DISTRIBUTION OF TIMING: SYNC OVER THE PACKET LAYER OF NETWORKS

WSTS TUTORIAL – 09 MAY 2022

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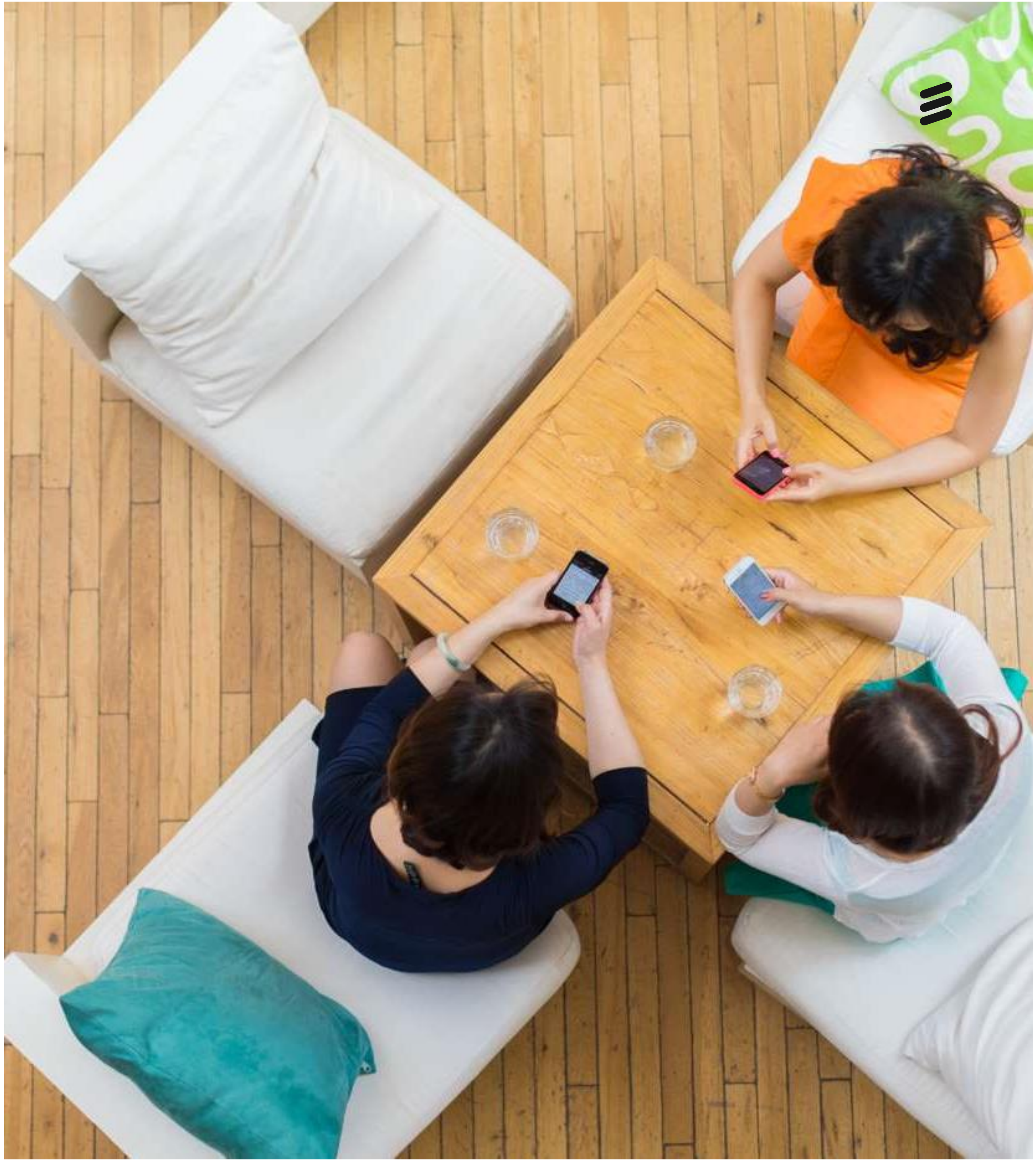
Credits:
Slide 20..23: courtesy by Maciej Lipinski

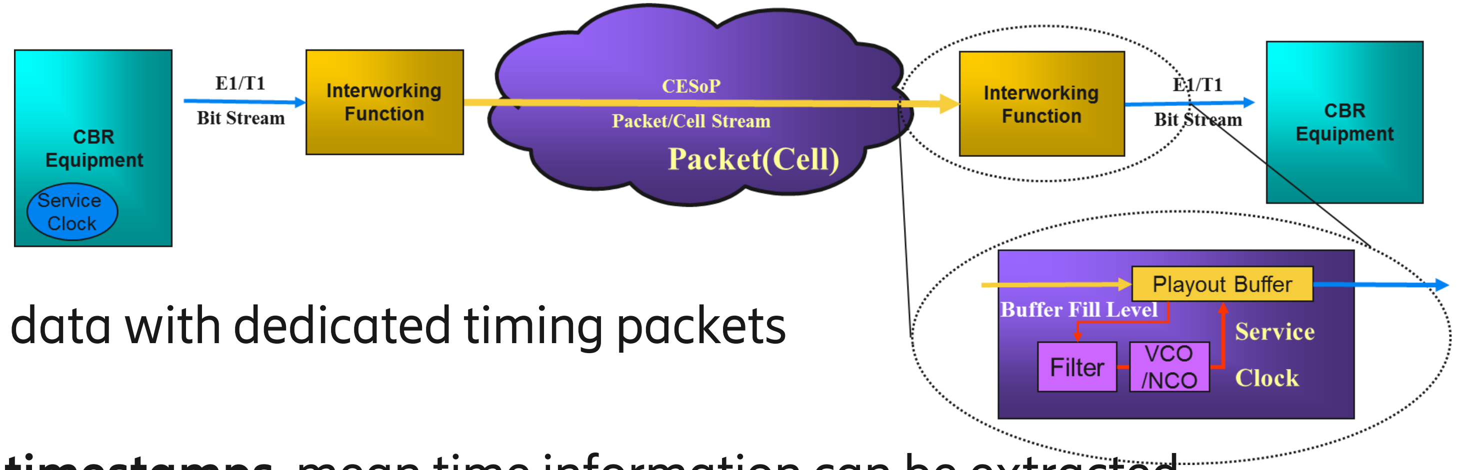


1. FREQUENCY SYNC VIA PACKETS

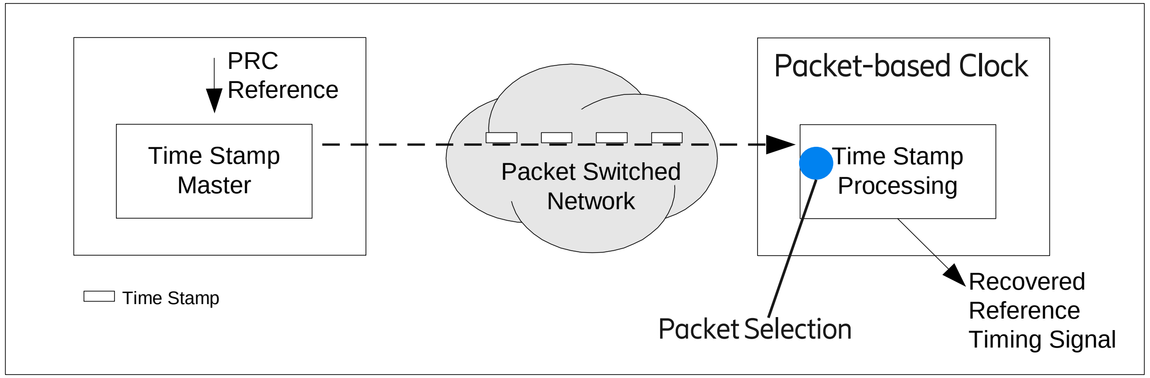
ERICSSON

Introduction

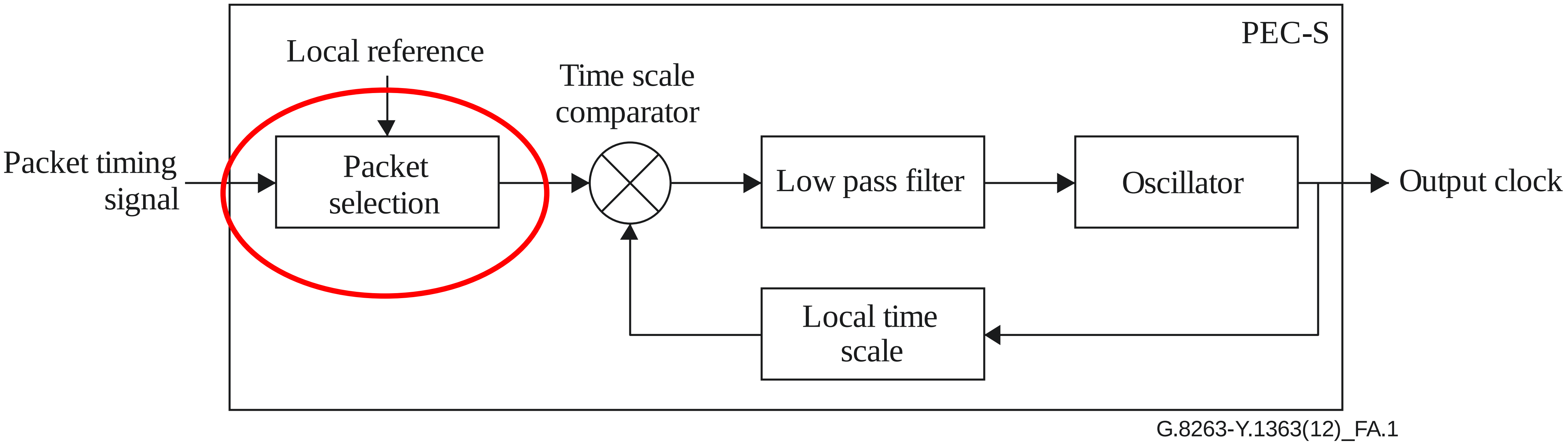
- Timing carried via packets was originally used to receiver the service timing (e.g., 2 Mbit/s service carried over packet networks); known as "Circuit Emulation"
  - Service clock adjusts based on buffer fill level / **packet arrival rate, PDV** influences wander at the network output



