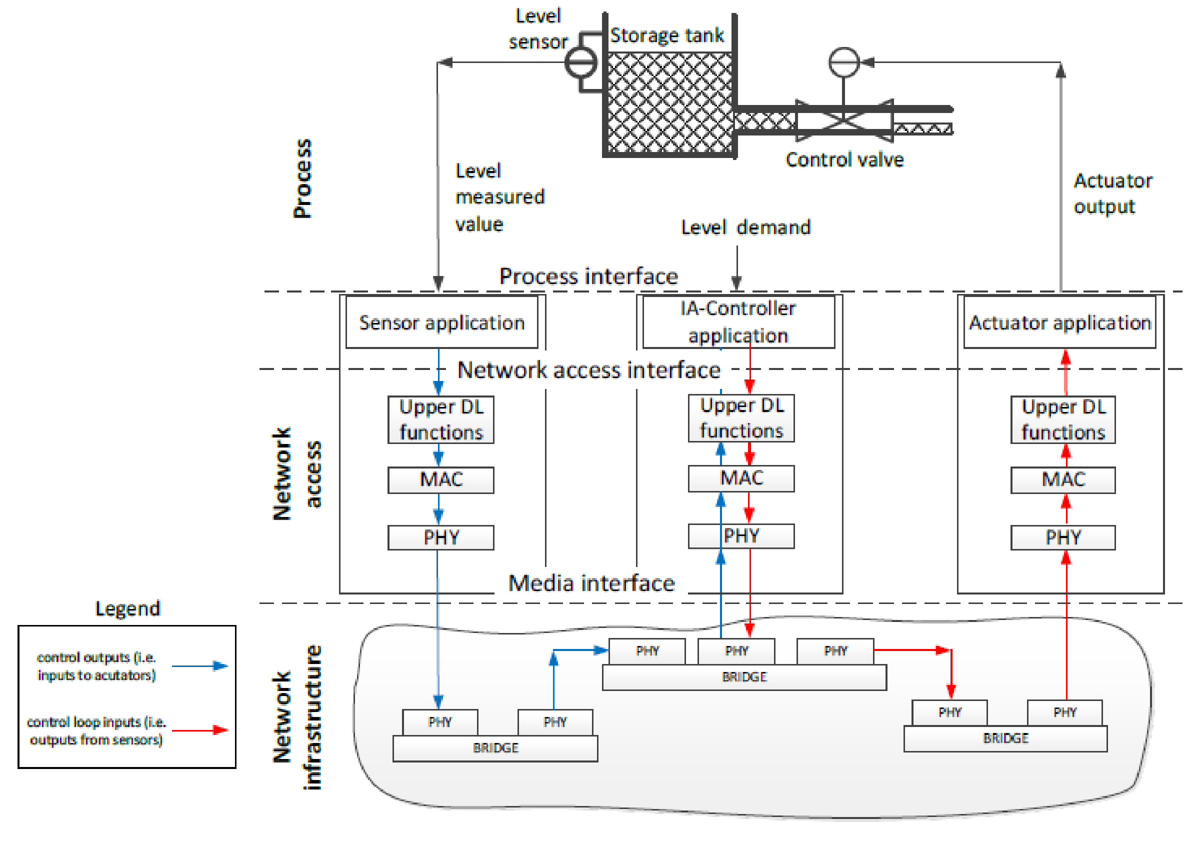
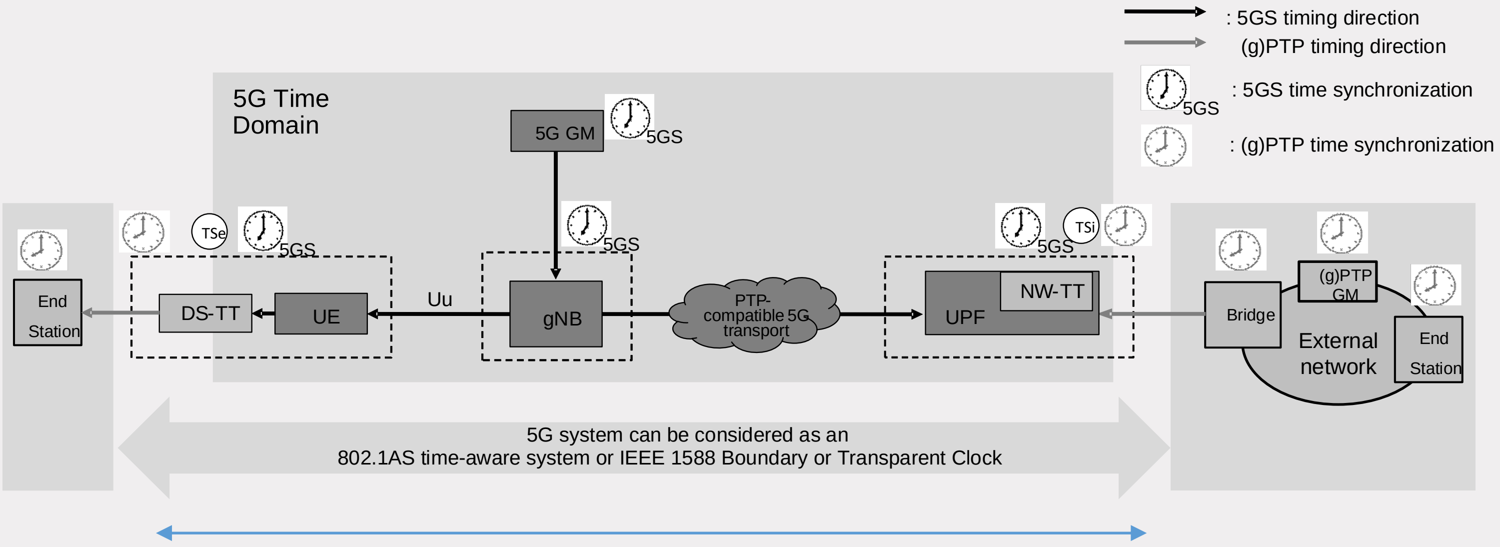


