DISTRIBUTION OF TIMING OVER TDM AND PACKET NETWORKS

WSTS 2019
SAN JOSE, MARCH 2019

Stefano Ruffini, Ericsson – Silvana Rodrigues IDT

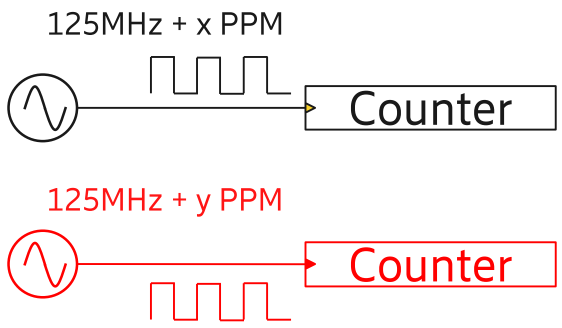
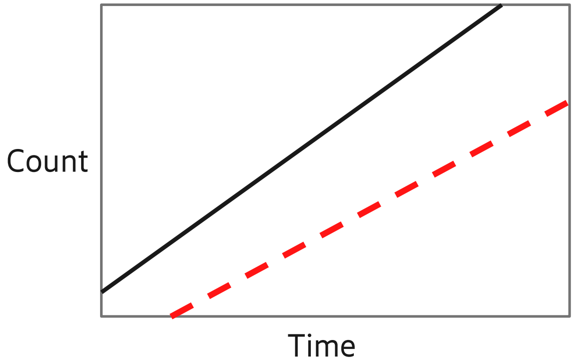
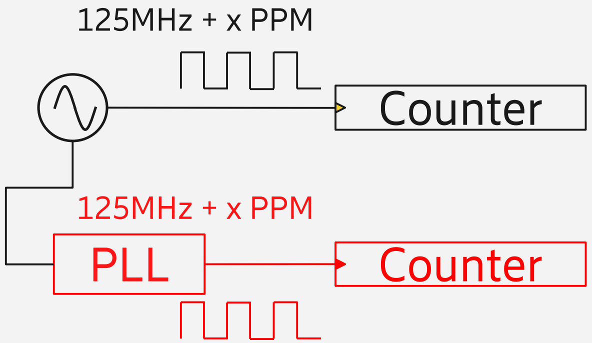
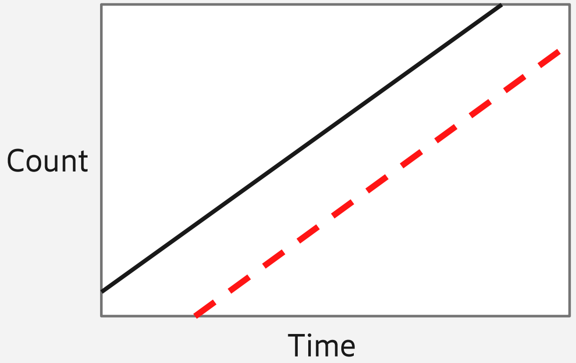
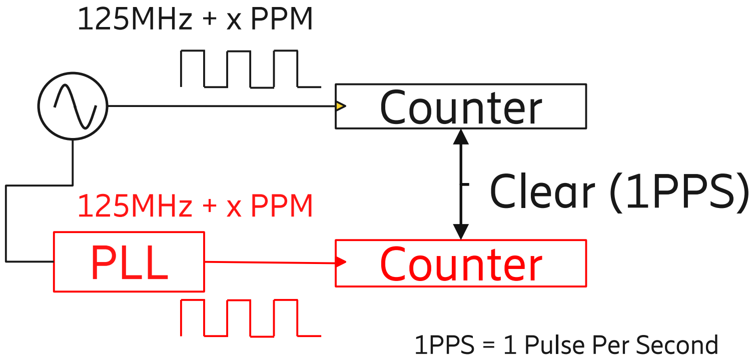
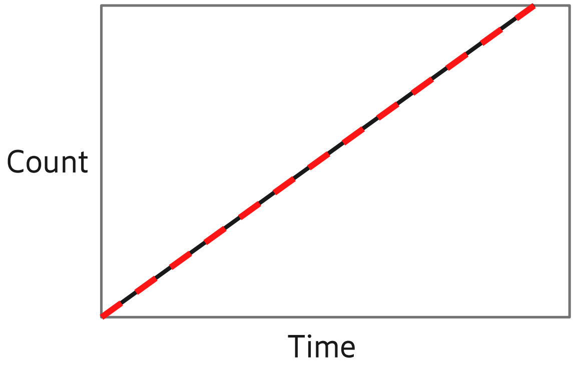
CONTENTS

- 1.General
  - 1.1 Time vs. Frequency
  - 1.2 Master-Slave vs. Plesiochronous
  - 1.3 Fundamental technologies
- 2. Frequency Sync over the Physical Layer
  - 2.1 Introduction
  - 2.2 SyncE
- 3. Frequency sync via packets
  - 3.1 Introduction
  - 3.2 G.8265.1 Profile
- 4. Time sync distribution
  - 4.1 Introduction (distributed vs. master-slave, etc.)
  - 4.2 Two-Way Time Transfer
  - 4.3 Architectures and Clocks
  - 4.5 Time sync Profiles

Credits:
- Figures in slides 5, 6, 9, 15 taken from book «Synchronous Ethernet and IEEE 1588 in Telecoms: Next Generation Synchronization Networks»
- Slide 37,38, 39: courtesy by Maciej Lipinski

