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DISTRIBUTION OF TIMING: SYNC OVER THE PACKET LAYER OF NETWORKS

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Credits:

Slide 20..23: courtesy by Maciej Lipinski

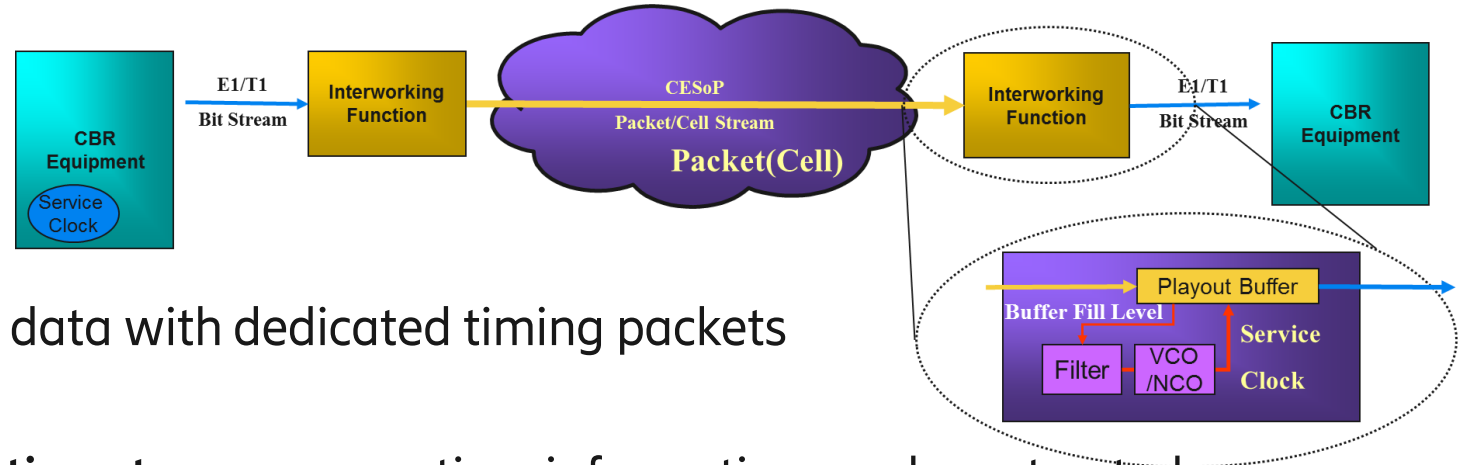


1. FREQUENCY SYNC VIA PACKETS

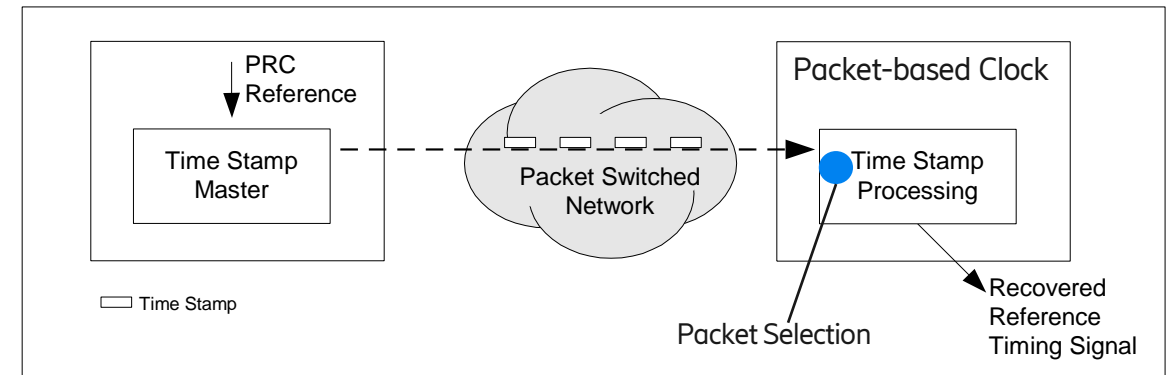
Introduction



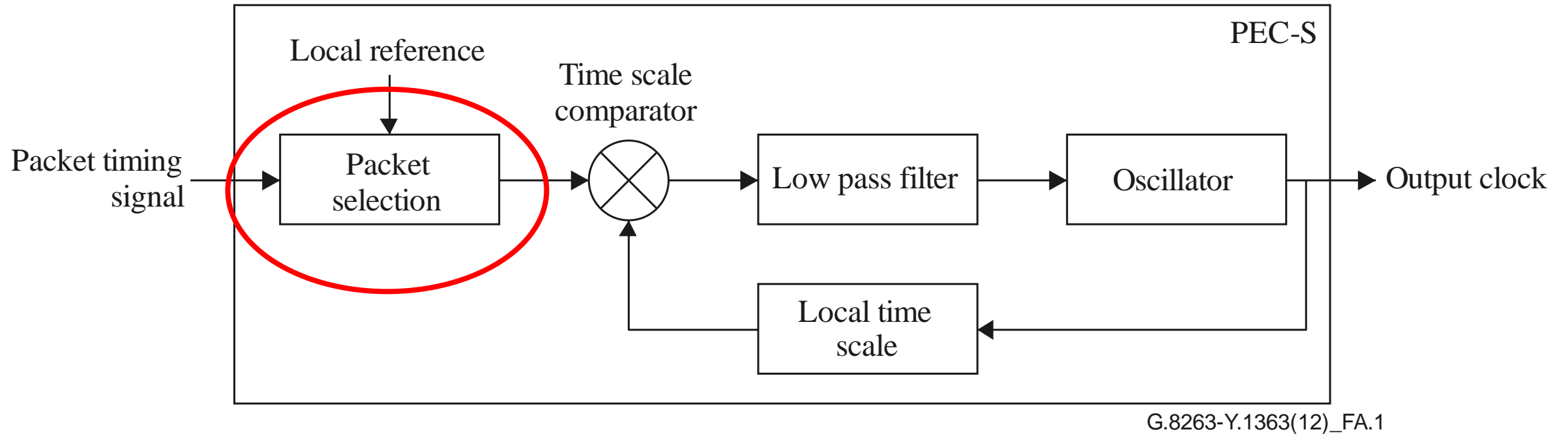
- Timing carried via packets was originally used to receiver the service timing (e.g., 2 Mbit/s service carried over packet networks); known as “Circuit Emulation”
 - Service clock adjusts based on buffer fill level / **packet arrival rate**, **PDV** influences wander at the network output



- 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

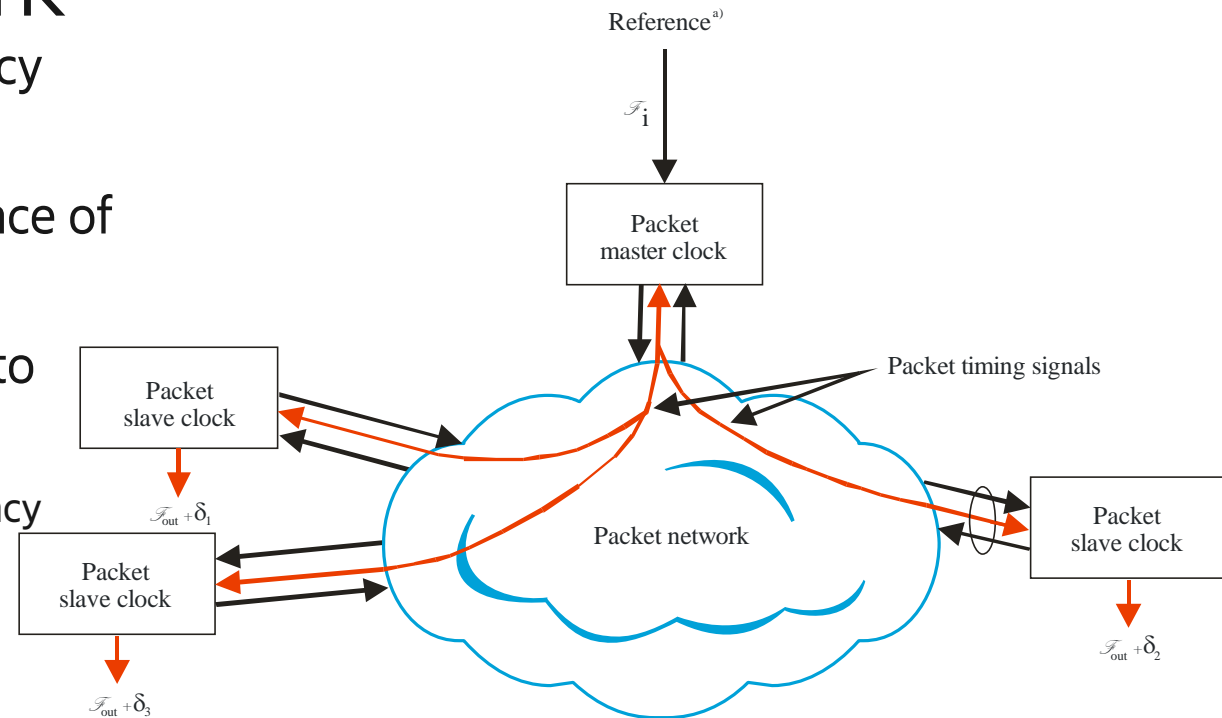


- Profile targeted for applications that need only frequency synchronization
- Packet delay variation (PDV) will impact the performance of the clock (PDV filtering is needed in the slave clocks)
- Several ITU-T Recommendations has been developed to support this profile