- 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**



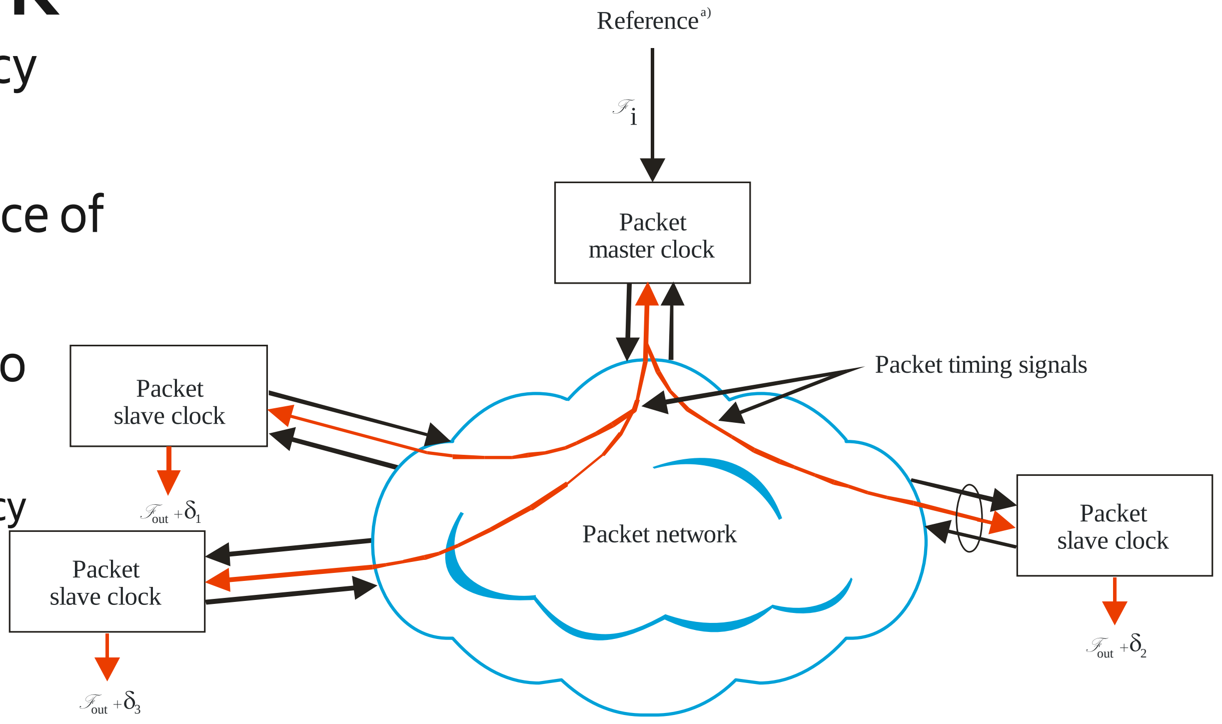
Packet-based Equipment Clock



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

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 has been developed to support this profile
  - **G.8265** (Architecture and requirements for packet-based frequency delivery),
  - **G.8265.1** (Precision time protocol telecom profile for frequency synchronization),
  - **G.8263** (Timing Characteristics of Packet based Equipment Clocks (PEC)),
  - **G.8261** (Timing and synchronization aspects in packet networks)
  - **G.8261.1** (Packet Delay Variation Network Limits applicable to Packet Based Methods),
  - **G.8260** (metrics)
  - **G.781.1** (Synchronization layer functions for packet-based synchronization)



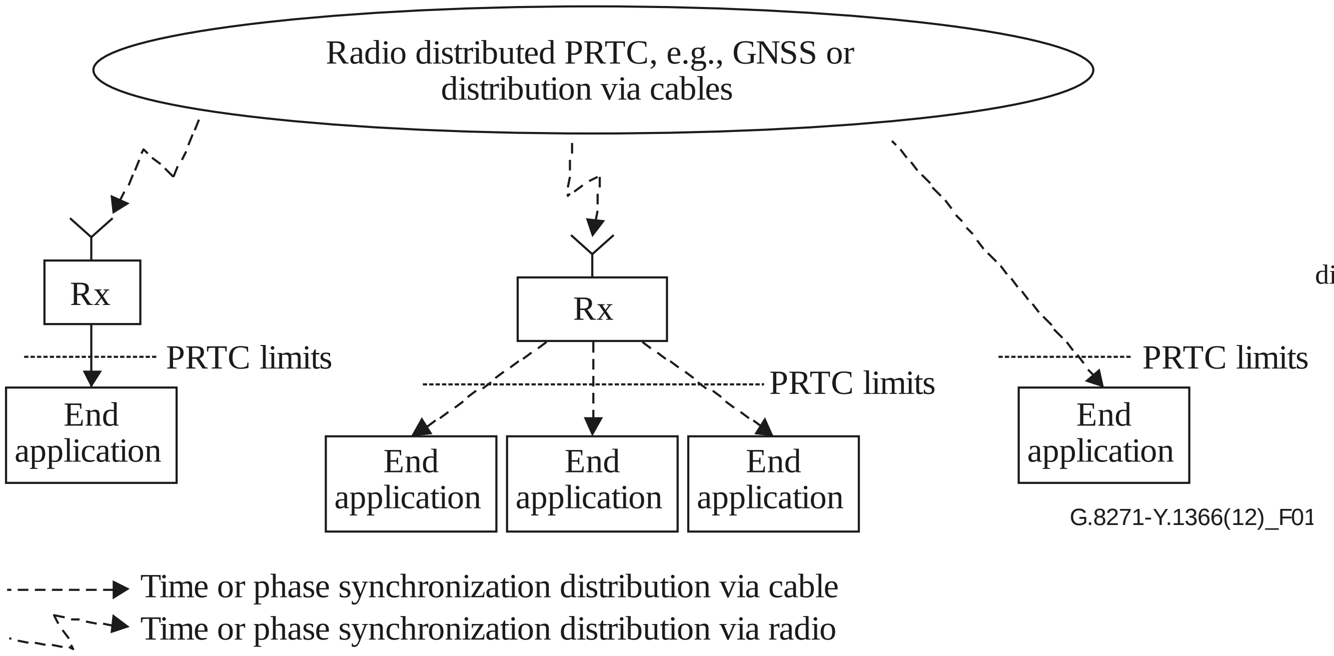
[a] The reference may be from a PRC directly, from a GNSS or via a synchronization network