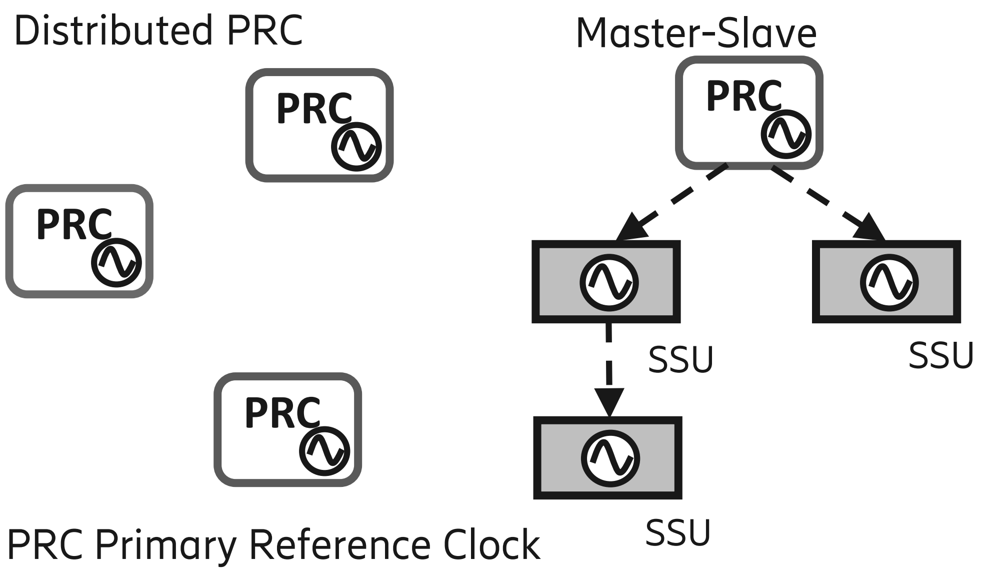
1. GENERAL

TIME VS FREQUENCY

		Not Synchronized
		Frequency Synchronized (Syntonized)
		Time/Phase Synchronized

MASTER-SLAVE VS. PLESIOCHRONOUS

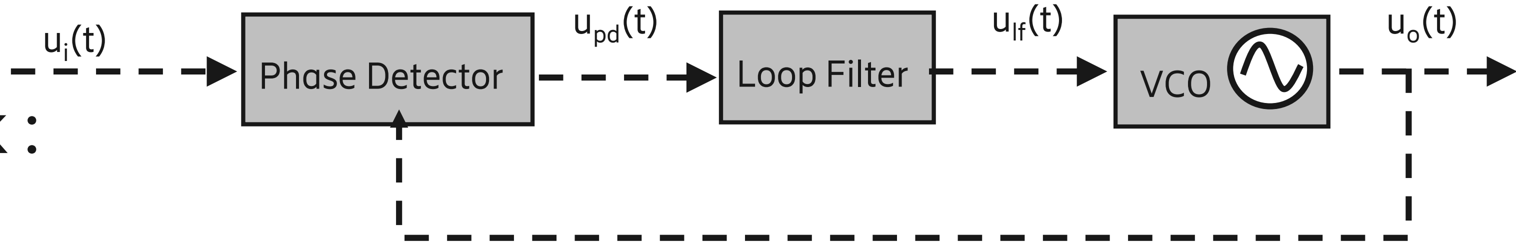
- Original focus is **Frequency synchronization**. Basic concepts in **ITU-T G.810**:
  - **plesiochronous mode** : *A mode where the essential characteristic of time scales or signals such that their corresponding significant instants occur at nominally the same rate, any variation in rate being constrained within specified limits*
  - **master slave mode** : *A mode where a designated master clock is used as a frequency standard which is disseminated to all other clocks which are slaved to the master clock*
  - **mutually synchronized mode** : A mode where all clocks exert a degree of control on each other.
- **PRC** originally mainly based on Cesium technology:
  - Timing Distribution based on Centralized architectures (based on «Master-Slave»)
  - Increased use of GNSS-based sync leading to a mix of «Distributed PRC» and «Master-Slave»
  - Renewed interest on Mutually Synchronized mode in the time sync domain



PRC Primary Reference Clock
SSU Synchronization Supply Unit

BASIC TECHNOLOGIES: GNSS, ATOMIC CLOCKS, PLL

- Master-Slave mode enabled by PLL techniques
- Sync Masters of the network :
  - GNSS Reveivers
  - Atomic Clocks (Cesium for frequency accuracy better than 10^{-11})



$u_i(t)$ input reference timing signal
$u_o(t)$ output reference timing signal
$u_{pd}(t)$ loop filter output signal
$u_{lf}(t)$ phase detector output signal