- **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)), ^{a)} The reference may be from a PRC directly, from a GNSS or via a synchronization network

- **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) (Work in progress)



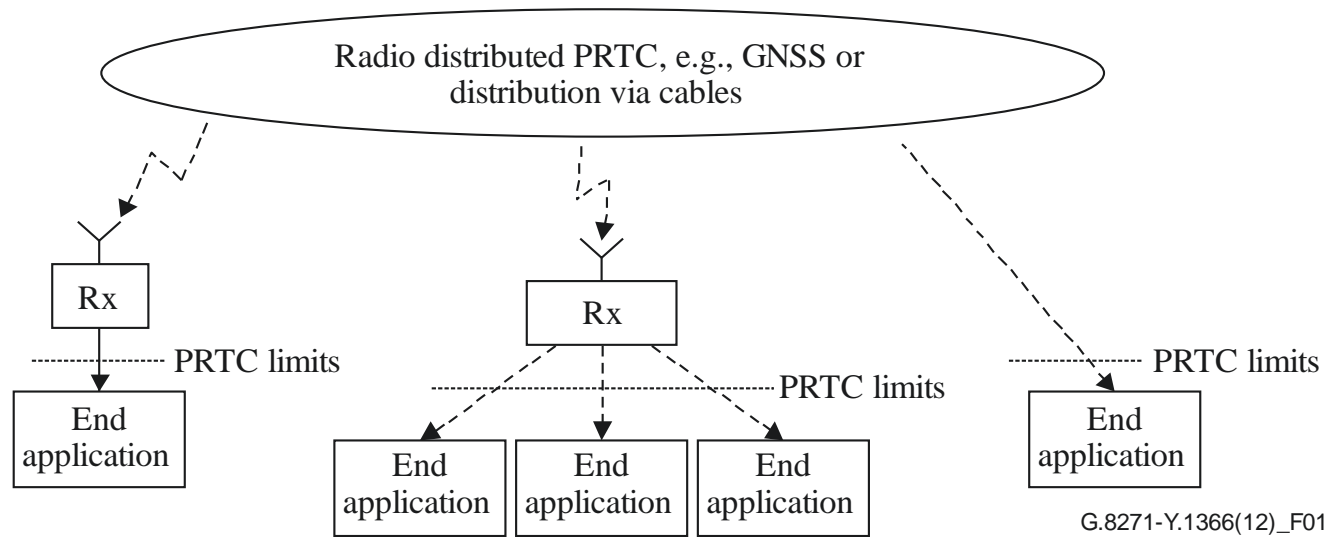
G.8265/Y.1365(10)_F01

2. TIME SYNC DISTRIBUTION

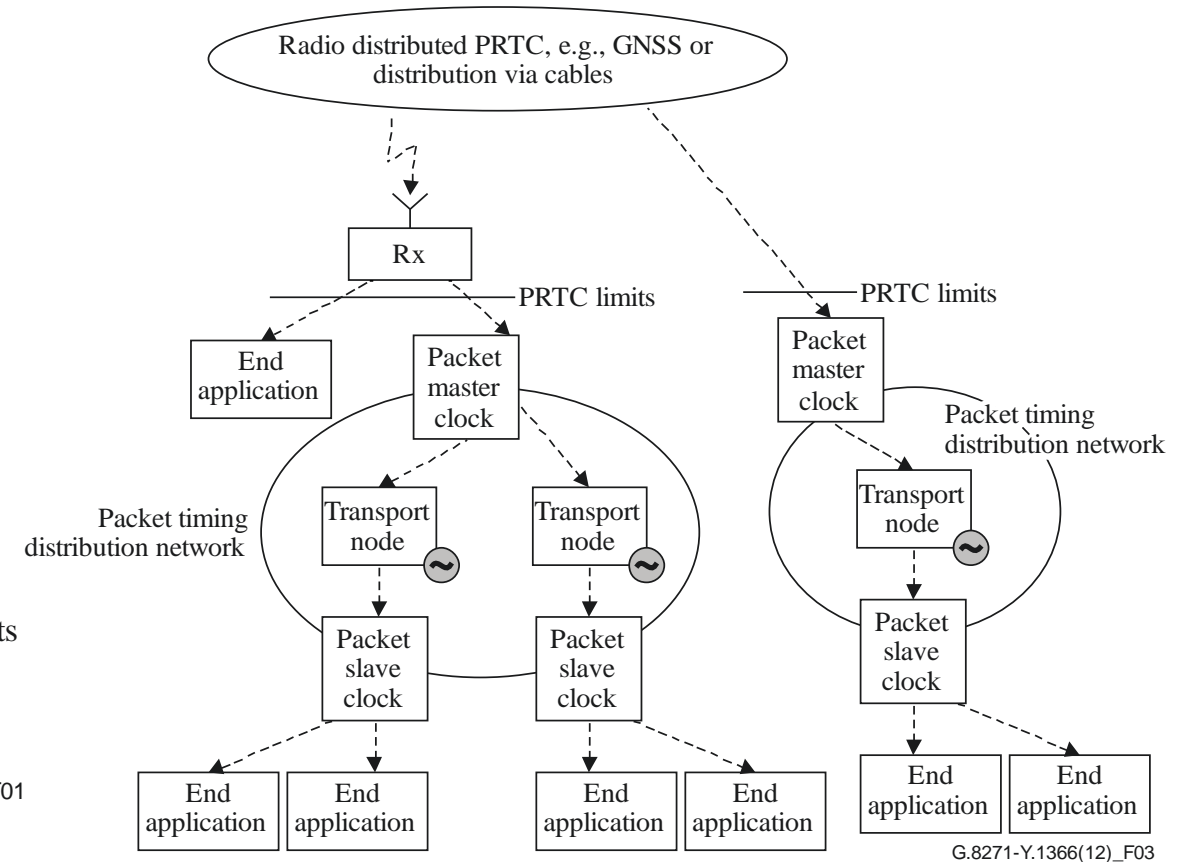
Introduction



- Distributed vs. packet-based



-----> Time or phase synchronization distribution via cable
- - - - -> Time or phase synchronization distribution via radio



~ T-BC

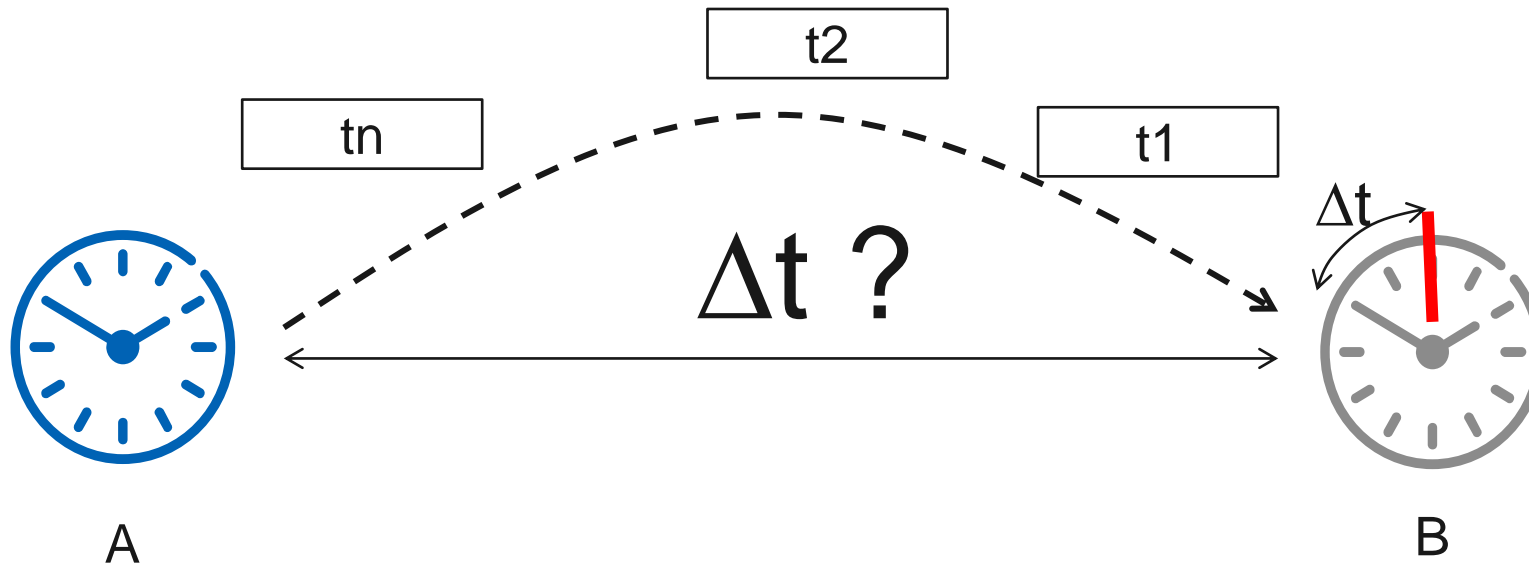
-----> Time or phase synchronization distribution via cable
- - - - -> Time or phase synchronization distribution via radio