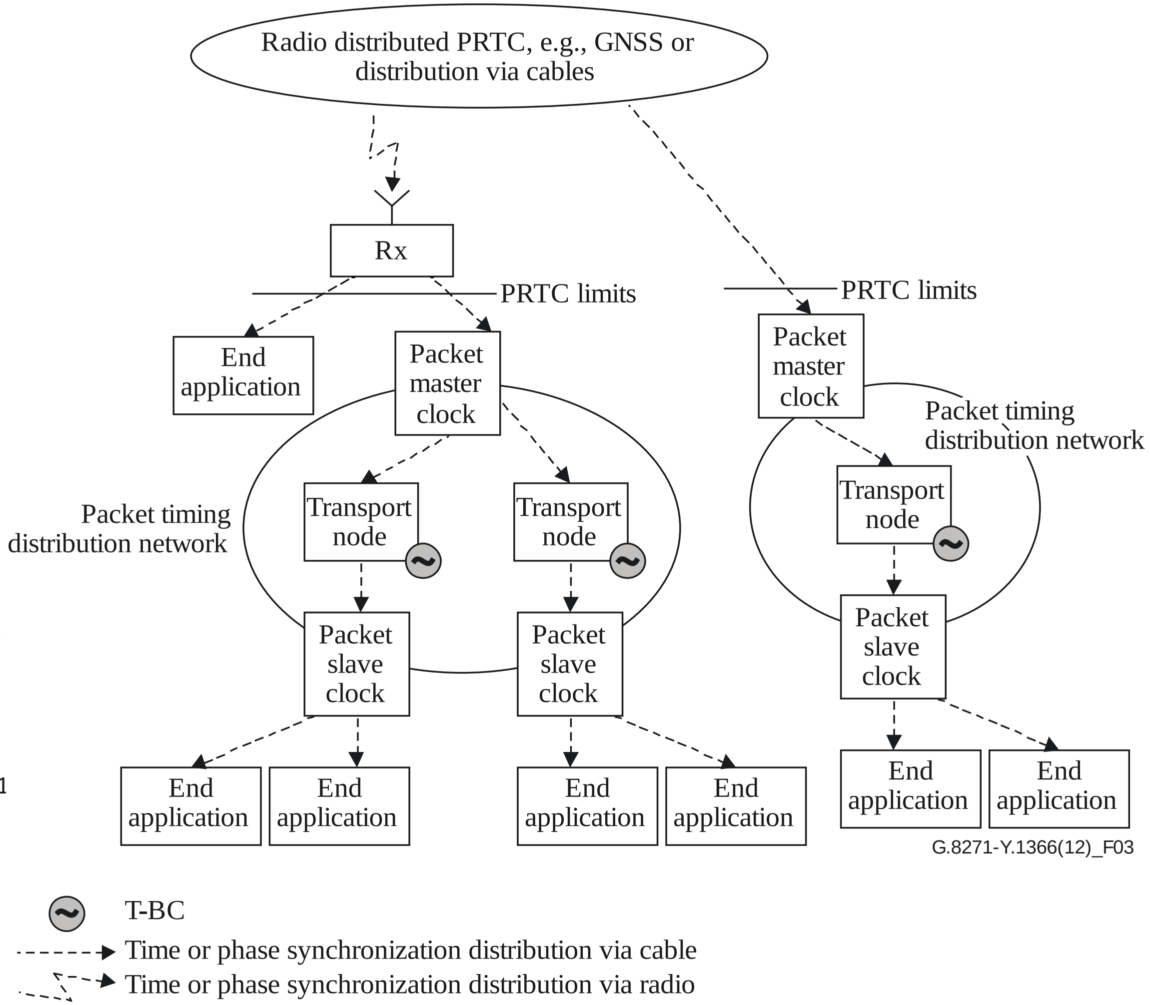
G.8265/Y.1365(10)_F01

2. TIME SYNC DISTRIBUTION

Introduction

- Distributed vs. packet-based

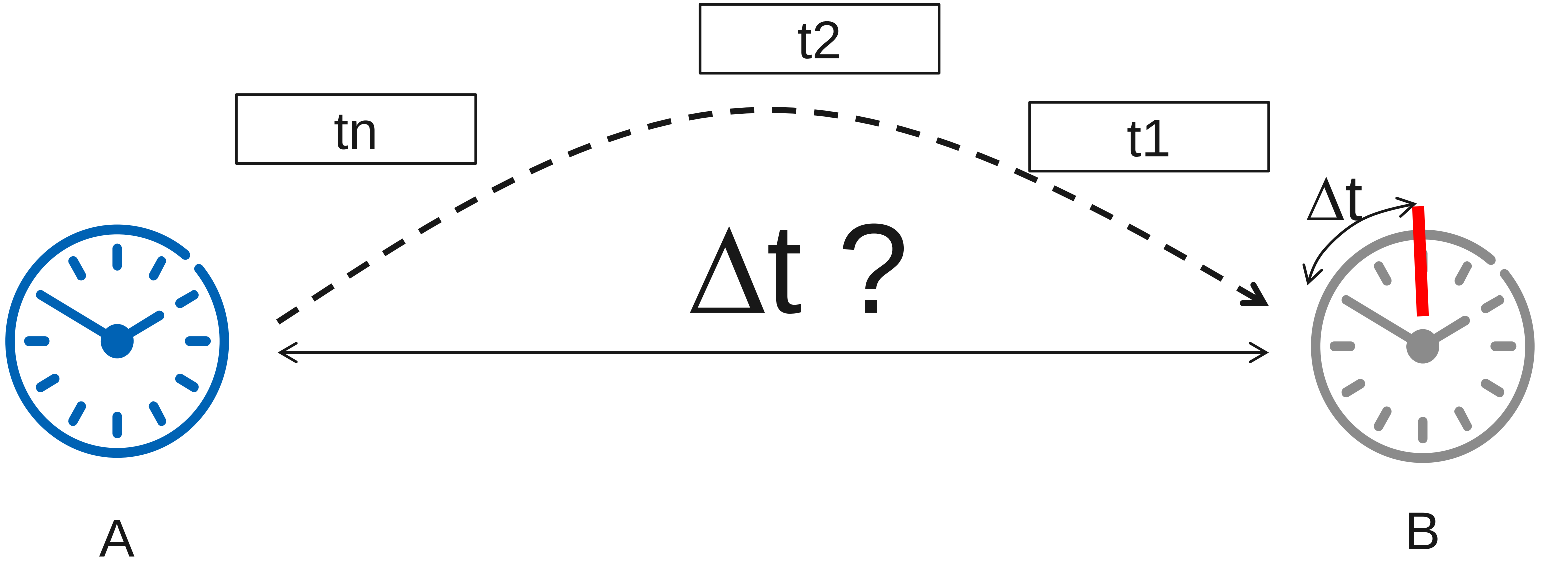




(From ITU-T G.8271)

Two-ways time transfer

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

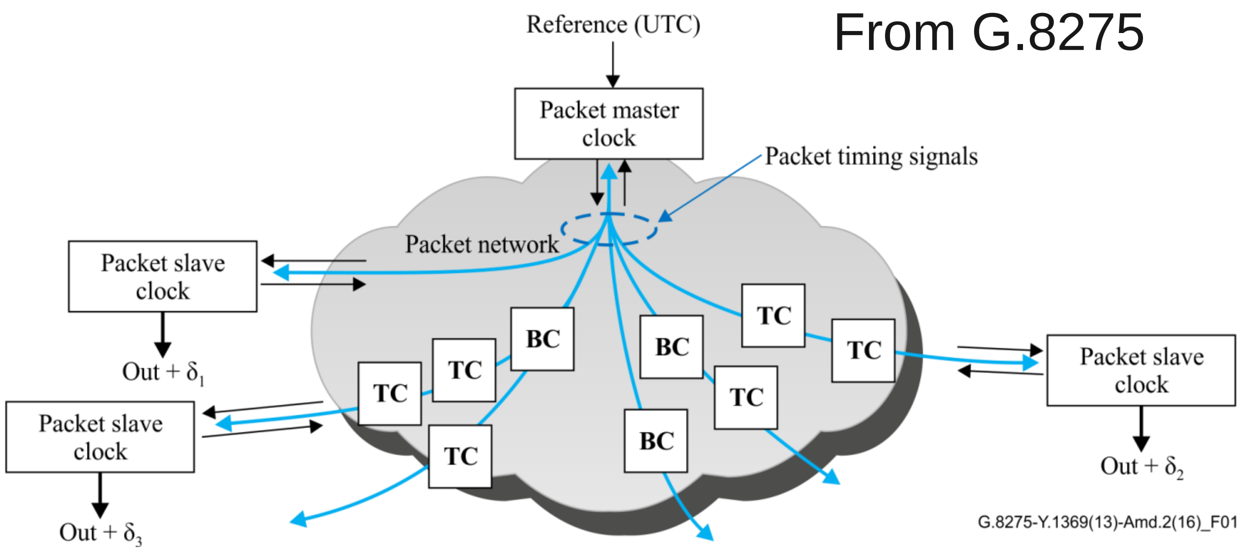


- Two-ways timing protocols (round trip delay)
  - Assumption for symmetric channel

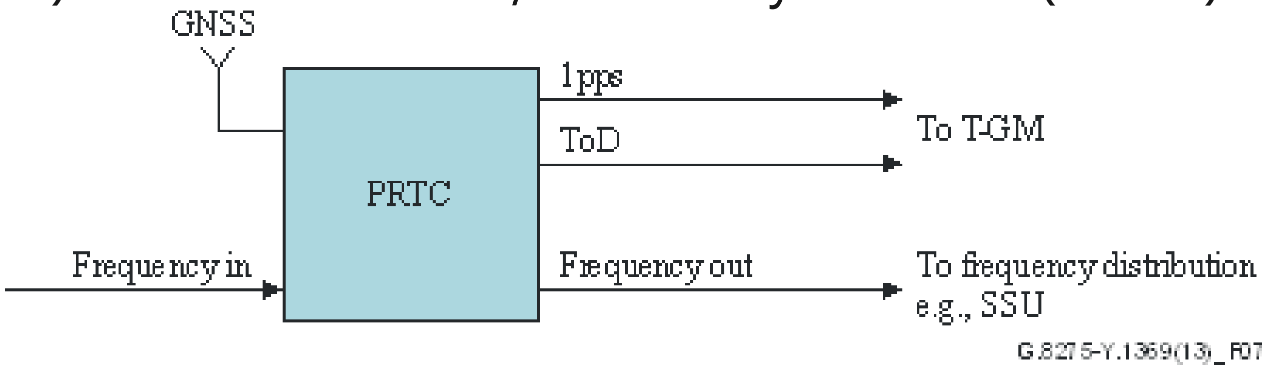
Time Synchronization Architecture (Telecom perspective)