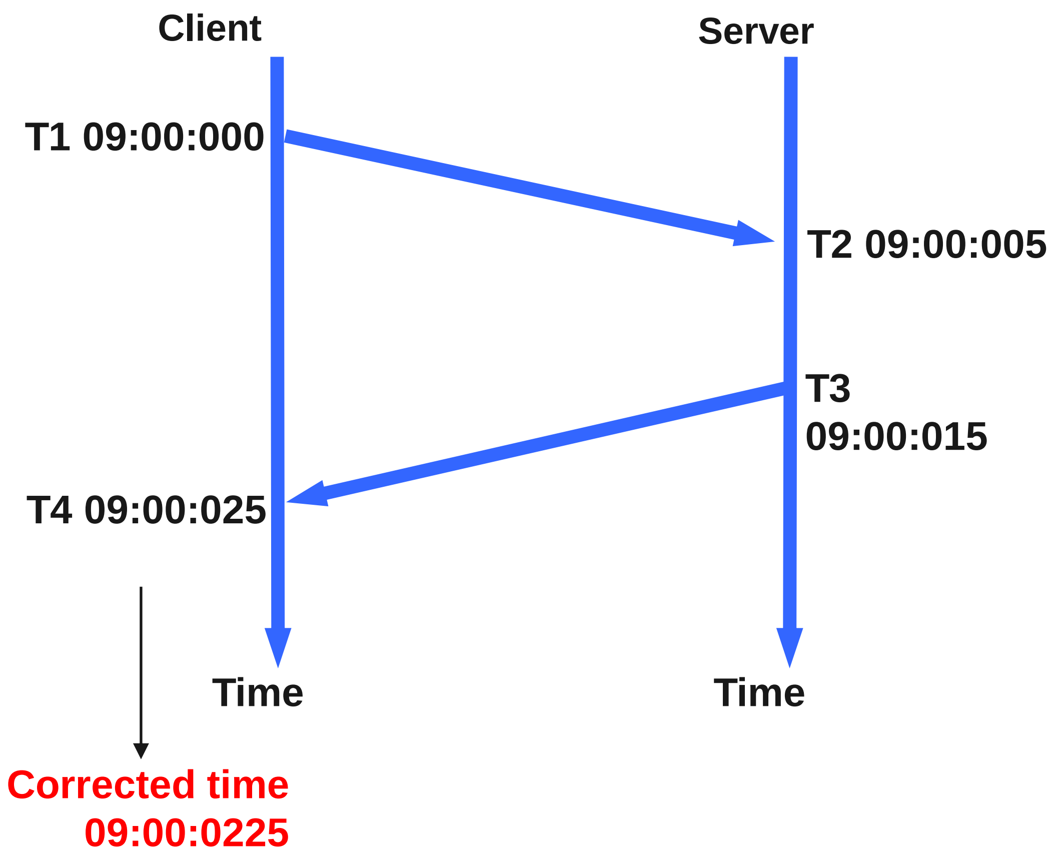
TIMING PROTOCOLS

- NTP, Network Time Protocol defined by IETF
  - protocol for clock synchronization between computer systems over packet-switched networks
  - RFC 1305 (NTP version 3) 1992
  - Latest version v4
    - RFC 5905: Network Time Protocol Version 4: Protocol and Algorithms Specification
    - RFC 5906: Network Time Protocol Version 4: Autokey Specification
    - RFC 5907: Definitions of Managed Objects for Network Time Protocol Version 4 (NTPv4)
    - RFC 5908: Network Time Protocol (NTP) Server Option for DHCPv6
- PTP, Precision Timing Protocol, defined by IEEE 1588
  - V1 (2002)
  - V2 (2008)
  - V2.1 (2019?)

HOW NTP WORKS

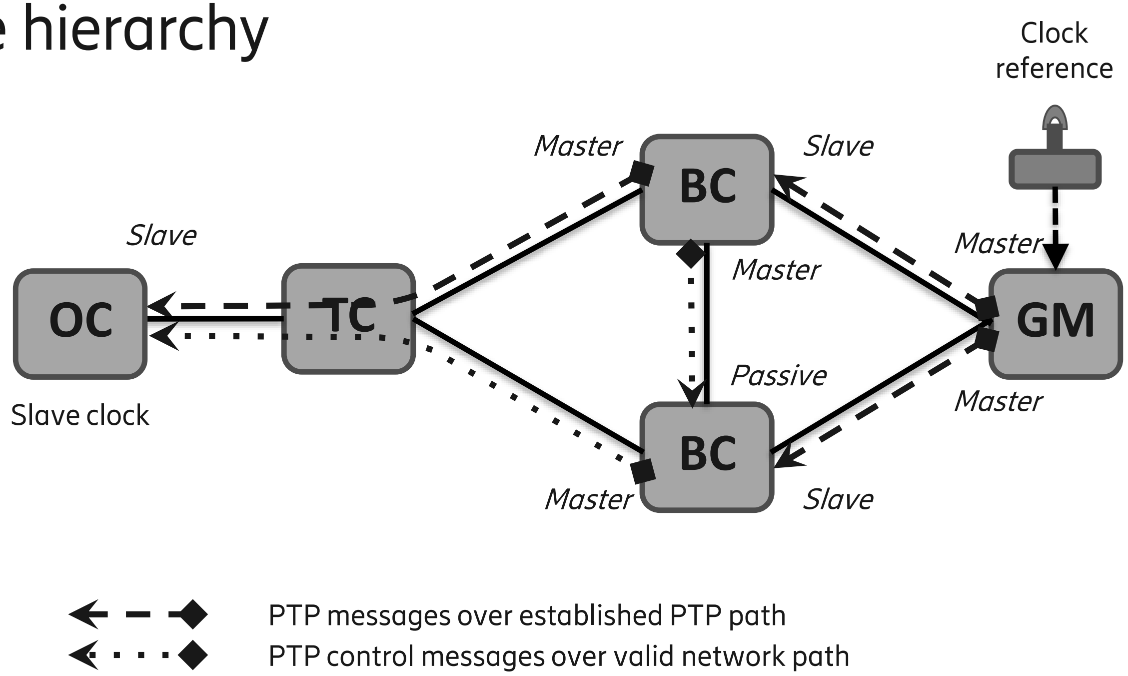
- T1 Originate Timestamp
  - Time request sent by client
- T2 Receive Timestamp
  - Time request received by server
- T3 Transmit Timestamp
  - Time reply sent by server
- T4 Destination Timestamp
  - Time reply received by client
- Round Trip Delay=(T4-T1)-(T3-T2)
  - Round Trip Delay =25-10=15
- Clock Offset= [(T2-T1)-(T4-T3)]/2
  - Clock Offset =[5-10]/2= **-2.5**
    (Clients actual time when reply received was therefore **09:00:0225**)