(From ITU-T G.8271)

Two-ways time transfer



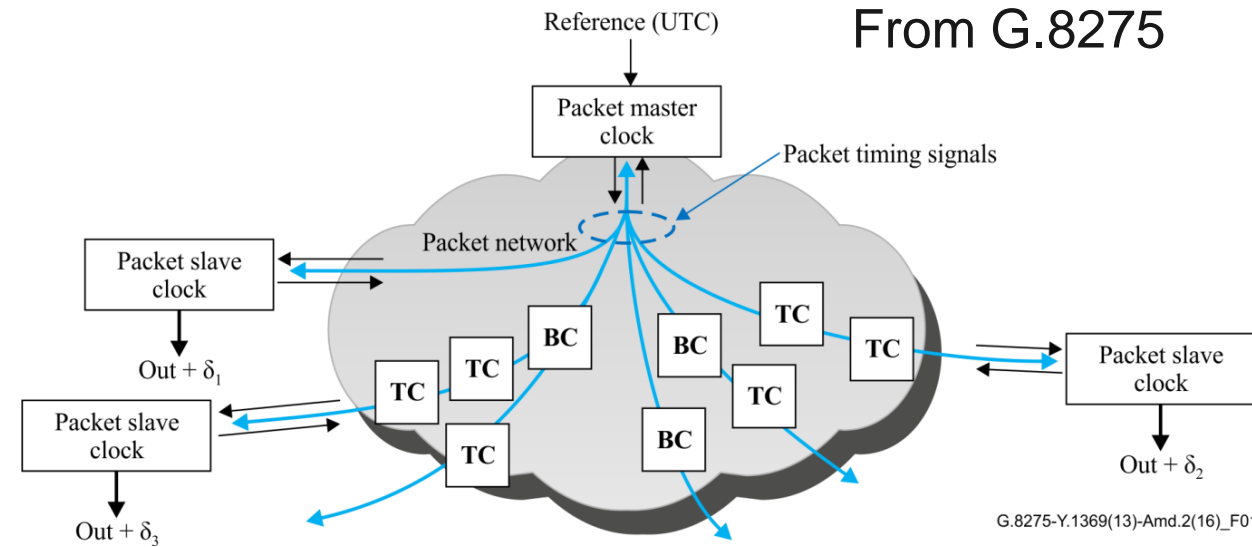
- Delivery of Time synchronization requires also the knowledge of «transit delay» from A to B



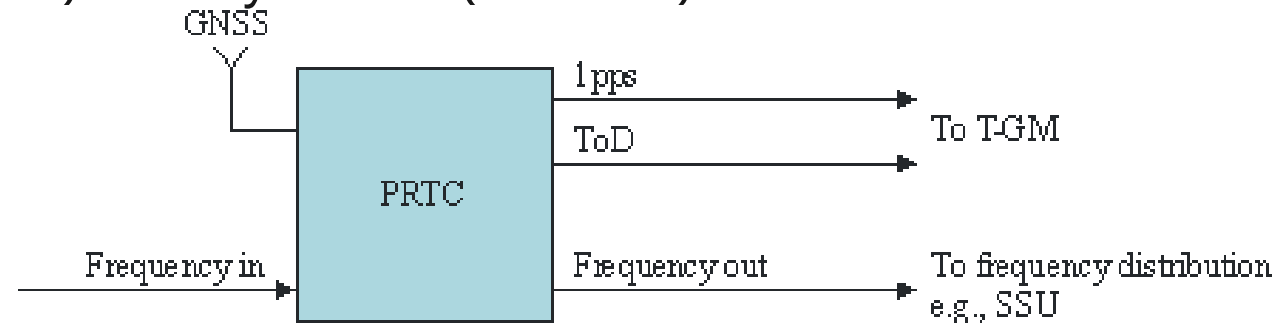
- Two-ways timing protocols (round trip delay)
 - Assumption for symmetric channel

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

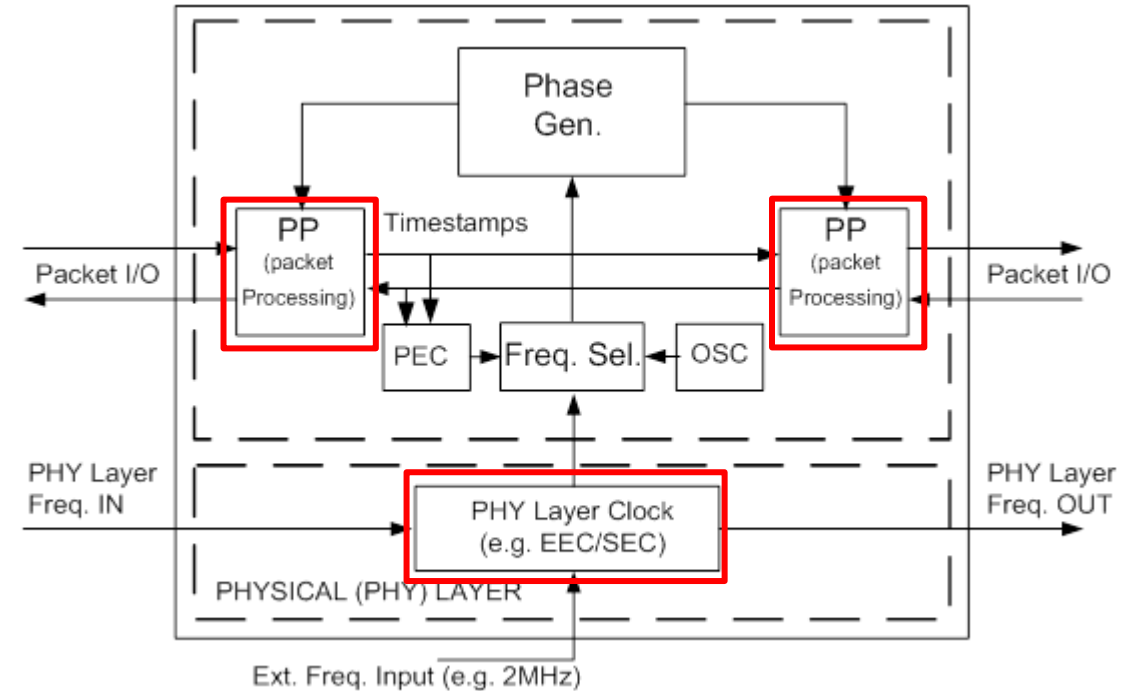
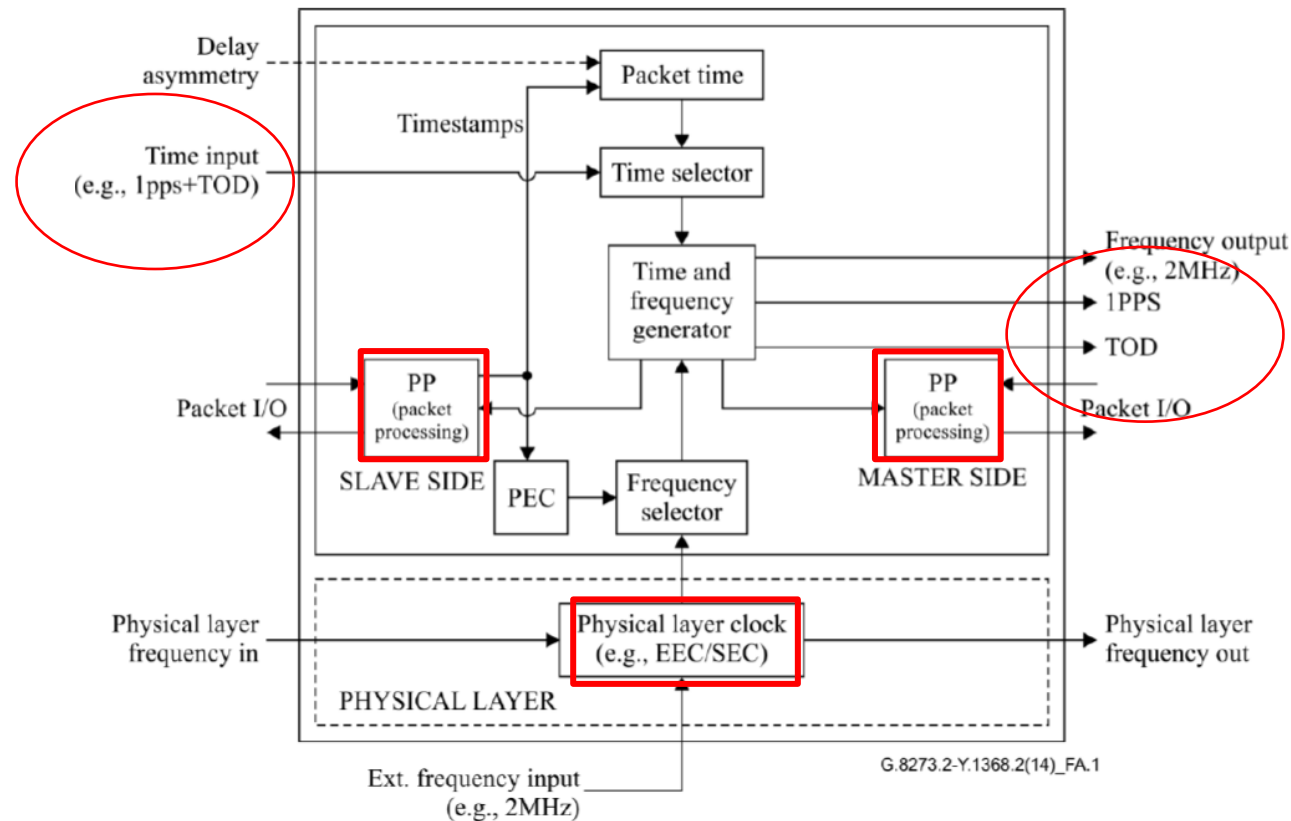