Figure 1 – Data flow in a control loop

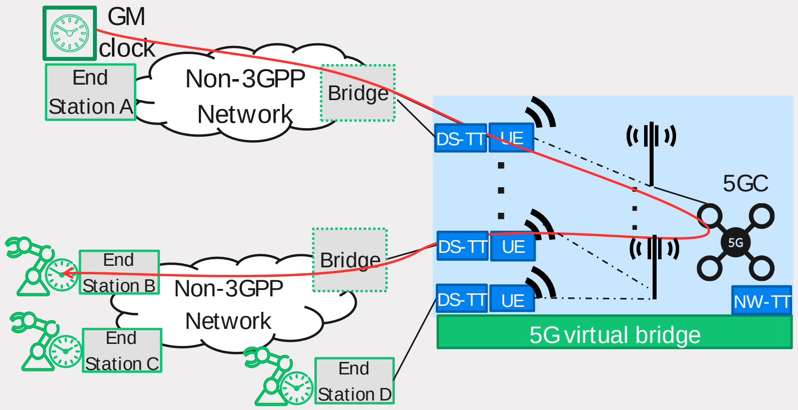
- Source: IEC/IEEE 60802 D1.4 draft

3GPP: Integration of 5G with «TSC»

- From 3GPP TS 23.501: Integration between 5G and TSC (Time Sensitive Communication)
- Replacing wired connection with a 5G link
- Original focus: TSN and IEEE 802.1AS (for Industrial Automation) ;
  - Extended to other profiles (e.g., SMPTE)
- The 5GS transparently carries the client PTP messages (e.g., according to IEEE802.1AS), updating the correction field
- DS-TT and NW-TT at the external interfaces must be synchronized
  - NW-TT via the Telecom Profile
  - DS-TT synchronized by the gNB (over the air)
- Various "Scenarios" are possible, with different budgeting examples for the Time Error allocated to the air interface
  - 145 ns / 275 ns for the most stringent scenarios (to support 900 ns total budget)