- **Key Assumptions:**
  - **One way delay is half Round Trip (symmetry!)**
  - Drift of client and server clocks are small and close to same value
  - Time is traceable



IEEE 1588-2008 (PTPV2)

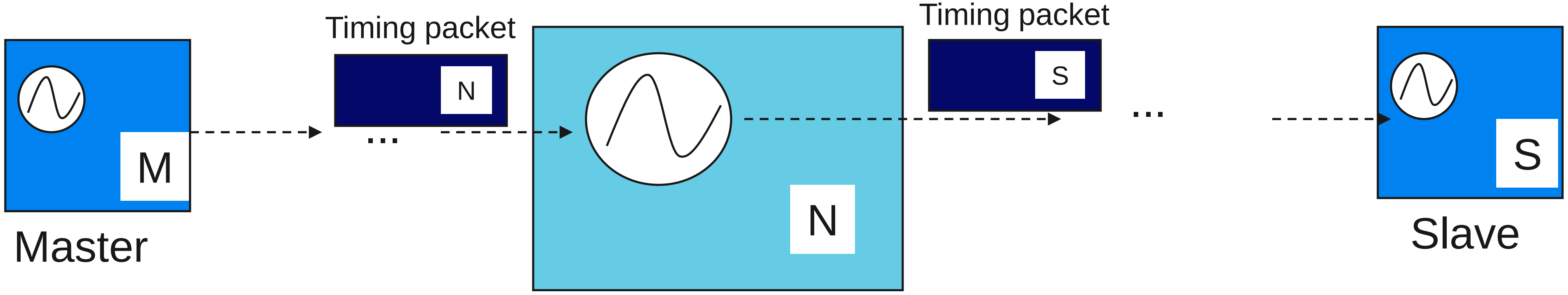
- The Grandmaster "reference clock" sends a series of time-stamped messages to slaves.
- Slaves process the round-trip delay & synchronize to the Grandmaster.
- Frequency can be recovered from an accurate time of day reference (but L1 can also be used …)
- Best Master Clock Algorithm to define the hierarchy
- Accuracy is possible by means of:
  - Proper packet rate (up to 128 per second)
  - Hardware time-stamping (eliminate software processing delays)
  - Timing support in the network (e.g. transparent clocks, boundary clocks)



› Note: IEEE 1588 under revision (planned 2019)