Primary Reference Time Clock (PRTC) is the master of the time synchronization network (G.8272).
ePRTC (enhanced PRTC) recently defined (G.8272.1)



G.8275-Y.1369(13)_F01

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

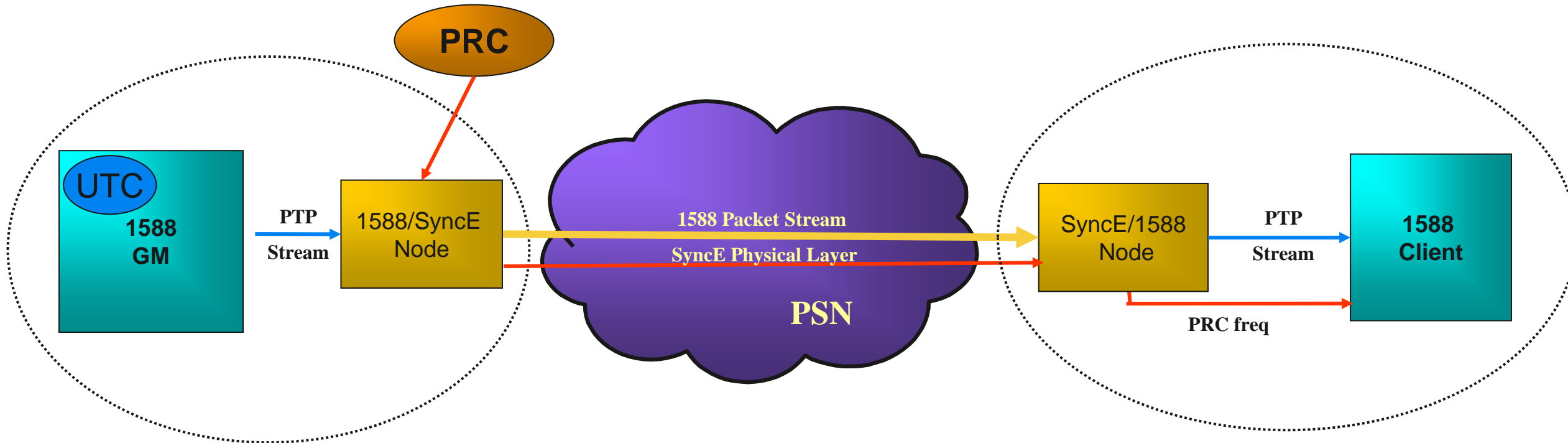


- G.8273.2 and G.8273.3 provide models for the Telecom Boundary and Transparent Clocks
- **Frequency sync via physical layer** (option without physical layer did not get much traction)

Combined PTP-SyncE

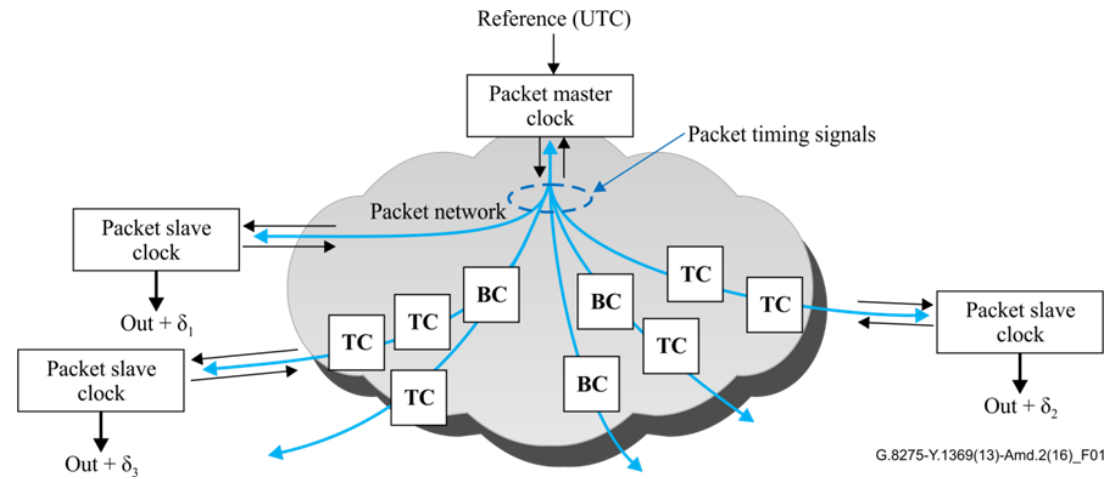


- SyncE as “frequency assistance” to 1588



- 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

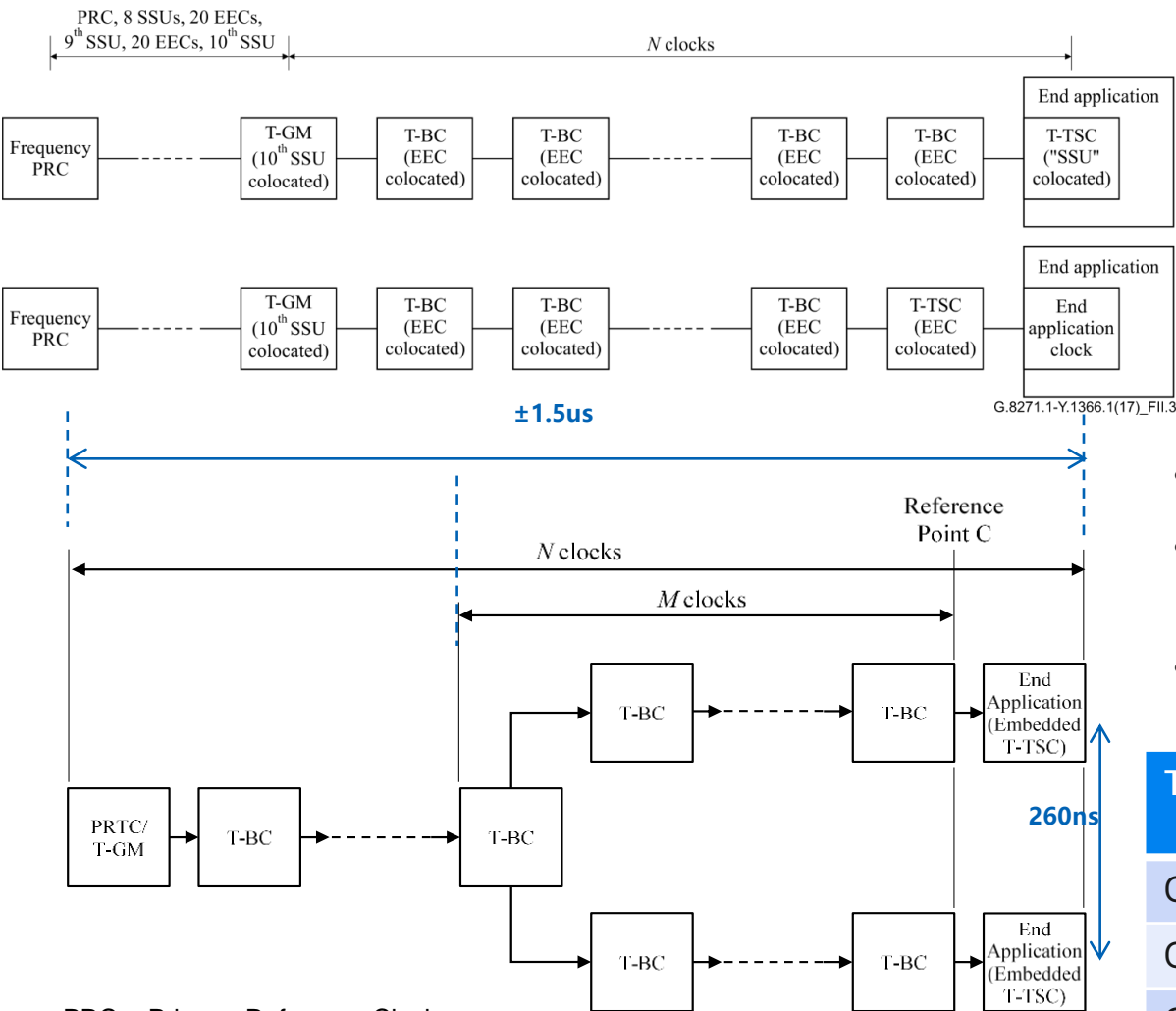
T-BC – Telecom Boundary Clock
T-TC – Telecom Transparent Clock