- 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

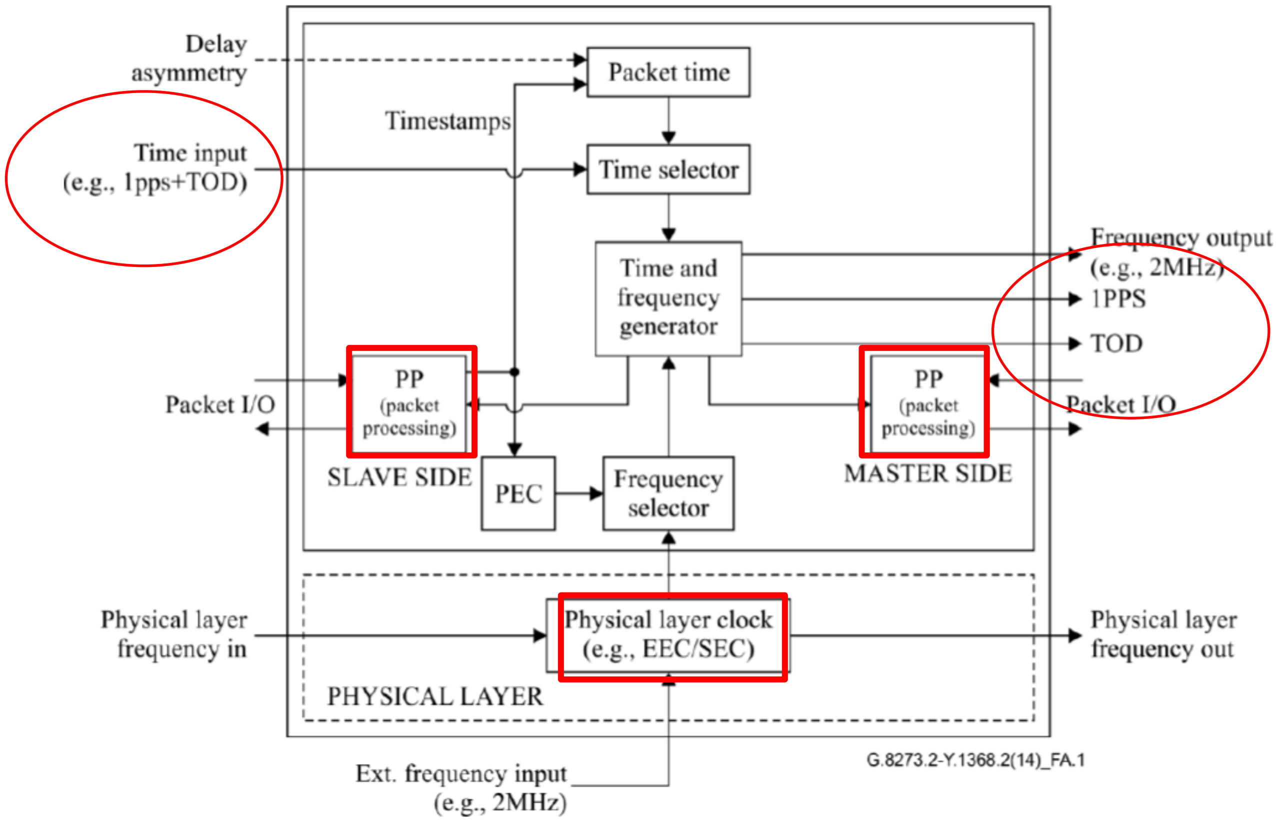
From G.8275

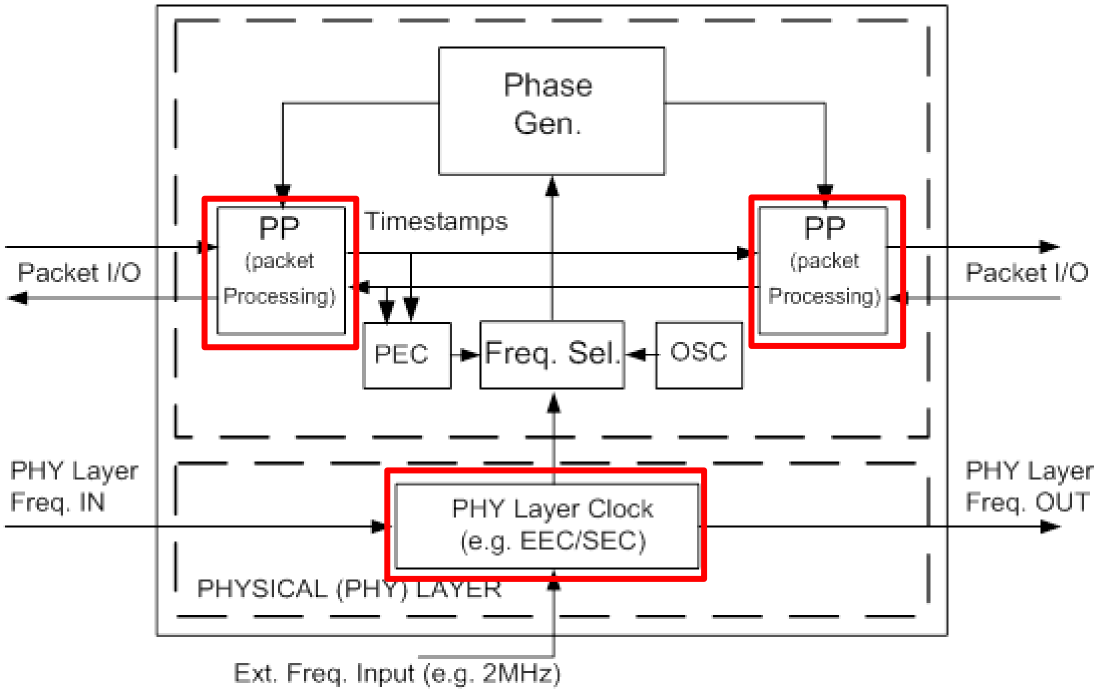


Primary Reference Time Clock (PRTC) is the master of the time synchronization network (G.8272).
ePRTC (enhanced PRTC) defined in G.8272.1, with 14 days Holdover (100 ns)



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

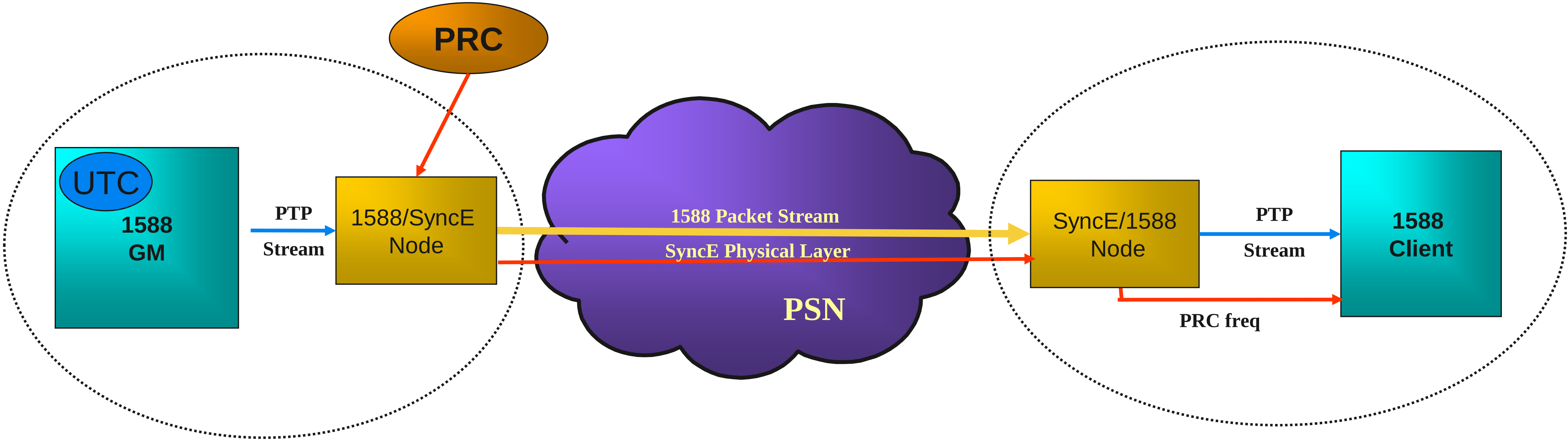




- **G.8273.2** and **G.8273.3** provide models for the Telecom Boundary and Transparent Clocks
  - **Frequency sync via physical layer** (option without physical layer did not get much traction)

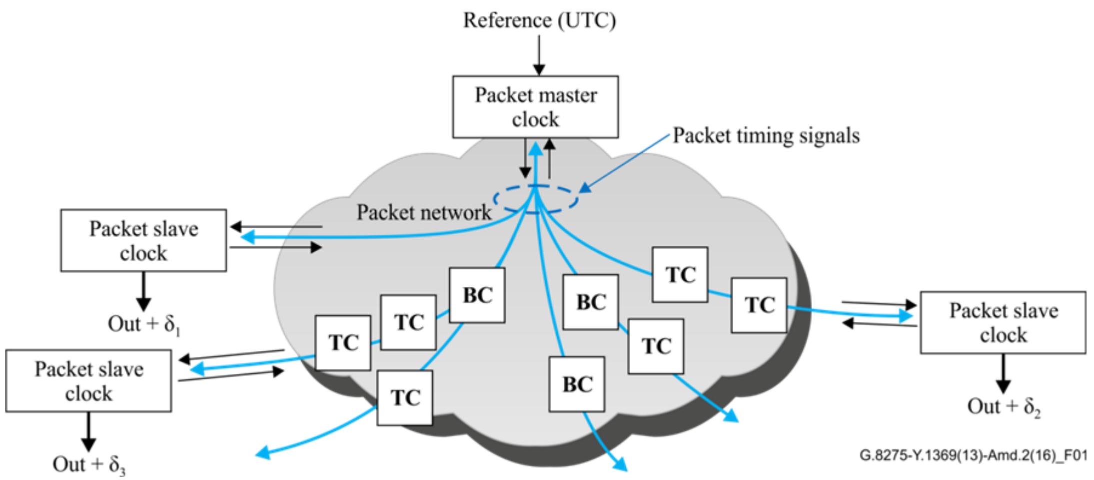
Combined PTP-SyncE

- SyncE as “frequency assistance” to 1588



- Gives immediate “frequency lock” to 1588 client
- SyncE & 1588 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 from Network