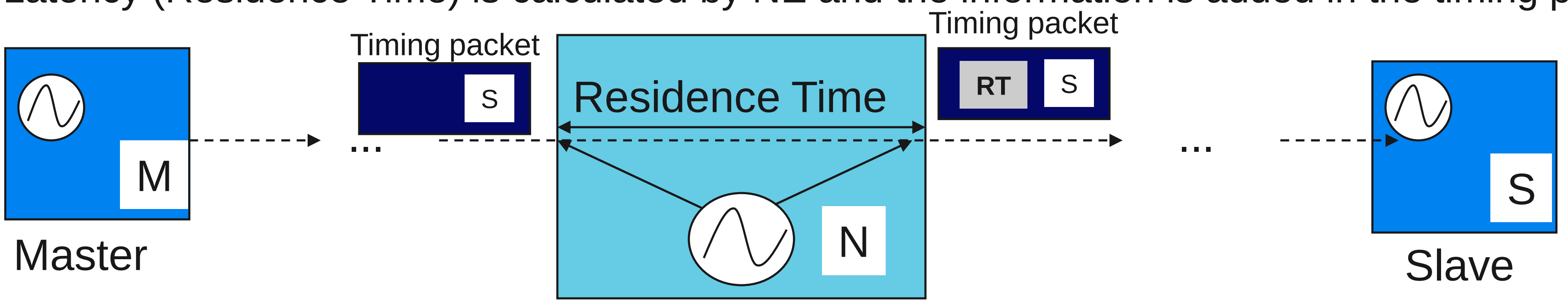
TIMING SUPPORT

Timing packets are terminated and regenerated by Node N



e.g. **IEEE1588 Boundary Clock**, NTP Stratum Clock

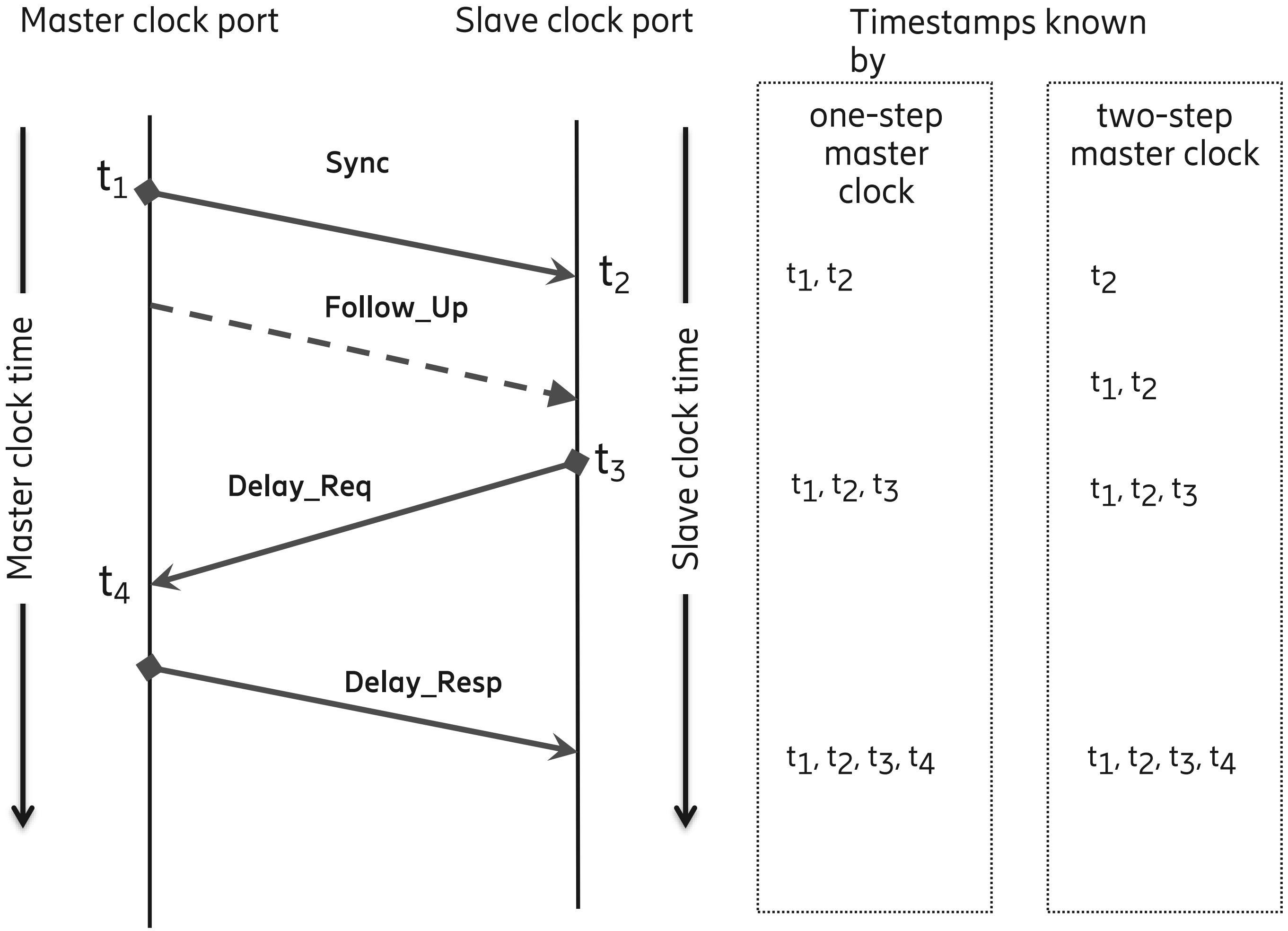
Latency (Residence Time) is calculated by NE and the information is added in the timing packet



e.g. **IEEE1588 Transparent Clock**

To remove (reduce) «Time Error» components internal to the nodes

PTP TIME TRANSFER TECHNIQUE



Round Trip Delay

RTD = (t2 - t1) + (t4 - t3)

Offset:

(slave clock error and one-way path delay)

$Offset_{SYNC}$ = t2 – t1

$Offset_{DELAY\_REQ}$ = t4 – t3

We assume path symmetry, therefore

One-Way Path Delay = RTD ÷ 2

Slave Clock Error = (t2 - t1) - (RTD ÷ 2)

Notes:

1. One-way delay cannot be calculated exactly, but there is a bounded error.
2. The protocol transfers TAI (Atomic Time).
   UTC time is TAI + leap second offset from the *announce* message.