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.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

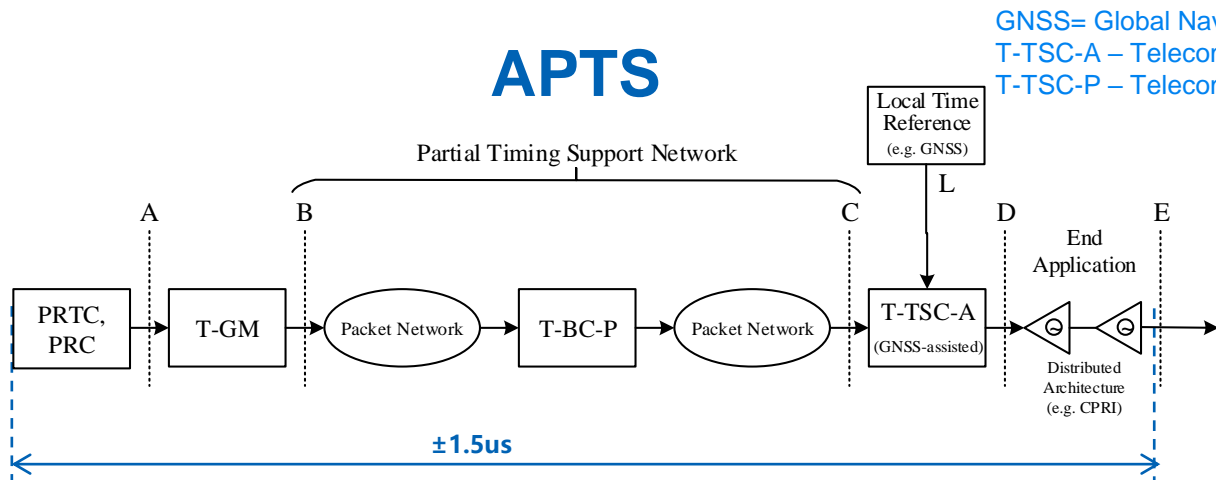


- G.8273.2 and G.8273.3 define several classes of T-BCs and T-TCs to be used in G.8271.1 architecture. Reference chains with class A and B have been fully studied for telecom backhaul
 - **For a shorter chain N=12 (uses T-BC/T-TC class A)**
 - **For longer chain N=22 (uses T-BC/T-TC class B)**
- Guidelines 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 ($M \leq 4$ with class C and $M= 1$ for class B)

T-BC/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	Under Study	Under Study	5 ns *	Under Study

*measured with a first order filter of 0.1Hz bandwidth

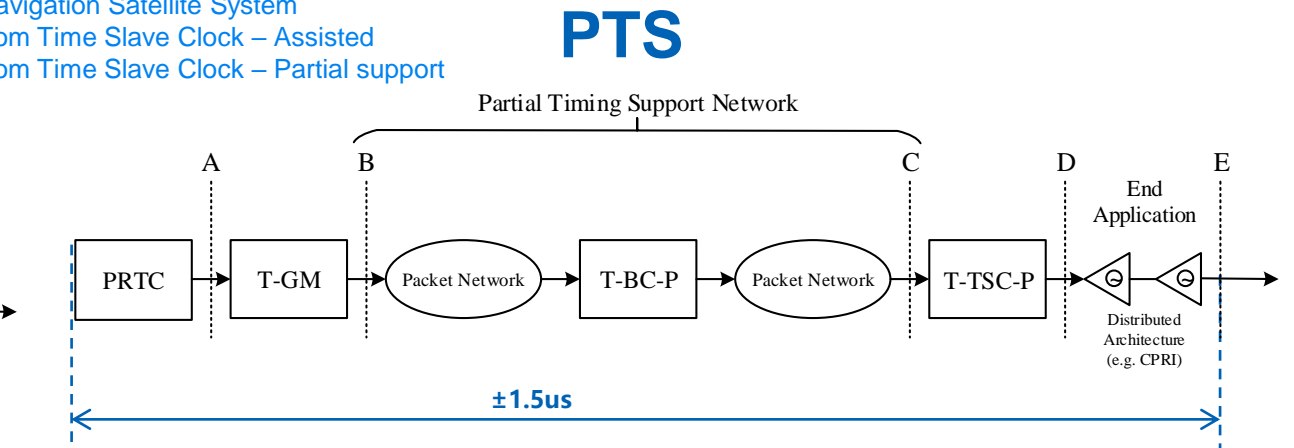
G.8275.2- ITU-T Time/Phase Profile – IEEE-1588 without timing support from Network



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

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



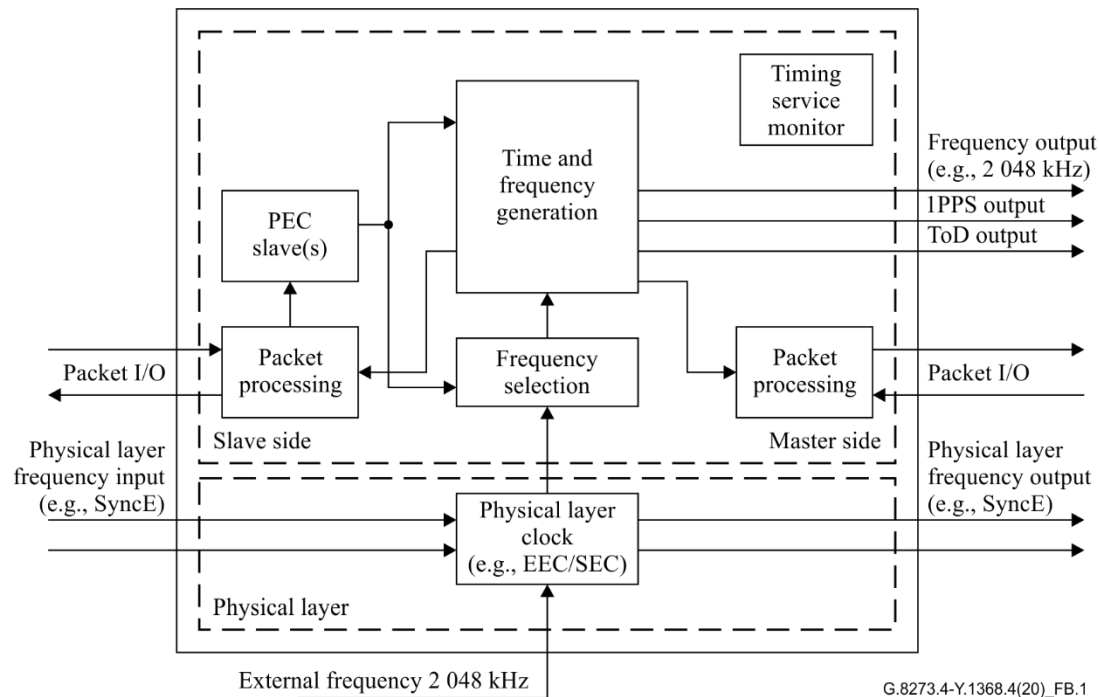
- ITU-T Recommendations to support phase/time synchronization (PTS):