900 ns (as per 3GPP TS 22.104)



From TD7-3 Liaison from 3GPP to Q13/15

3GPP: Timing Resiliency

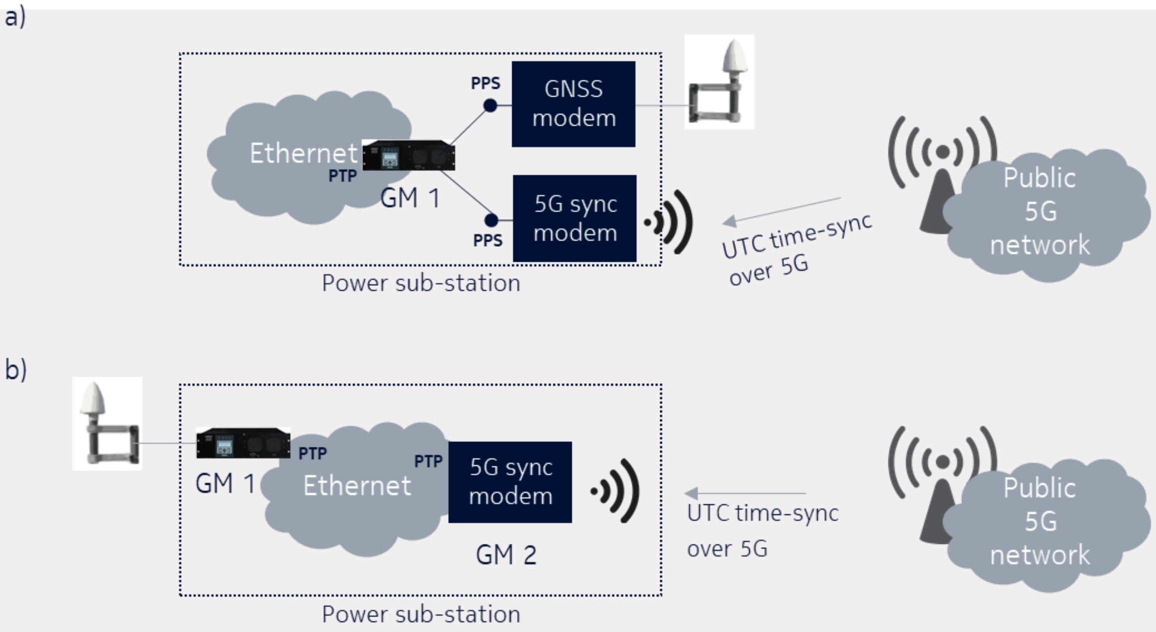
- New requirements from 3GPP related the 5G Timing Resiliency applications (TS 22.261, TR 22878)
  - Timing over 5G used as back –up (or primary reference) for connected devices
- Example Applications: Power Grid, Trading, etc.
- Ongoing study item on monitoring and reporting for timing synchronization status in the 5G system (TR 23.700-25)
  - Liaison from 3GPP SA2 to Q13

Use case	Holdover time (note 3)	Sync target	Sync accuracy	Service area	Mobility	Remarks
Power grid (5G network)	Up to 24 hour	UTC (note 1)	<250 ns to1000 ns (note2)	< 20 km^2	low	When 5G System provides direct PTP Grandmaster capability to sub-stations
Power grid (time synchronization device)	>5 s	UTC (note 1)	<250 ns to1000 ns (note2)	< 20 km^2	low	When 5G sync modem is integrated into PTP grandmaster solution (with 24h holdover capability at sub-stations)

NOTE 1: A different synchronization target is acceptable as long as the offset is preconfigured when an alternatively sourced time differs from GNSS. In this case, a 5G end device will provide PPS output which can be used for measuring the difference.

NOTE 2: Different accuracy measurements are based on different configurations needed to support the underlying requirements from IEC 61850-9-3 [32]. The range is between 250 ns and 1000 ns. The actual requirement depends on the specific deployment.

NOTE 3: This requirement will vary based on deployment options.