BC – Boundary Clock
TC – Transparent Clock

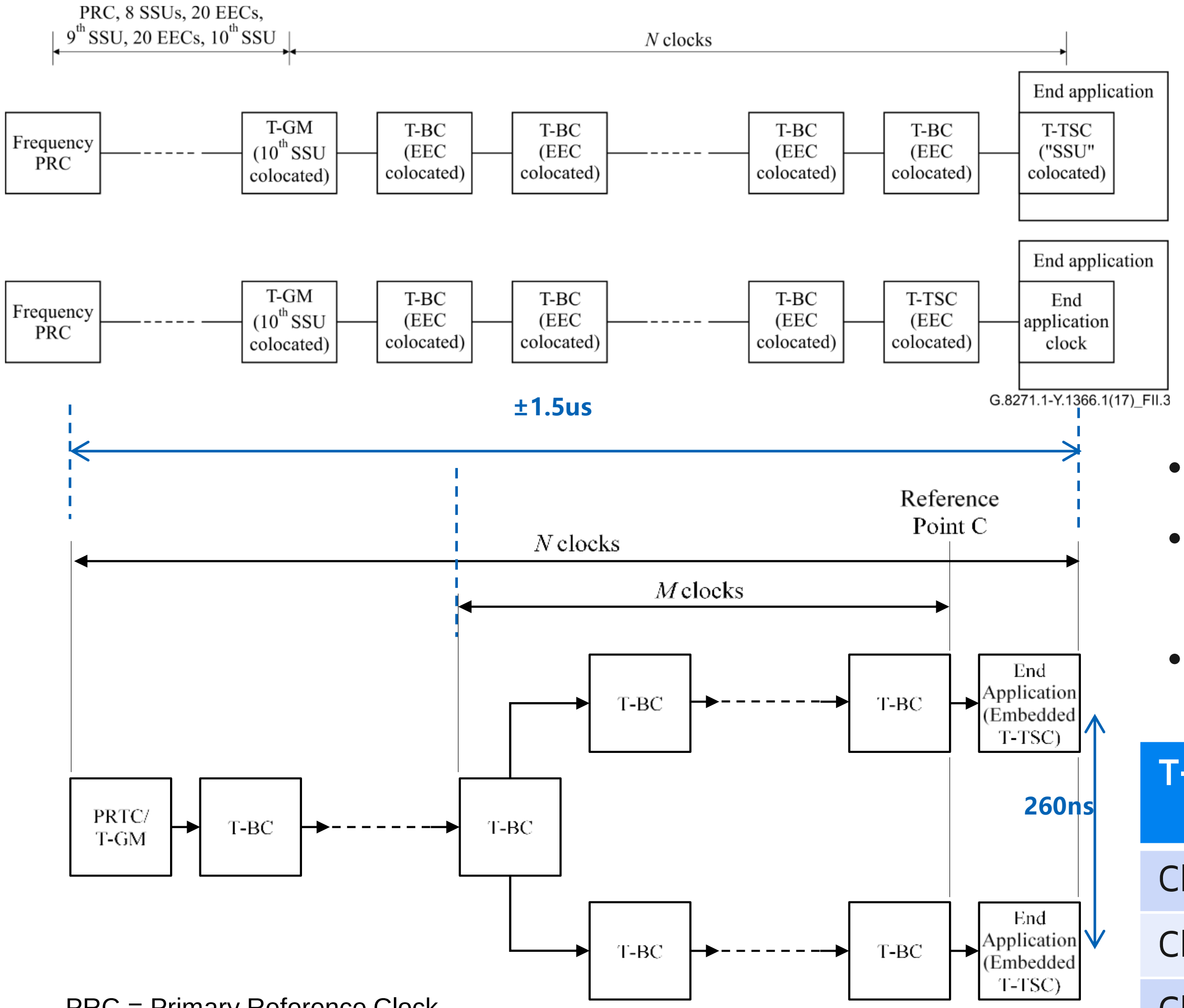
T-BC – Telecom Boundary Clock
T-TC – Telecom Transparent Clock

Figure 1 from ITU-T G.8275

- This profile is targeted 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)

- ITU-T Recommendations to support accurate phase/time synchronization
  - **G.8275** (Architecture)
  - **G.781.1** (Synchronization layer functions for packet-based synchronization)
  - **G.8275.1** (PTP telecom profile for phase/time synchronization with full timing support from the network),
  - **G.8271** (Network limits for time synchronization in packet networks with full timing support from the network),
  - **G.8271.1** (Network limits for time synchronization in packet networks with full timing support from the network),
  - **G.8272** (Timing characteristics of Primary reference time clock),
  - **G.8272.1** (Timing characteristics of enhanced primary reference time clock),
  - **G.8273** (Framework of phase and time clocks),
  - **G.8273.2** (Timing characteristics of telecom boundary clocks and telecom time slave clocks for use with full timing support from the network),
  - **G.8273.3** (Timing characteristics of telecom transparent clocks for use with full timing support from the network)

ITU-T G.8271.1 Sync Network Architecture



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 use 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)

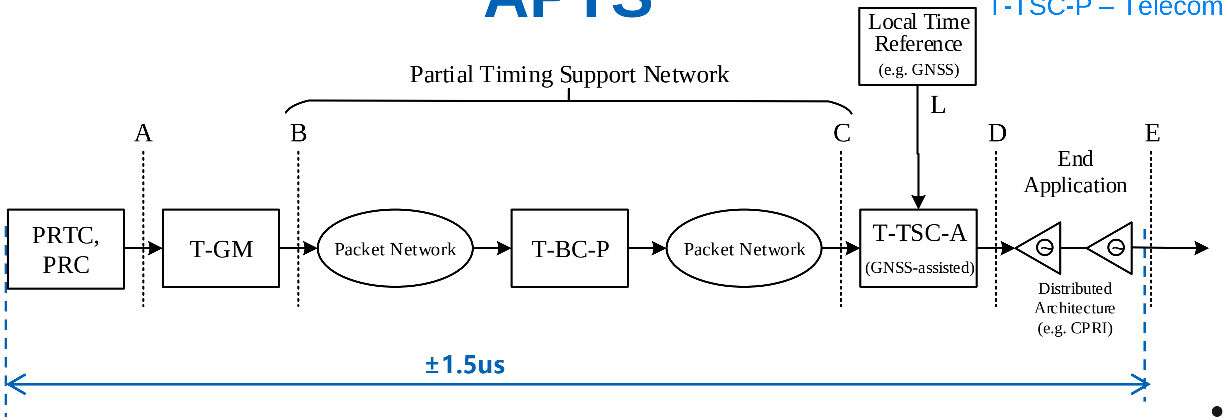
T-BC/T-TSC/T-TC	cTE	dTE (MTIE)	max|TE|	dTE (High-Pass filtered)
Class A (with SyncE)	+/-50ns	40 ns	100 ns	70ns
Class B (with SyncE)	+/-20ns	40ns	70ns	70ns
Class C (with eSyncE)	+/-10ns	10ns	30 ns (T-BC) Under Study for T-TC	Under Study
Class D(with eSyncE) Only T-BC/T-TSC	Under Study	Under Study	5 ns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

*measured with a first order filter of 0.1Hz bandwidth

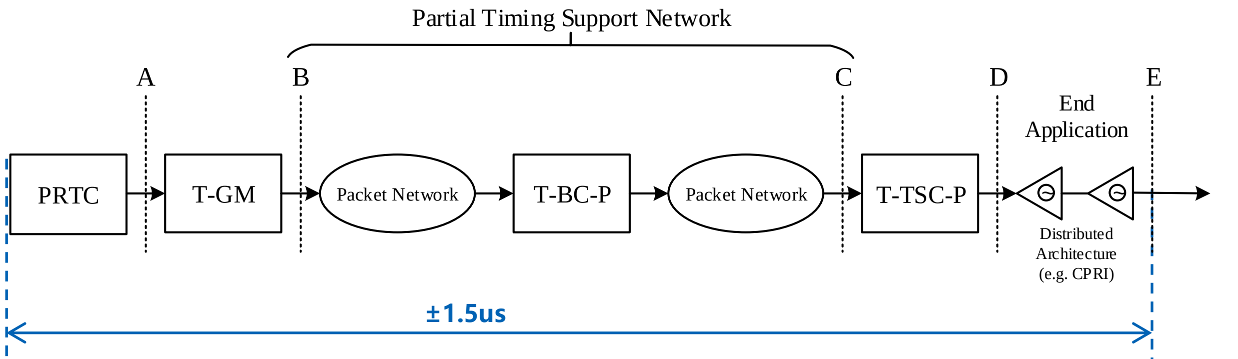
G.8275.2- ITU-T Time/Phase Profile – IEEE-1588 without timing support from Network

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

APTS



PTS



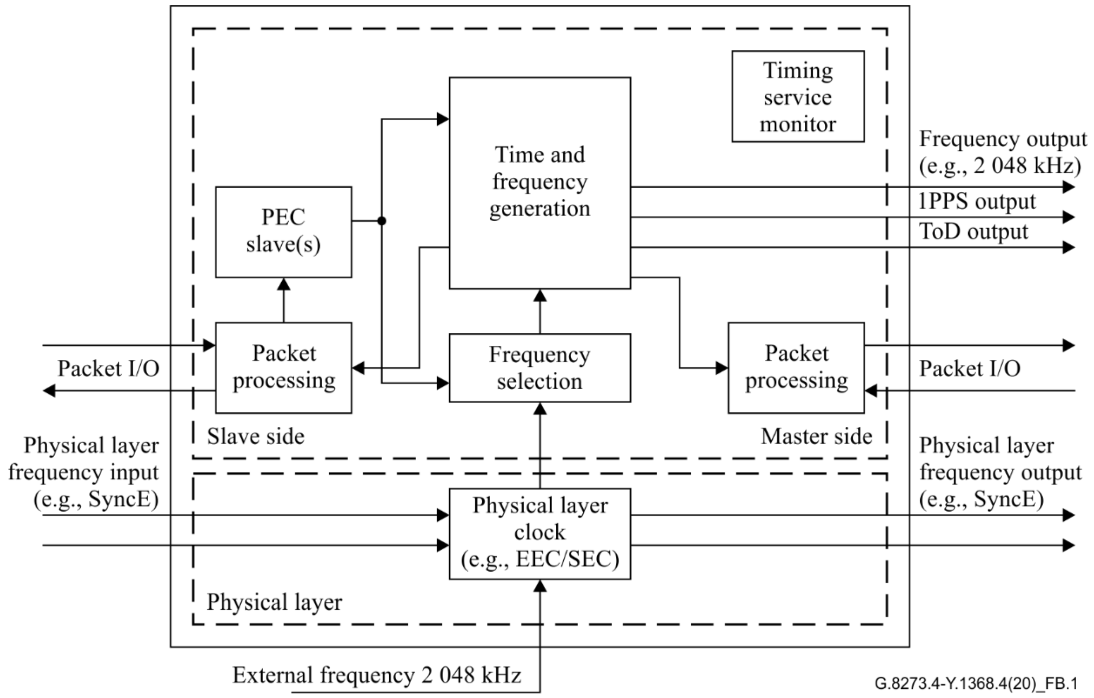
Figures I.1 and I.2 from ITU-T G.8275.2 latest draft