- 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

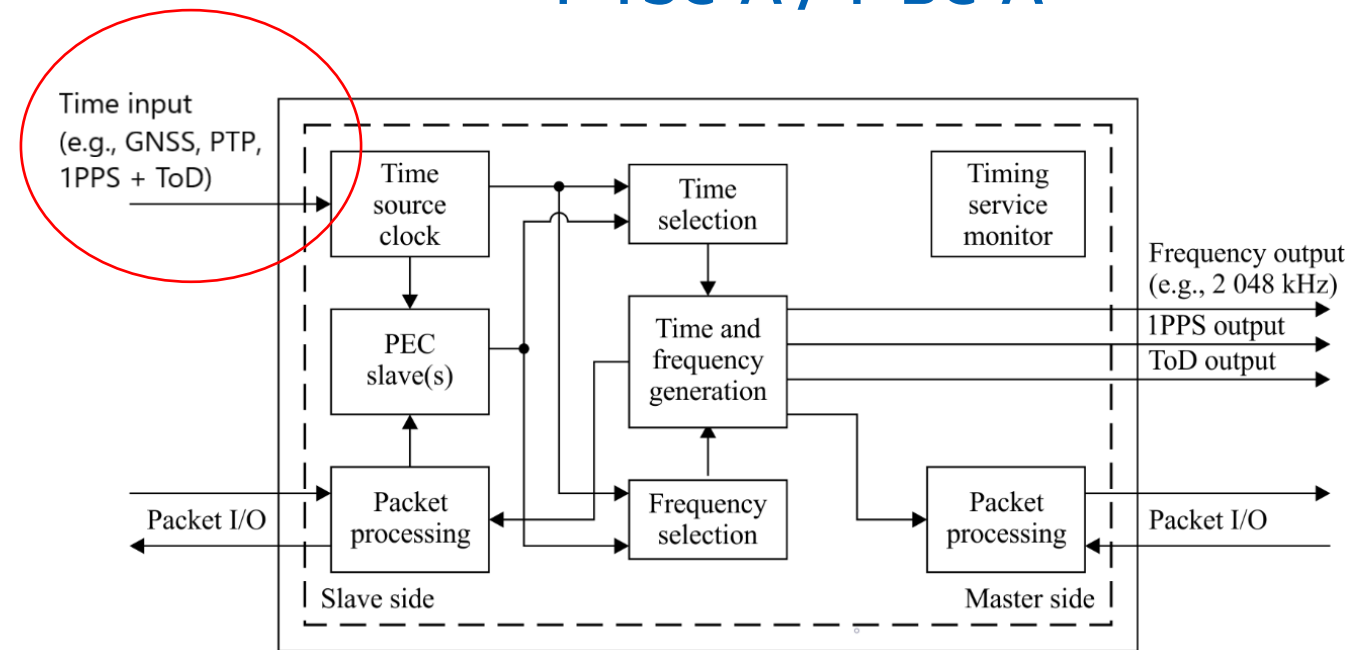


T-TSC-P / T-BC-P



G.8273.4-Y.1368.4(20)_FB.1

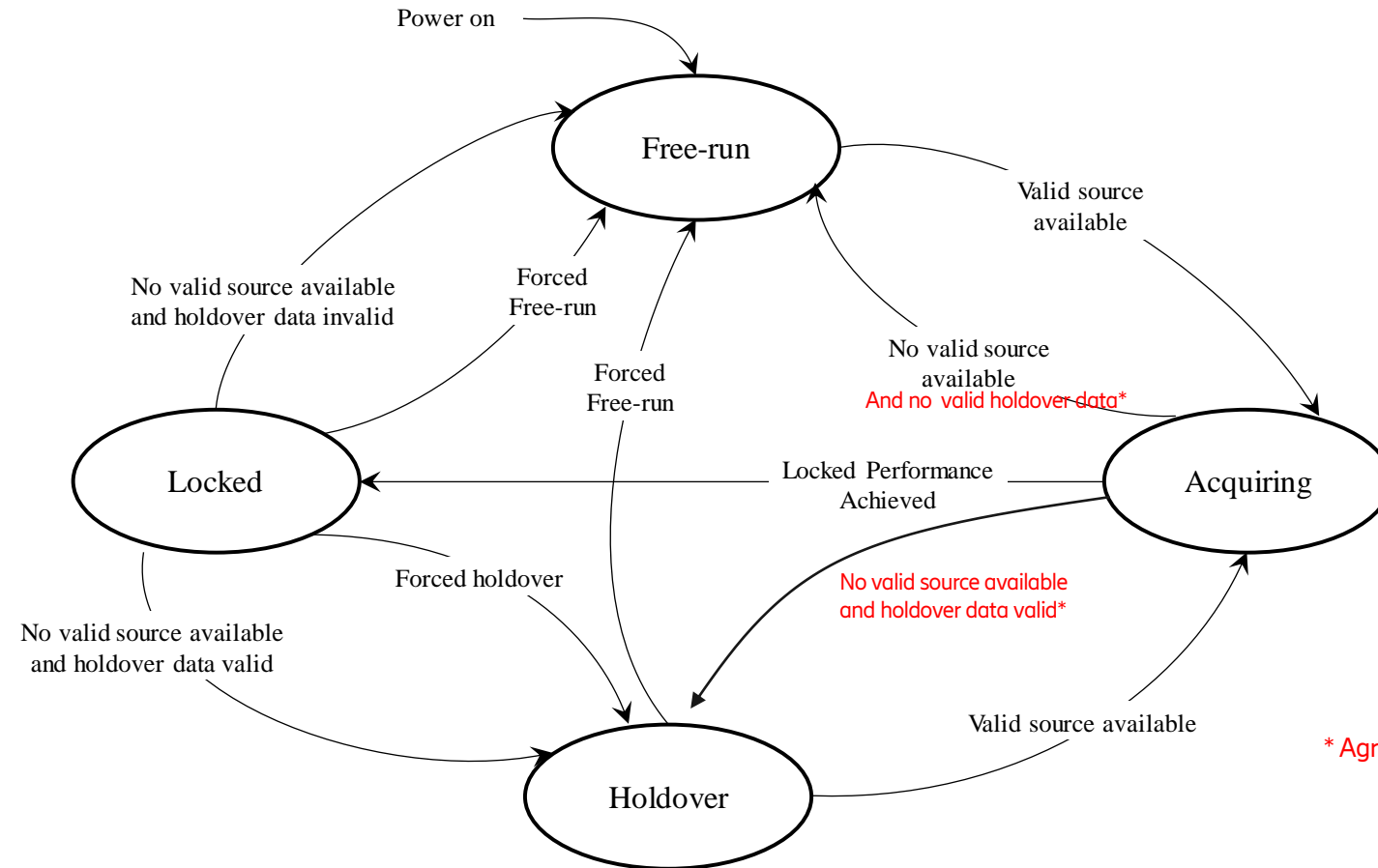
T-TSC-A / T-BC-A



- 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

Packet Clock Mode State Transition (G.781.1)

- (Packet) Clock operation described in terms of a state diagram



* Agreed at last Q13 meeting (23-26 February 2021)

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



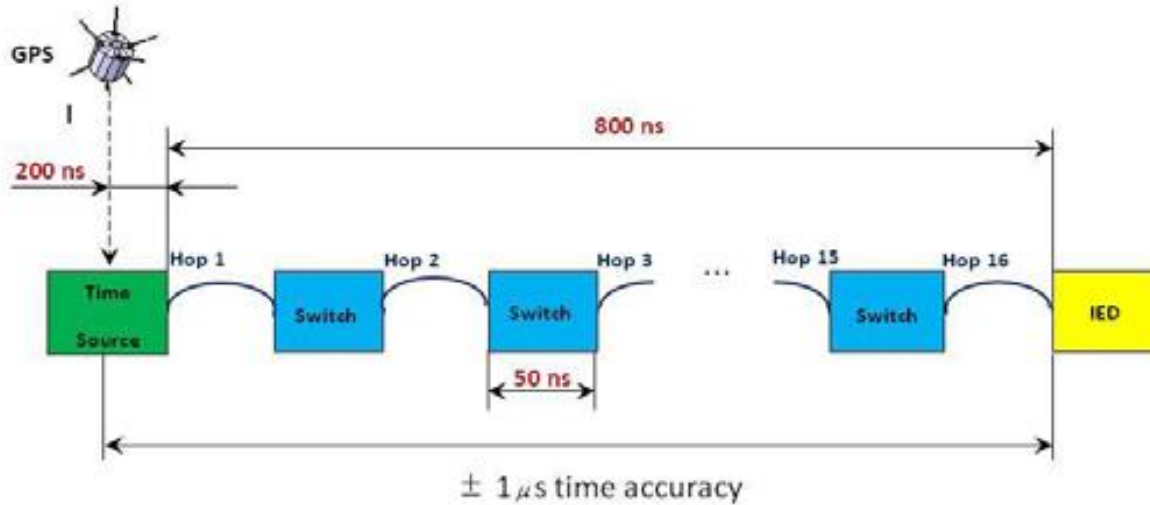
PTP Options/Attributes	G.8265.1	G.8275.1	G.8275.2
Domain Number	default : 4, range: {4-23}	default : 24, range: {24-43}	default : 44, range: {44-63}
Types of Clocks	Ordinary clocks (i.e. Grandmasters, slave-only clocks)	- Ordinary clocks (i.e. Grandmasters, slave-only clocks) - Boundary clocks - End-to-end 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: Adding support for IEEE1588-2019 into all Profiles (as agreed at last Q13 meeting, 23-26 April 2021)

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.