From TR 22.878 Figure 4.1.3-2:
5G integration into system – resilience and alternative mode

Type of trading activity	Maximum divergence from UTC	Granularity of the timestamp (note 1)
Activity using high frequency algorithmic trading technique	100 µs	≤1 µs
Activity on voice trading systems	1 s	≤1 s
Activity on request for quote systems where the response requires human intervention or where the system does not allow algorithmic trading	1 s	≤1 s
Activity of concluding negotiated transactions	1 s	≤1 s
Any other trading activity	1 ms	≤1 ms

NOTE 1: Only relevant for the case where the time synchronization assists in configuring the required granularity for the timestamp (for direct use), otherwise it will be configured separately as part of the financial transaction timestamp process.

Time-Sensitive Networking (TSN) Automotive Profile

- IEEE 802.1 TSN working group is working on a set of profiles to address bridges and end stations for automotive (P802.1DG)
- Time synchronization is based on IEEE 802.1AS
- Targeting Ethernet networks to support in-vehicle applications
- The current draft addresses 3 profiles as follows:
  - *Base profile* – this profile defines a set of minimum requirements of an in-vehicle TSN implementation. Time synchronization is important to support Infotainment and for timestamping data from sensors for advanced driver assistance systems (ADAS).
  - *Extended profile* – this profiles includes the "Base profile" requirements and adds more capability to support autonomous driving and next generation architecture
  - *Profile for Audio Systems* – this profile defines a set of minimum requirements in-vehicle Audio Systems using TSN
- Synchronization aspects for this profile are being discussed
- Best Master Clock Algorithm (BMCA) may not be needed
- Synchronization performance for the different applications. For video and audio, time accuracy of 1ms has been proposed
- Message rates need to be defined to meet applications requirements

IEEE P802.3cx: Accurate Timestamping; MOPA: Time Error in pluggables

- IEEE P802.3cx «Improved Precision Time Protocol (PTP) Timestamping Accuracy» (recently Approved)
  - Enhancements to Ethernet support for time synchronization protocols to provide improved timestamp accuracy in support of ITU-T Recommendation G.8273.2 'Class C' and 'Class D' clocks

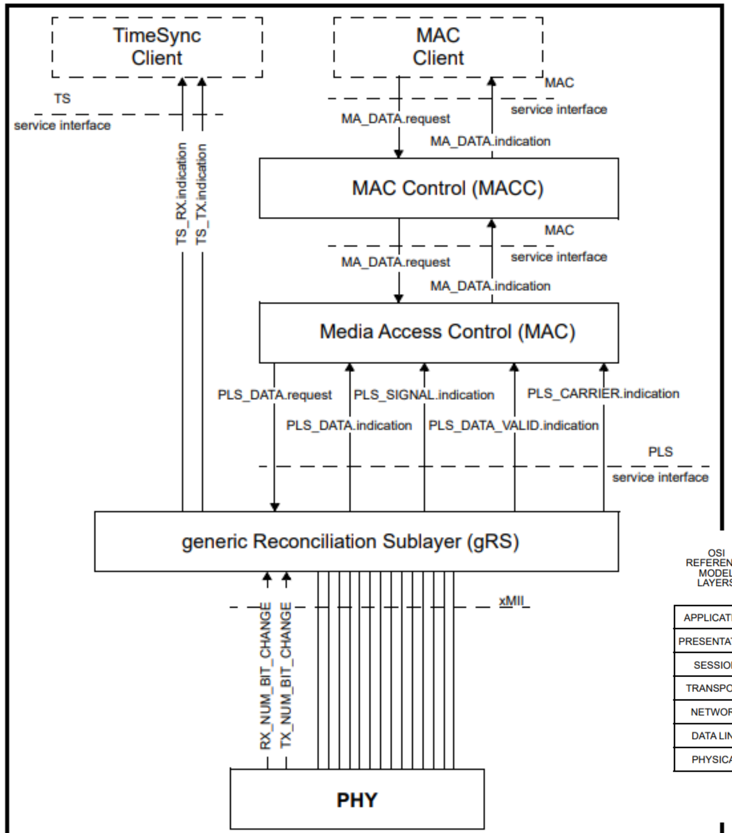


Figure 90–1—Relationship of the TimeSync Client, TSSI and gRS sublayer relative to MAC and MAC Client and associated interfaces