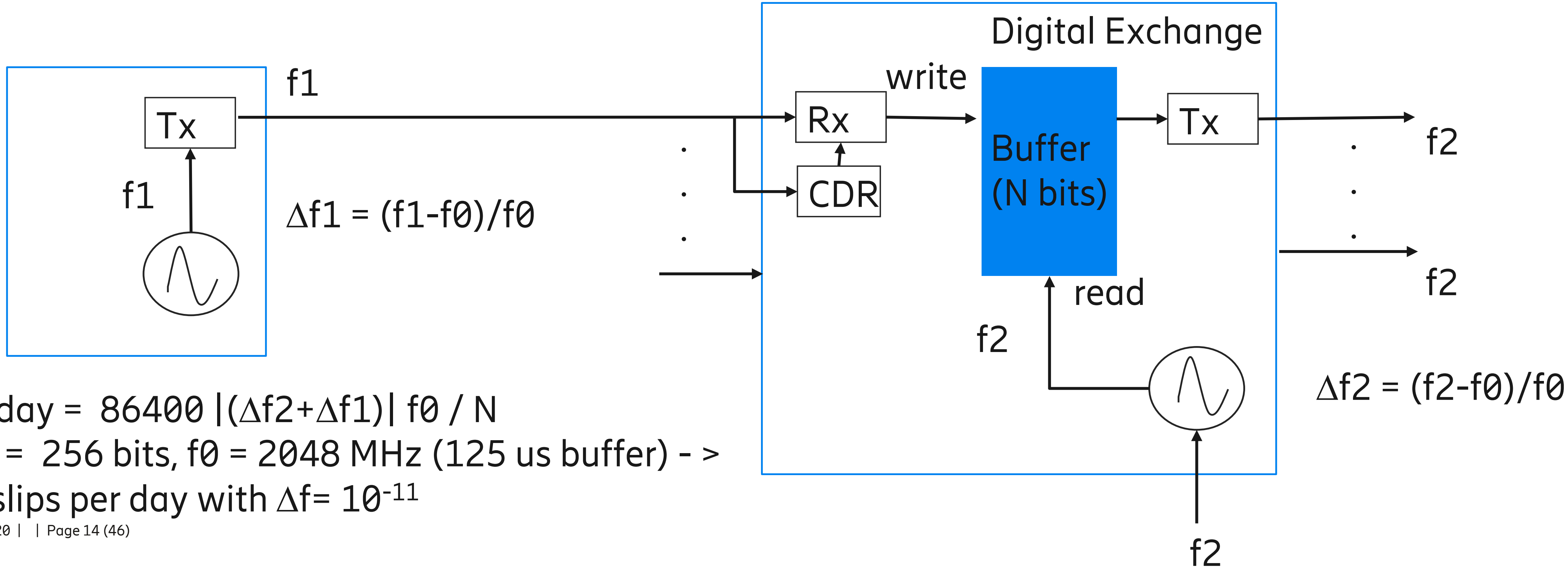
THE CONCEPT OF PROFILE

- A **profile** is a subset of required **options**, prohibited options, and the ranges and defaults of configurable attributes
  - e.g. for Telecom: Update rate, unicast/multicast, etc.
- PTP profiles are created to allow organizations to specify selections of attribute values and optional features of PTP that, when using the same transport protocol, **inter-works** and achieve a **performance** that meets the requirements of a particular application
- Telecom Profiles: G.8265.1, G.8275.1, G.8275.2
- Other (non-Telecom) profiles:
  - IEEE C37.238 (Standard Profile for Use of IEEE 1588 Precision Time Protocol in Power System Applications,)
  - IEEE 802.1AS (Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks); Under revision (targeting a full compliance with the next IEEE 1588 revision)

2. FREQUENCY SYNC OVER THE PHYSICAL LAYER

INTRODUCTION

- Frequency distribution required originally in PDH / SDH-based networks
  - To control the Slip rate (in circuit-switched networks) and control of jitter/wander in SDH networks
  - Timing carried by the bit rate of the traffic signal (typically extracted by the frame alignment word in a TDM frame)
- Slip: « *The repetition or deletion of a block of bits in a synchronous or plesiochronous bit stream due to a discrepancy in the read and write rates at a buffer.* » (G.810)



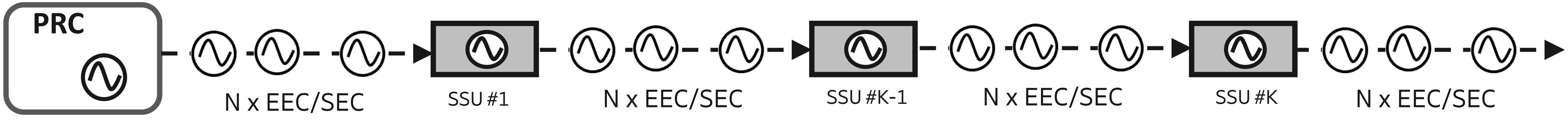
Slips/day = 86400 |(Δf2+Δf1)| f0 / N

Ex.: N = 256 bits, f0 = 2048 MHz (125 us buffer) - >

1/72 slips per day with $\Delta f = 10^{-11}$

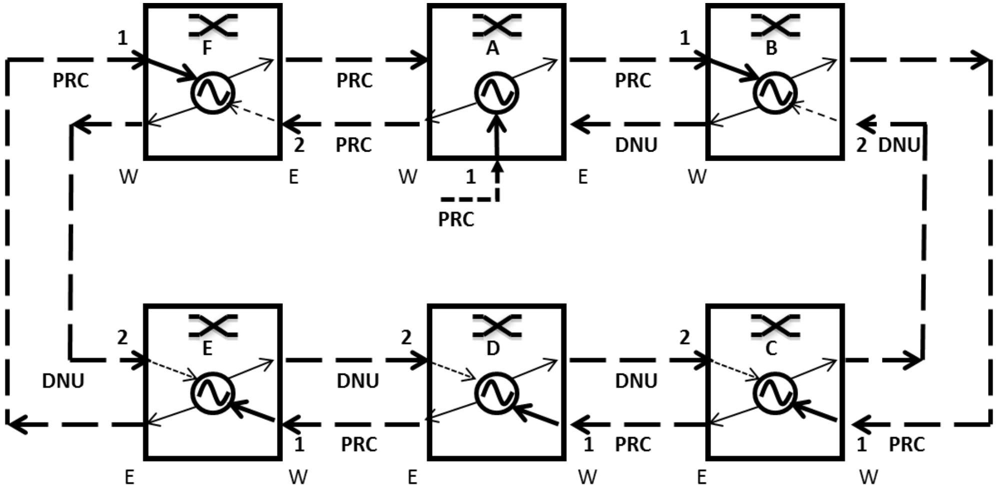
BASIC PRINCIPLES

- G.803 specifes the reference chain as a combination of this clocks, that can guarantee to meet specified performance objectives