- 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

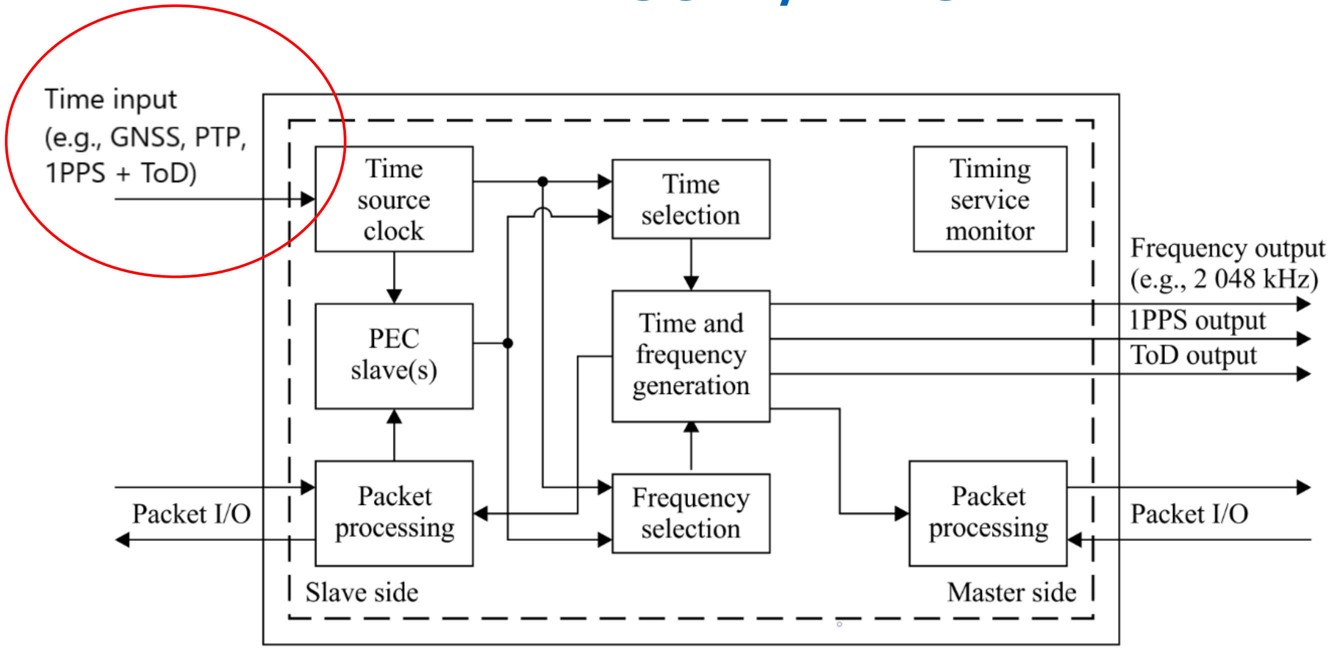
- ITU-T Recommendations to support phase/time synchronization (PTS):
  - G.8275 (Architecture)
  - G.8275.2 ((Precision time Protocol Telecom Profile for time/phase synchronization with partial timing support from the network)
  - G.8271 (Time and phase synchronization aspects of packet networks)
  - G.8271.2 (Network limits for time synchronization in packet networks with partial timing support from the network)
  - G.8272 (Timing characteristics of Primary reference time clock),
  - G.8272.2 (Network limits for time synchronization in packet networks with partial timing),
  - G.8273 (Framework of phase and time clocks),
  - G.8273.4 (Timing characteristics of partial timing support telecom boundary clocks and telecom time slave clocks)

G.8273.4: Clock functional models for Partial Timing Support

T-TSC-P / T-BC-P



T-TSC-A / T-BC-A



- **G.8273.4** provide models for the Telecom Boundary and Telecom Slave clocks for PTS and APTS
  - **Frequency sync via physical layer** is optional for PTS

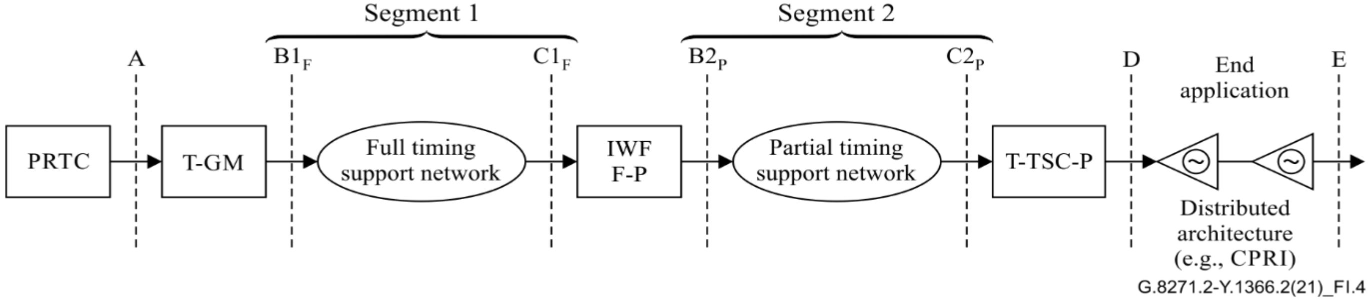
G.8265.1, G.8275.1, G.8275.2 - PTP Options and Configurable Attributes

PTP Options/Attributes	G.8265.1	G.8275.1	G.8275.2
Domain Number	default : 4, range: {4-23}	default : 24, range: {24-43}	default : 44, range: {44-63}
Types of Clocks	Ordinary clocks (i.e. Grandmasters, slave-only clocks)	- Ordinary clocks (i.e. Grandmasters, slave-only clocks) - Boundary clocks - End-to-end transparent clocks	- Ordinary clocks (i.e. Grandmasters, slave-only clocks) - Boundary clocks
Time Transfer	- One-way - Two-way	- Two-way	- Two-way
Type of clocks	One-step and two-step	One-step and two-step	One-step and two-step
Transport Mode	Unicast - IEEE1588-2008 Annex D IPv4/UDP stack - IEEE1588-2008 Annex E IPv6/UDP stack	Multicast - IEEE1588-2008 Annex F - Transport of PTP over OTN (based on G.7041 and G.709)	Unicast - IEEE1588-2008 Annex D IPv4/UDP stack - IEEE1588-2008 Annex E IPv6/UDP stack
Path delay measurement	delay request/delay response mechanism	delay request/delay response mechanism	delay request/delay response mechanism
PTP Message rate (packets/s)	Sync /Follow-up – min rate:1/16, max rate: 128 Delay_Request/Delay_Response – min rate:1/16, max rate: 128 Announce – min rate:1/16, max rate: 128	Sync /Follow-up – fixed rate of 16 Delay_Request/Delay_Response – fixed rate of 16 Announce – fixed rate of 8	Sync /Follow-up – min rate:1, max rate: 128 Delay_Request/Delay_Response – min rate:1, max rate: 128 Announce – min rate:1, max rate: 128 Signaling messages – no rate is specified
BMCA	Alternate BMCA	alternate BMCA based on the IEEE 1588 default BMCA	alternate BMCA based on the IEEE 1588 default BMCA

- Note 1: support for IEEE1588-2019 recently added into all the Telecom Profiles
- Note 2 : *support for IPV6 was made mandatory for G.8275.2 and G.8265.1 last December*

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.



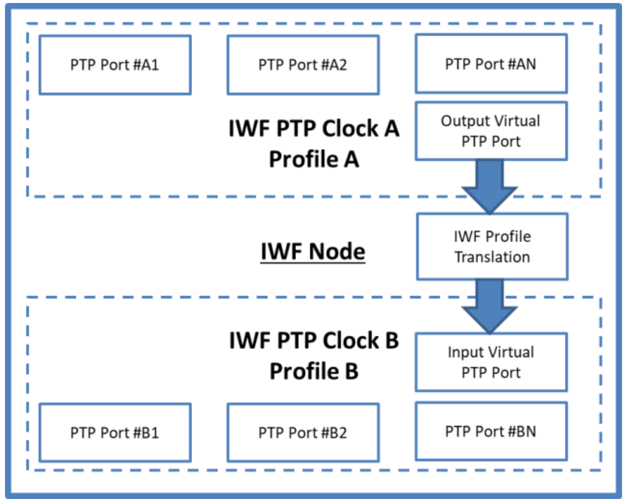


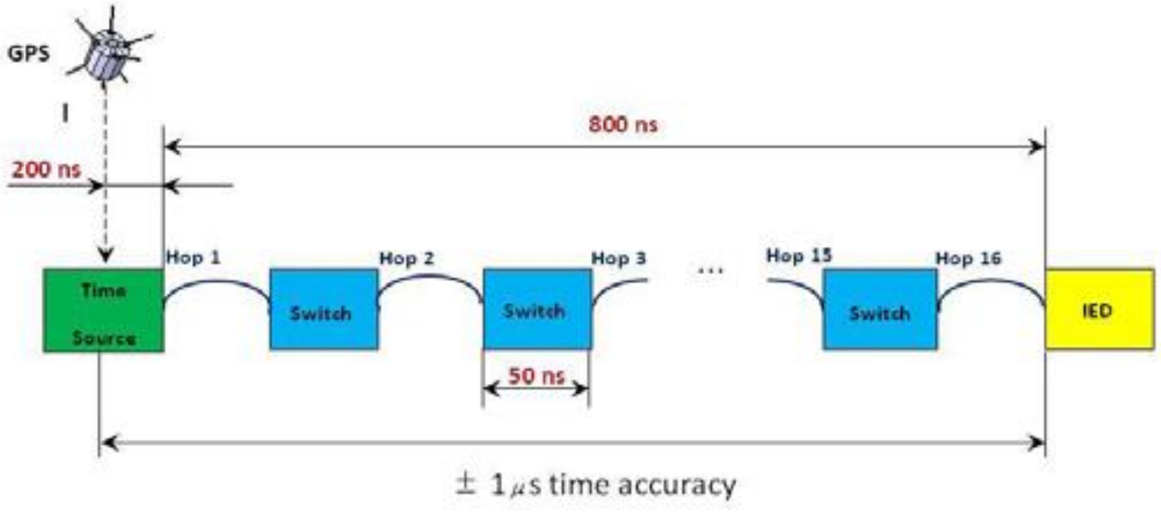
Table 1 – Mapping between IWF, ITU-T G.8275.1, ITU-T G.8275.2 and PTP clock types

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

Recently added in G.8275

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 slaves 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.