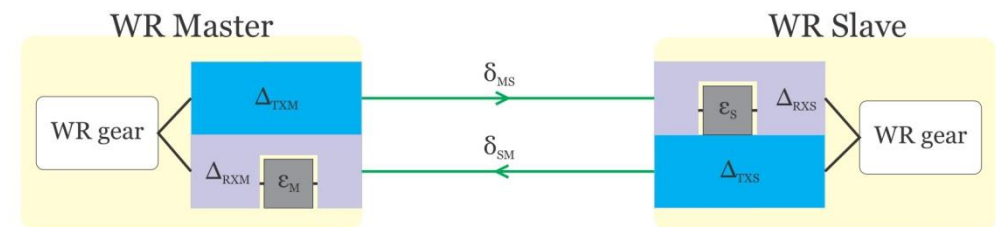
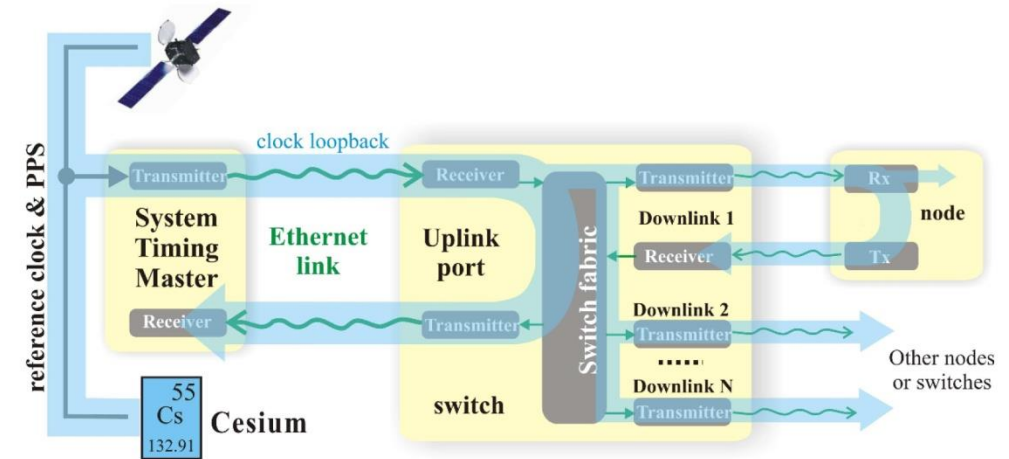
From Standard Profile for Use of IEEE Std 1588-2008
Precision Time Protocol (PTP) in Power System
Applications, IEEE PES PSRC Working Group H7/Sub C7
Members and Guests, 2012 IEEE Conference

- **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

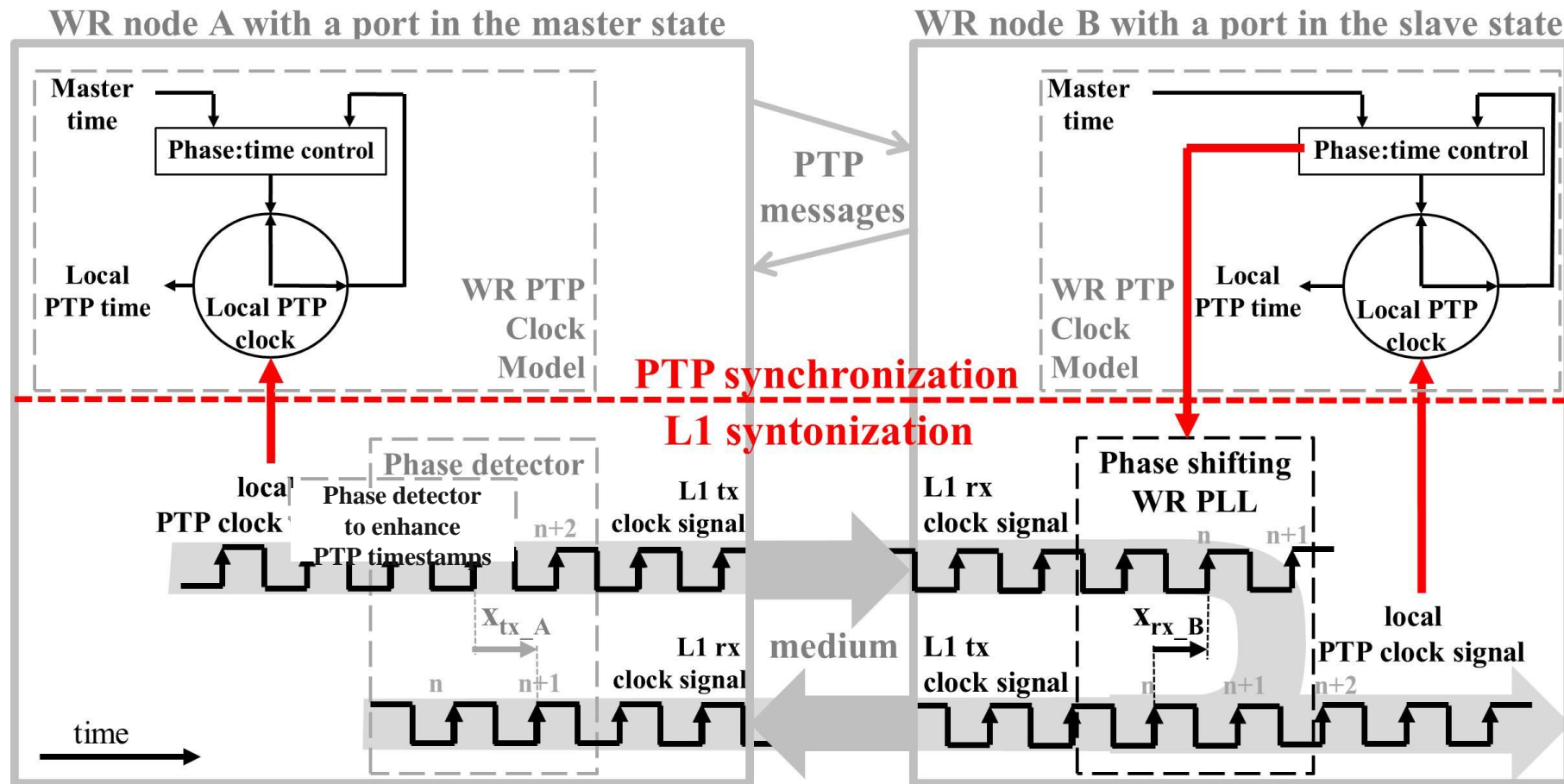
High Accuracy/«White Rabbit» Architecture and Profile



- PTP-based solution originally specified by the CERN targeting sub-ns accuracy, $\max(|TE|) < 1\text{ns}$ (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 the new Edition of the IEEE 1588 (J.5 in IEEE1588-2019)
- 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



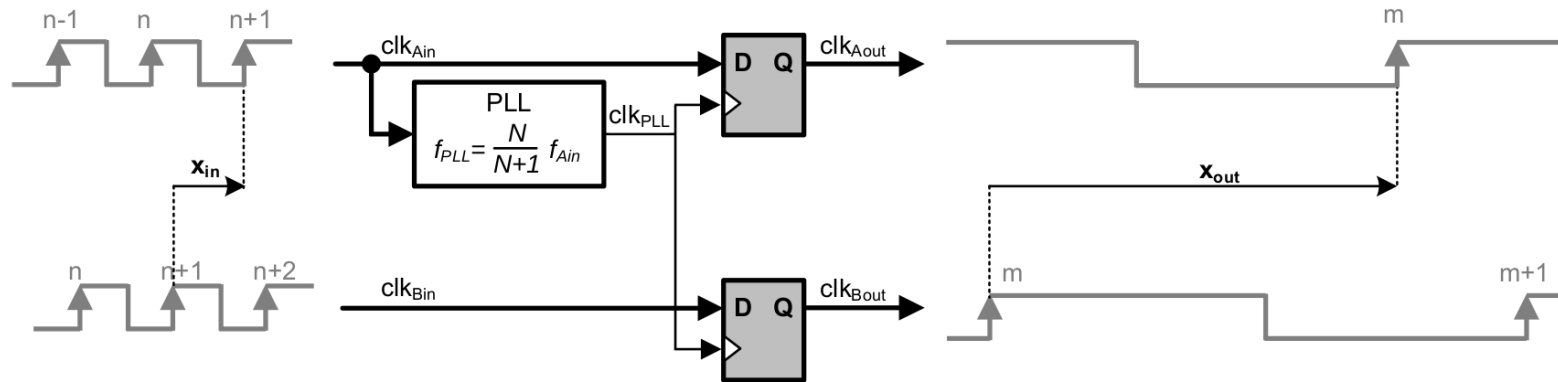
PTP Synchronization and L1 Syntonization in the White Rabbit



Digital Dual Mixer Time Difference (DDMTD)