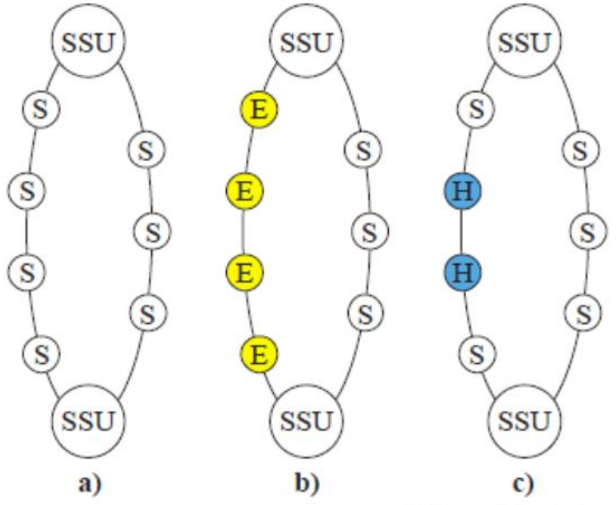
Worst case scenario calculation purposes:
K=10 and N= 20, with limitation that total number of clock is limited to 60

- Clocks have been specified in ITU-T G.812 and G.813
- G.781 specifies the synchronziation function layer, including the basics for use of the Synchronization Status Message (SSM)
  - To avoid timing loops (DNU = Do Not Use !)
  - To inform downstream clocks when traceability is lost
    - G.781 provides encoded QL values (PRC, SSU, SEC..)



SYNCE: INTRODUCTION

- Several applications requiring **accurate frequency are reached by Ethernet**
  - Since the very start of timing over packet network activities, it was proposed to use a synchronous Ethernet physical layer
  - Not in contradiction with IEEE (10^{-11} within the +/-100 ppm - 20 ppm)
  - Only in full duplex mode (continuous signal required)
- **Based on SDH** specification (for interoperability and simplifying the standardization task)
  - Synchronous Ethernet equipment equipped with a **synchronous Ethernet Equipment Clock – EEC** (G.8262). Synchronous Ethernet interfaces extract the received clock and pass it to the system clock.
  - Synchronization Status Message as per G.8264
  - Enhanced SyncE recently approved (G.8262.1)
- It does not transport Time
  - but it was proposed
- All nodes must support SyncE: sync chain as per G.803
  - Cannot be transported transparently across network boundaries



G.8261-Y.1361(13)_FD.1

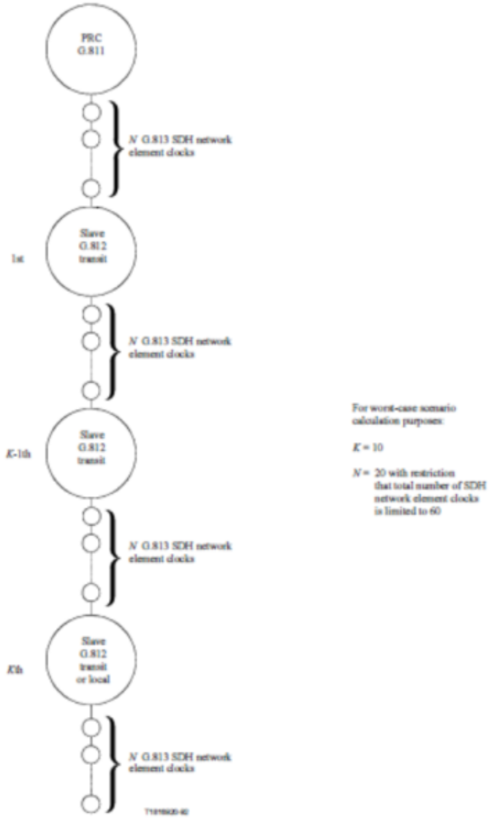
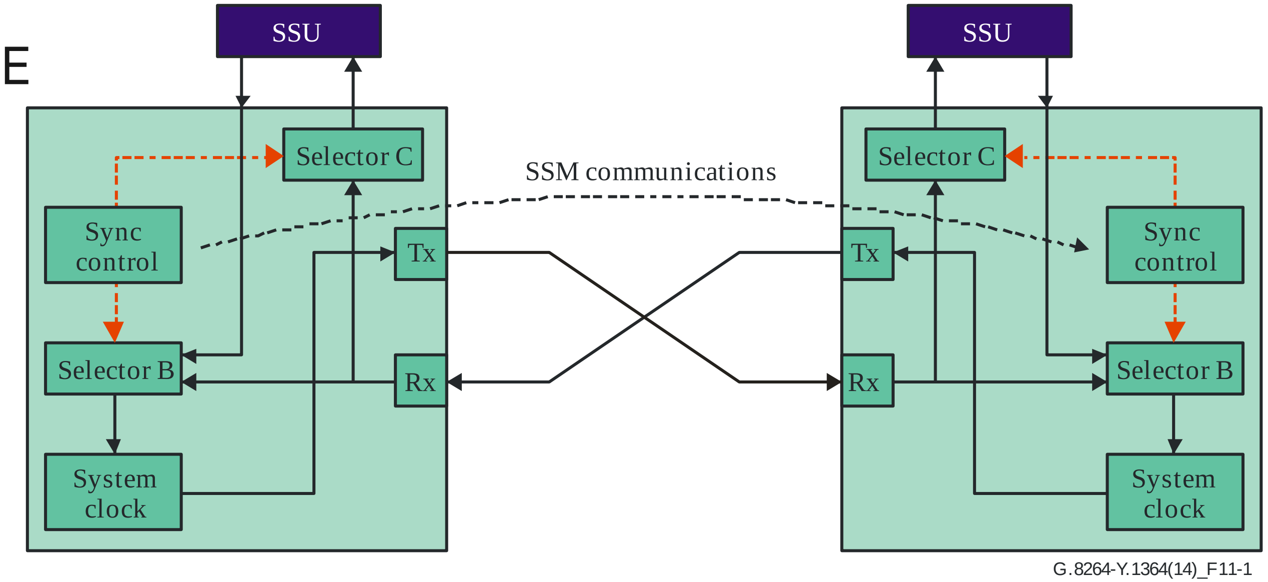