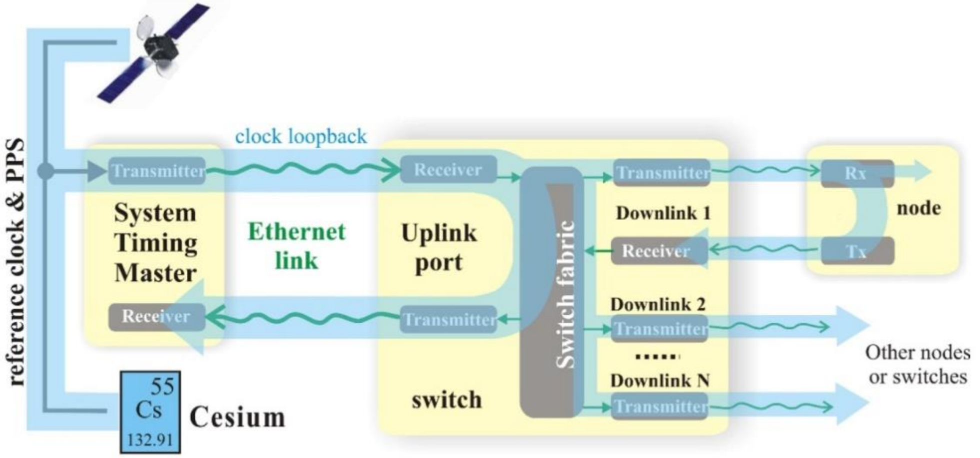


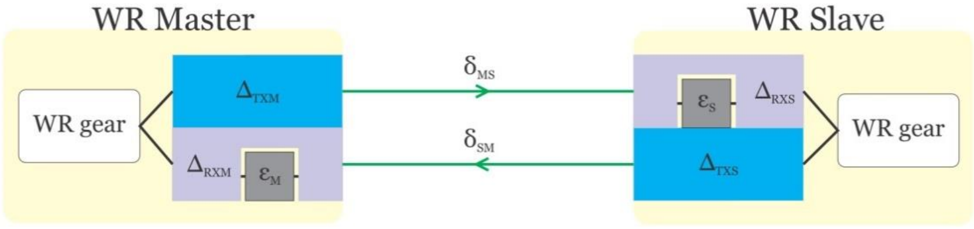
From Standard Profile for Use of IEEE Std 1588-2008 Precision Time Protocol (PTP) in Power System Applications, IEEE PES PSRC Working Group H7/Sub C7 Members and Guests, 2012 IEEE Conference

- **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

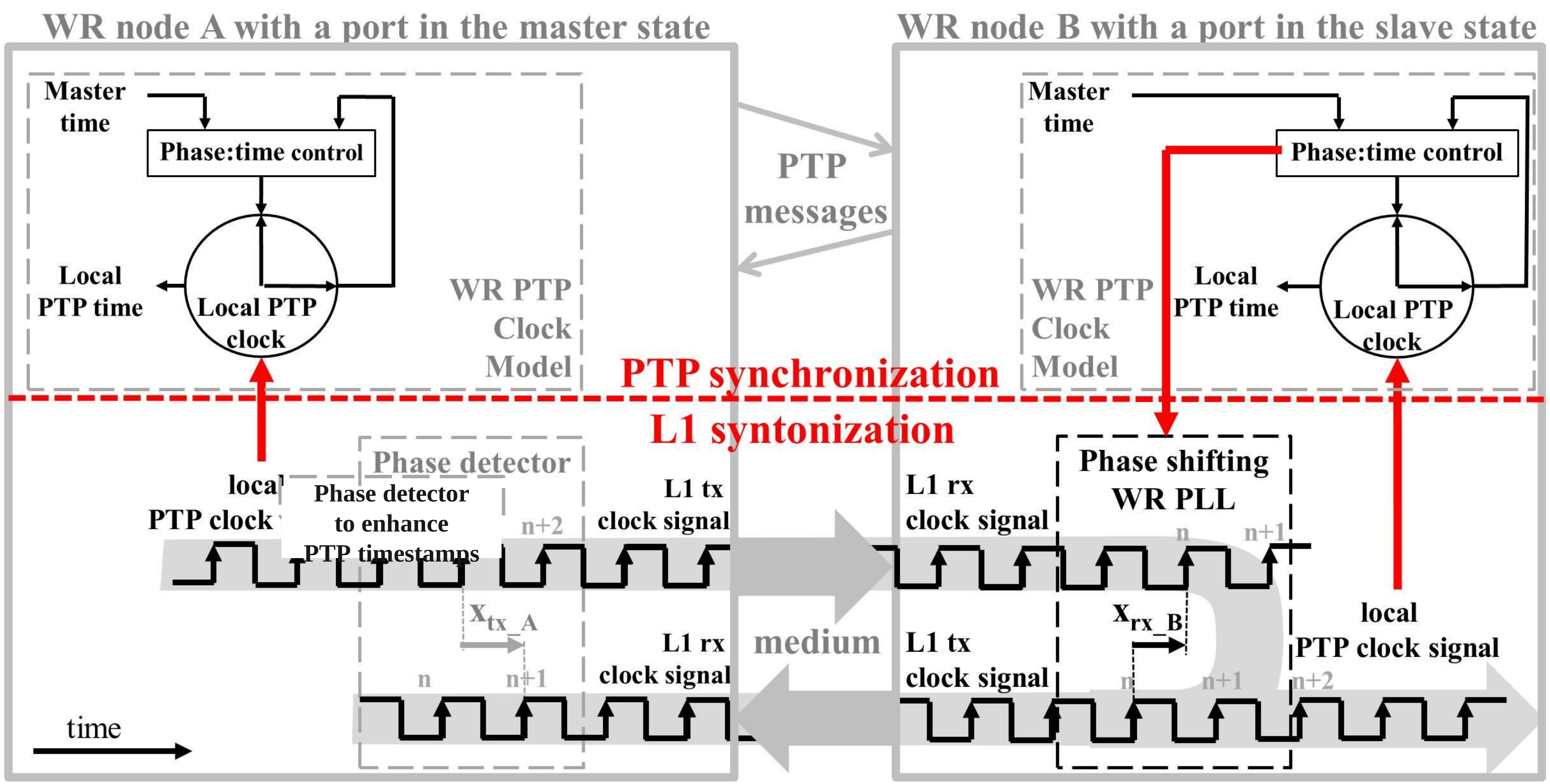
High Accuracy/«White Rabbit» Architecture and Profile