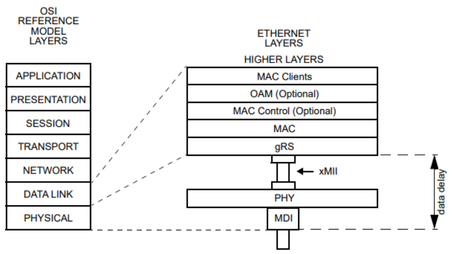


Figure 90–5—Data delay measurement

- MOPA (Mobile Optical Pluggable Alliance)
- Classes of pluggables based on achievable accuracy. Examples
  - a "Class C.2" pluggable : 2% of the cTE budget ITU-T G.8273.2 allocated for Class C nodes. (i.e, +/-0.2ns, that translates in both Δtmax and Δrmax = +/-0.2ns). For very simple pluggable implementations, maintaining an analogue signal chain.
  - - A "Class A.20" pluggable : 20% of the cTE budget ITU-T G.8273.2 allocated for Class A nodes. (i.e., +/-10ns, that translates in both Δtmax and Δrmax = +/-10ns). To enable use of complex digital parts inside the pluggable.

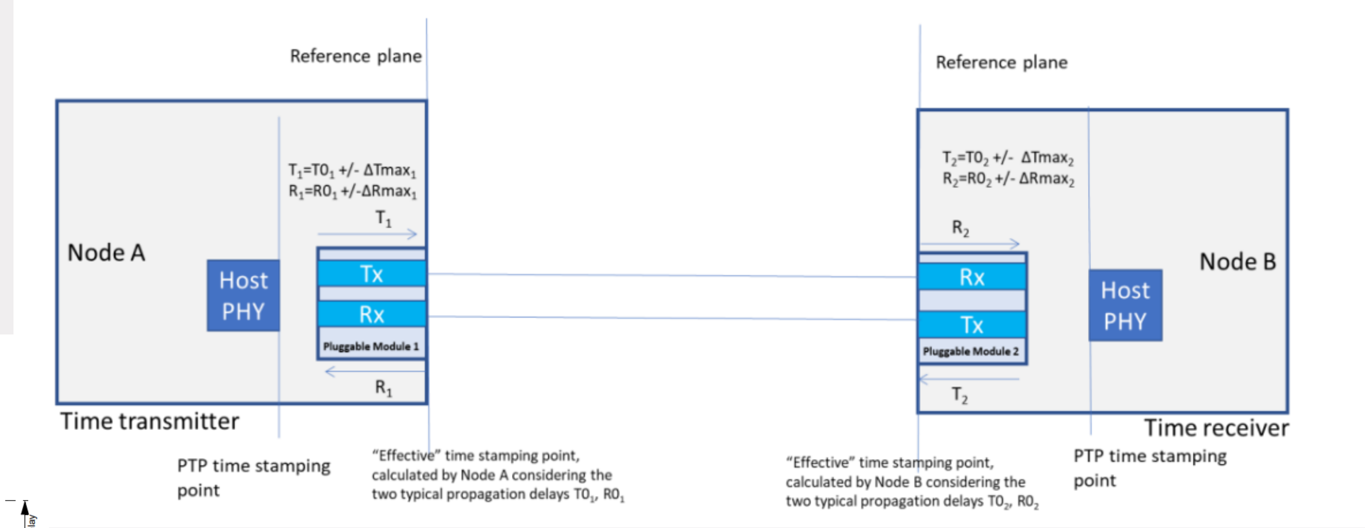


Figure APB.8 from [MOPA_Technical_Paper-v2.0-Final.pdf (mopa-alliance.org)](MOPA_Technical_Paper-v2.0-Final.pdf)

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Insight and
Innovation