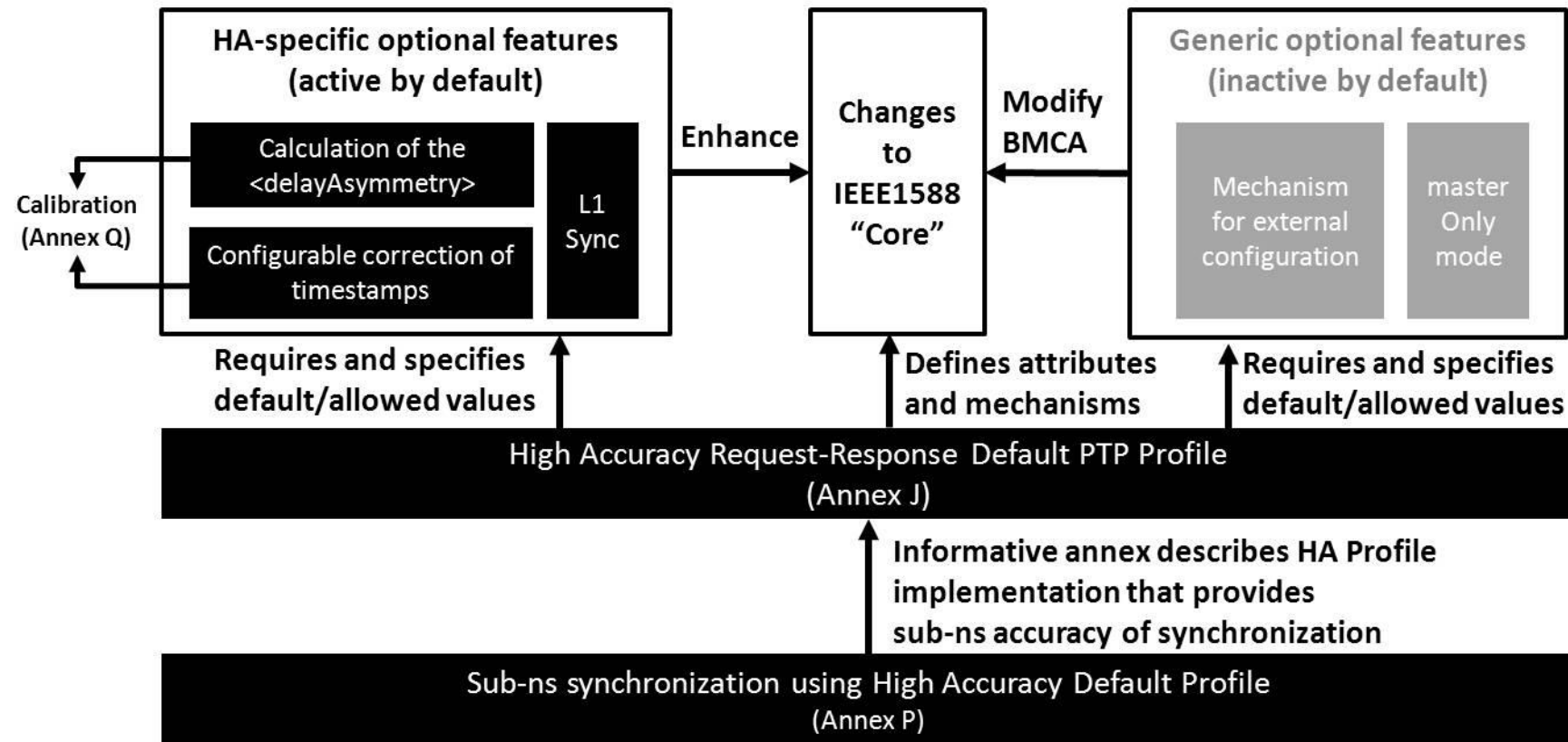


- Clever implementation of a phase detector in an FPGA
- Uses D-flip-flops to zoom-in phase offset
- Allows for phase measurements at picosecond level



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

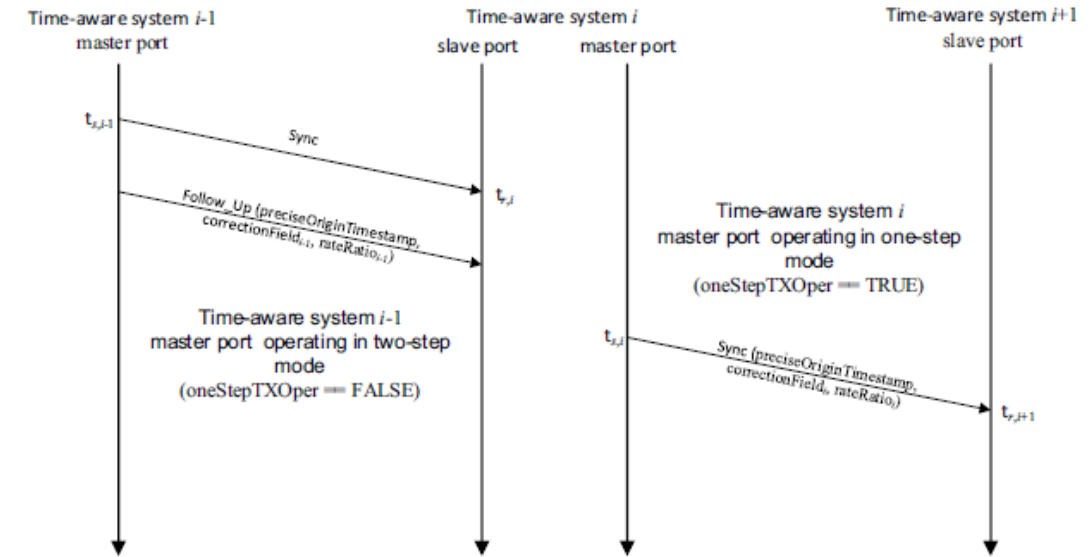
White Rabbit integrated into IEEE1588-2019 as High Accuracy



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



- To support time-sensitive applications, such as audio, video, automotive, and time-sensitive control, across networks
- First released in 2011; New revision: 802.1AS-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 μ s 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 to be compliant with IEEE1588-2019



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



Timing and Synchronization for Time-Sensitive Applications : New Profiles



- **IEC/IEEE 60802 Joint Project**

- IEC and IEEE 802.1 TSN are working on a profile to address bridges and end stations for industrial automation
- Based on IEEE 802.1AS
- Typically, Industrial automation uses time sensitive traffic to control loops
- 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.
- The profile is aiming to address applications with up to 100 nodes in the network
 - Need to meet a maximum Time Error (maxTE) of $\pm 1\mu\text{s}$
 - Simulations are being run to define the network and clock specifications

- **IEEE 802.1DG – profile for Automotive**

- IEEE 802.1 TSN is working group is working on a set of profiles to address bridges and end stations for automotive
- 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. It can be used for Infotainment, Active Safety/ADAS, and Security
 - 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

ITU-T Recommendations (PDH/SDH)



- All ITU-T Published Recommendations can be downloaded from: <http://www.itu.int/rec/T-REC-G/e>
- ITU-T Recommendation G.803, Architecture of transport networks based on the synchronous digital hierarchy (SDH).
- ITU T Recommendation G.810, Definitions and terminology for synchronization networks.
- ITU T Recommendation G.811, Timing characteristics of primary reference clocks.
- ITU T Recommendation G.812, Timing requirements of slave clocks suitable for use as node clocks in synchronization networks.
- ITU T Recommendation G.813, Timing characteristics of SDH equipment slave clocks (SEC).
- ITU-T Recommendation G.823, The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy
- ITU-T Recommendation G.824, The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy
- Recommendation ITU-T G.825, The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH)

ITU-T Recommendations (Packet Sync - Frequency)



- All ITU-T Published Recommendations can be downloaded from: <http://www.itu.int/rec/T-REC-G/e>
- ITU-T Recommendation G.8260, Definitions and terminology for synchronization in packet networks
- ITU T Recommendation G.8261, Timing and synchronization aspects in packet networks.
- Recommendation ITU-T G.8261.1, Packet Delay Variation Network Limits applicable to Packet Based Methods (Frequency Synchronization)
- ITU T Recommendation G.8262, Timing characteristics of Synchronous Equipment slave clock.
- ITU T Recommendation G.8262.1, Timing characteristics of an enhanced synchronous equipment slave clock
- Recommendation ITU-T G.8263, Timing Characteristics of Packet based Equipment Clocks
- ITU T Recommendation G.8264, Distribution of timing through packet networks
- ITU-T Recommendation G.8265, Architecture and requirements for packet based frequency delivery
- ITU-T Recommendation G.8265.1, Precision time protocol telecom profile for frequency synchronization
- ITU T Recommendation G.8266, Timing characteristics of telecom grandmaster clocks for frequency synchronization

ITU-T Recommendations (Packet Sync – Phase/Time)



- All ITU-T Published Recommendations can be downloaded from: <http://www.itu.int/rec/T-REC-G/e>
- ITU T Recommendation G.8271, Time and phase synchronization aspects of telecommunication networks
- ITU T Recommendation G.8271.1, Network limits for time synchronization in packet networks with full timing support from the network
- ITU T Recommendation G.8271.2, Network limits for time synchronization in packet networks with partial timing support from the network
- ITU T Recommendation G.8272, Timing characteristics of Primary reference time clock
- ITU T Recommendation G.8272.1, Timing characteristics of enhanced primary reference time clock
- ITU T Recommendation G.8273, Framework of phase and time clocks
- ITU T Recommendation G.8273.2, Timing characteristics of telecom boundary clocks and telecom time slave clocks for use with full timing support from the network
- ITU T Recommendation G.8273.3, Timing characteristics of telecom transparent clocks for use with full timing support from the network
- ITU T Recommendation G.8273.4, Timing characteristics of partial timing support telecom boundary clocks and telecom time slave clocks
- ITU T Recommendation G.8275, Architecture and requirements for packet-based time and phase delivery
- ITU T Recommendation G.8275.1, Precision time protocol telecom profile for phase/time synchronization with full timing support from the network
- ITU T Recommendation G.8275.2, Precision time Protocol Telecom Profile for time/phase synchronization with partial timing support from the network
- ITU T G.Sup65, Simulations of transport of time over packet networks
- ITU T 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)

ITU-T Recommendations (Packet Sync – Phase/Time) work in progress



- ITU T Recommendation G.8273.1 , Timing characteristics of Telecom Grandmaster clocks

References: Others



- NTP: IETF RFC 5905/6/7/8
- PTP: IEEE 1588-2008
- 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

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