- 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



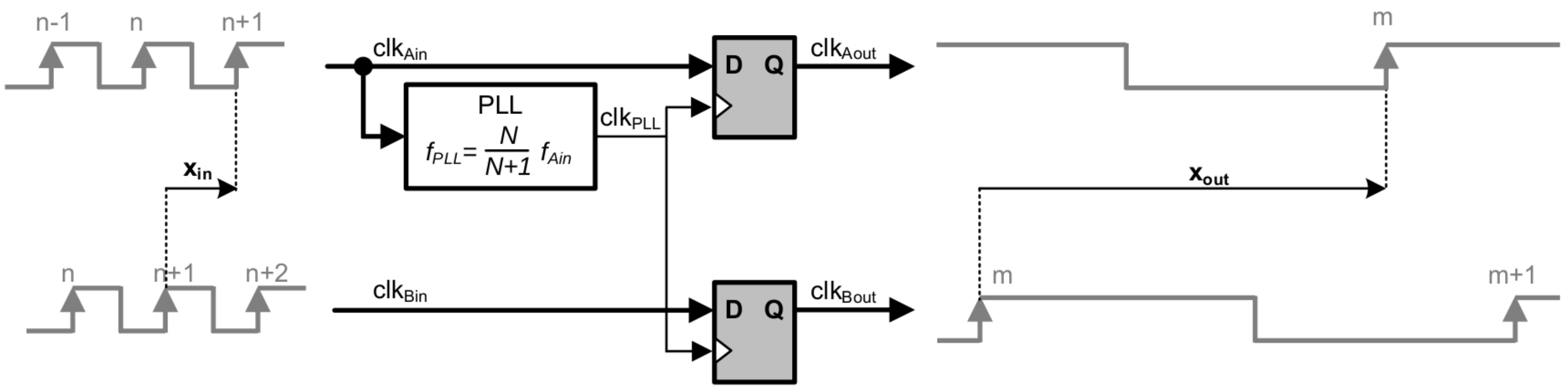


PTP Synchronization and L1 Syntonization in the White Rabbit



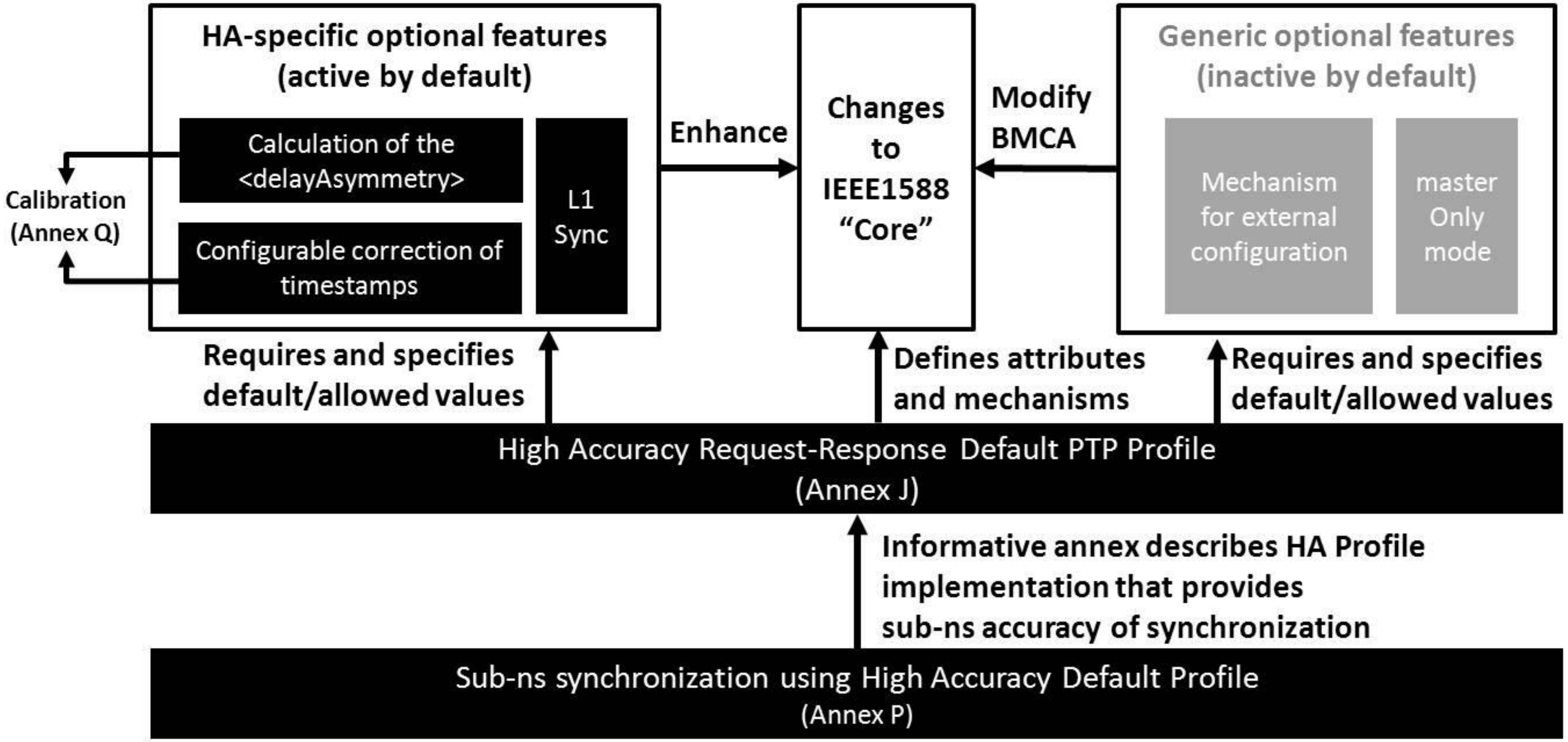
Digital Dual Mixer Time Difference (DDMTD)

- Clever implementation of a phase detector in an FPGA
- Uses D-flip-flops to zoom-in phase offset
- Allows for phase measurements at picosecond level



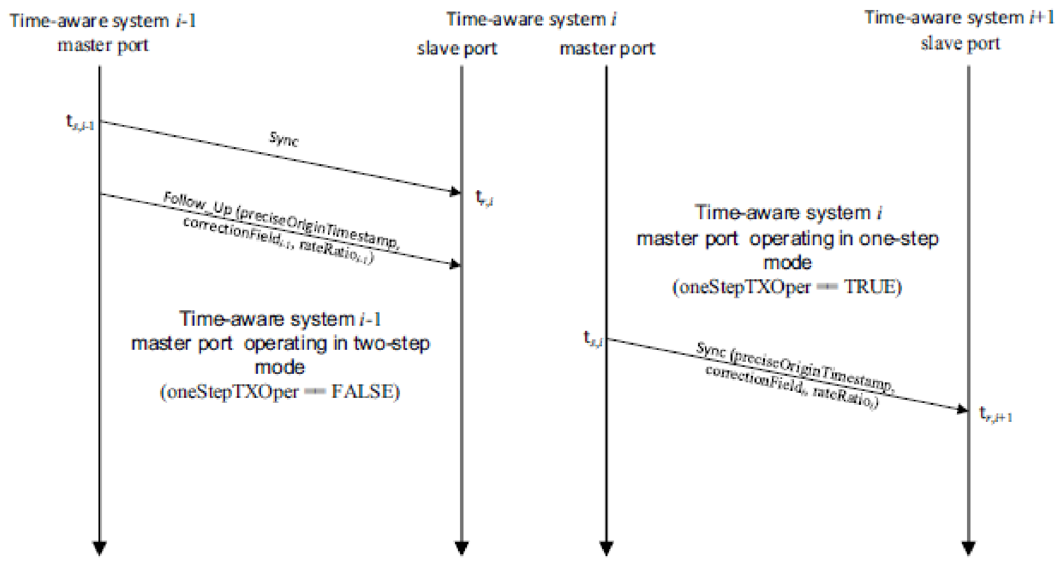
www.cern.ch/white-rabbit/documents/DDMTD_for_Sub-ns_Synchronization.pdf

White Rabbit integrated into IEEE1588-2019 as High Accuracy



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 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)

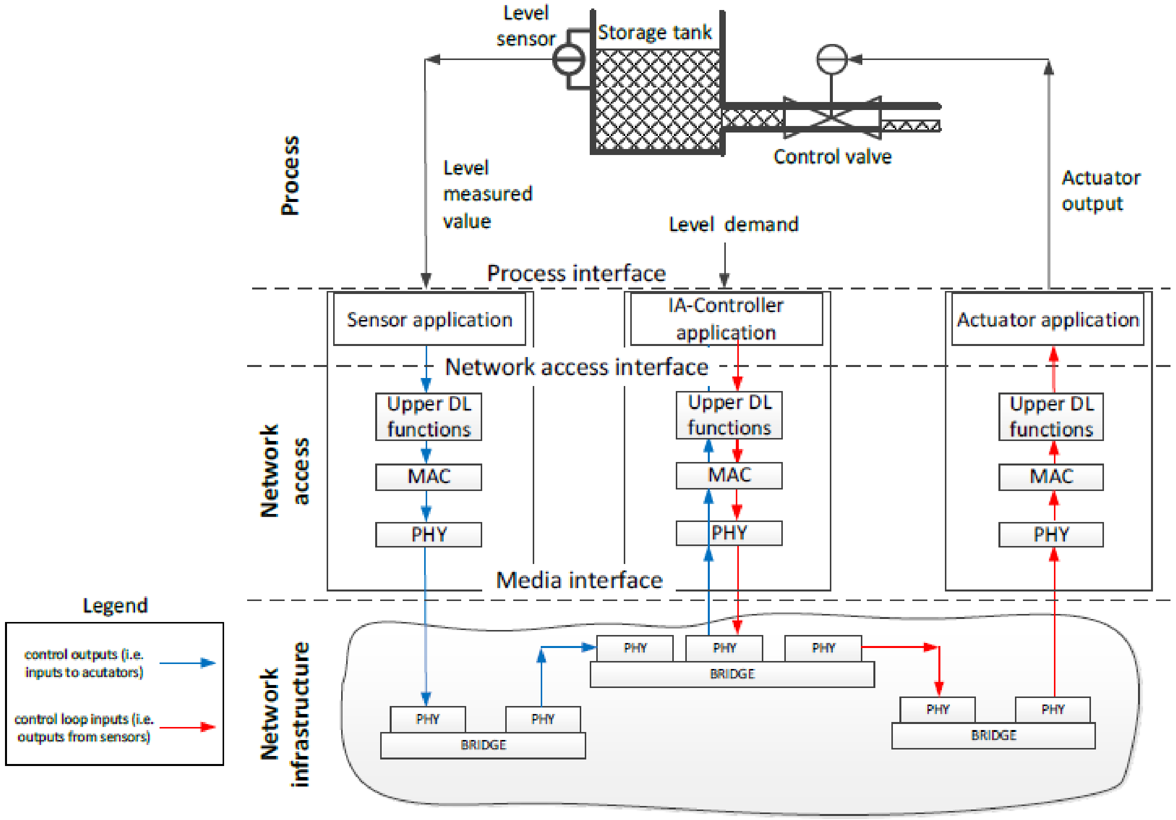


Figure 1 – Data flow in a control loop

- Source: IEC/IEEE 60802 D1.3 draft

Time-Sensitive Networking (TSN) Automotive Profile

- IEEE 802.1 TSN is working group is working on a set of profiles to address bridges and end stations for automotive
- 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 is being discussed
  - Best Master Clock Algorithm (BMCA) may not be needed
  - Synchronization performance for the different applications. For video and audio, time accuracy of 1μs has been proposed
  - Message rates need to be defined to meet applications requirements

Thank you!

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References

- ITU T Recommendations (**Published Recommendations can be downloaded from:** http://www.itu.int/rec/T-REC-G/e)
  - G.810, Definitions and terminology for synchronization networks.
  - G.811, Timing characteristics of primary reference clocks.
  - time sync: G.827x
  - frequency sync: G.826x
  - G.Sup65, Simulations of transport of time over packet networks
  - G.Sup68, Synchronization OAM requirements
  - ITU-T GSTR-GNSS - Considerations on the use of GNSS as a primary time reference in telecommunications (https://www.itu.int/dms_pub/itu-t/opb/tut/T-TUT-HOME-2020-PDF-E.pdf
- NTP: IETF RFC 5905/6/7/8
- PTP: IEEE 1588-2008, IEEE1588-2019
- CES: RFC 5087, RFC 5086, RFC4533, ITU-T Y.1413, ITU-T Y.1453, MEF3, MEF 8
- Power Profile: IEC/IEEE 61850-9-3:2016, IEEE C37-238
- High Accuracy/White Rabbit:
  - IEEE1588-2019 (High Accuracy Default PTP Profile in Annex J.5);
  - WR-PTP = White Rabbit Profile defined in WR Spec
- TSN: IEEE 802.1AS-2020