Figure 8-5/G.803 – Synchronization network reference chain

SSM (SYNCHRONIZATION STATUS MESSAGE) IN SYNCE

- SSM required to prevent timing loops and to support reference selection (as per SDH)
  - Details according to G.781 and G.8264
- In SDH SSM delivered in fixed locations of the SDH frame
  - Packet based mechanism required in case of SyncE
- OUI (organizationally unique identifier) from IEEE reused to specify exchange of QLs over the OAM specific slow protocol (OSSP)
- EEC option 1 clock treated as G.813 option 1 (QL-SEC), EEC option 2 as an G.812 type IV clock (QL-ST3).
- Two types of protocol message types are defined
  - "heart-beat" message (once per second)
  - Event message generated immediately
- SSM QL value is considered failed if no SSM messages are received after a five second period.



ETHERNET SYNCHRONIZATION MESSAGING CHANNEL (ESMC) FORMAT

— ESMC PDU with QL TLV always sent as the first TLV in the Data and padding field

Octet number	Size/bits	Field
1-6	6 octets	Destination Address = 01-80-C2-00-00-02 (hex)
7-12	6 octets	Source Address
13-14	2 octets	Slow Protocol Ethertype = 88-09 (hex)
15	1 octet	Slow Protocol Subtype = 0A (hex)
16-18	3 octets	ITU-OUI = 00-19-A7 (hex)
19-20	2 octets	ITU Subtype
21	bits 7:4 (Note 1)	Version
	bit 3	Event flag
	bits 2:0 (Note 2)	Reserved
22-24	3 octets	Reserved
25-1532	36-1490 octets	Data and padding (See point j)
Last 4	4 octets	FCS

NOTE 1 – Bit 7 is the most significant bit of octet 21. Bit 7 to bit 4 (bits 7:4) represent the four number for the ESMC.

NOTE 2 – The three LSBs (bits 2:0) are reserved.

Octet number	Size/bits	Field
1	8 bits	Type: 0x01
2-3	16 bits	Length: 00-04
4	bits 7:4 (Note)	0x0 (unused)
	bits 3:0	SSM code

NOTE – Bit 7 of octet 4 is the most significant bit. The least significant nibble, bit 3 to bit 0 (bits 3:0) contains the four-bit SSM code.

— Recently extended to carry new clock types (and inform on PRTC traceability)

  — Extended QL TLV

— Use of Padding bits also recently revised (set to all zero and ignored by receivers)

EXTENDED QL TLV

Octet number	Size/bits	Field
1	8 bits	Type: 0x02
2-3	16 bits	Length: 0x0014
4	8 bits	Enhanced SSM code (see Table 11-6)
5-12	64 bits	SyncE clockIdentity of the originator of the extended QL TLV, Note1,
13	8 bits	Flag; Note2
14	8 bits	Number of cascaded eEECs from the nearest SSU/PRC/ePRC
15	8 bits	Number of cascaded EECs from the nearest SSU/PRC/ePRC
16-20	40 bits	Reserved for future use

SyncE clockIdentity follows the IEEE 1588 rules

Clock	Quality level	Enhanced SSM code
EEC1	QL-EEC1	0xFF
EEC2	QL-EEC2	0xFF
Other clock types contained in [ITU-T G.781] Note 1	QL message (refer to the QL TLV) Note 1	0xFF
PRTC	QL-PRTC	0x20
ePRTC	QL-ePRTC	0x21
eEEC	QL-eEEC	0x22
ePRC	QL-ePRC	0x23

Note 1: Tables 11-8 and 11-9 illustrate the full set of clock types from [ITU-T G.781]

Note: ePRC SSM code (0x23) recently added (G.8264 Amd1, February 2018)

SSM CODES FOR SYNCE

Table 11-7 (G.8264-2017): Option I

Clock	Quality level	SSM code	Enhanced SSM code
PRC	QL-PRC	0010	0xFF
SSU-A	QL-SSU-A	0100	0xFF
SSU-B	QL-SSU-B	1000	0xFF
EEC1	QL-EEC1	1011	0xFF
Note 1	QL-DNU	1111	0xFF
PRTC	QL-PRTC	0010	0x20
ePRTC	QL-ePRTC	0010	0x21
eEEC	QL-eEEC	1011	0x22
ePRC	QL-ePRC	0010	0x23

Note 1: There is no clock corresponding to this quality level.

Note 2: When processing the SSM QL, The SSM code should be processed first, followed by processing the Enhanced SSM code.

Table 11-8 (G.8264-2017): Option II

Clock	Quality level	SSM code	Enhanced SSM code
PRS	QL-PRS	0001	0xFF
Note 1	QL-STU	0000	0xFF
ST2	QL-ST2	0111	0xFF
TNC	QL-TNC	0100	0xFF
ST3E	QL-ST3E	1101	0xFF
ST3	QL-ST3	1010	0xFF
EEC2	QL-EEC2	1010	0xFF
Note 1	QL-PROV	1110	0xFF
Note 1	QL-DUS	1111	0xFF
PRTC	QL-PRTC	0001	0x20
ePRTC	QL-ePRTC	0001	0x21
eEEC	QL-eEEC	1010	0x22
ePRC	QL-ePRC	0001	0x23

Note 1: There is no clock that corresponds to this quality level.

Note 2: When processing the SSM QL, The SSM code should be processed first, followed by processing the Enhanced SSM code.

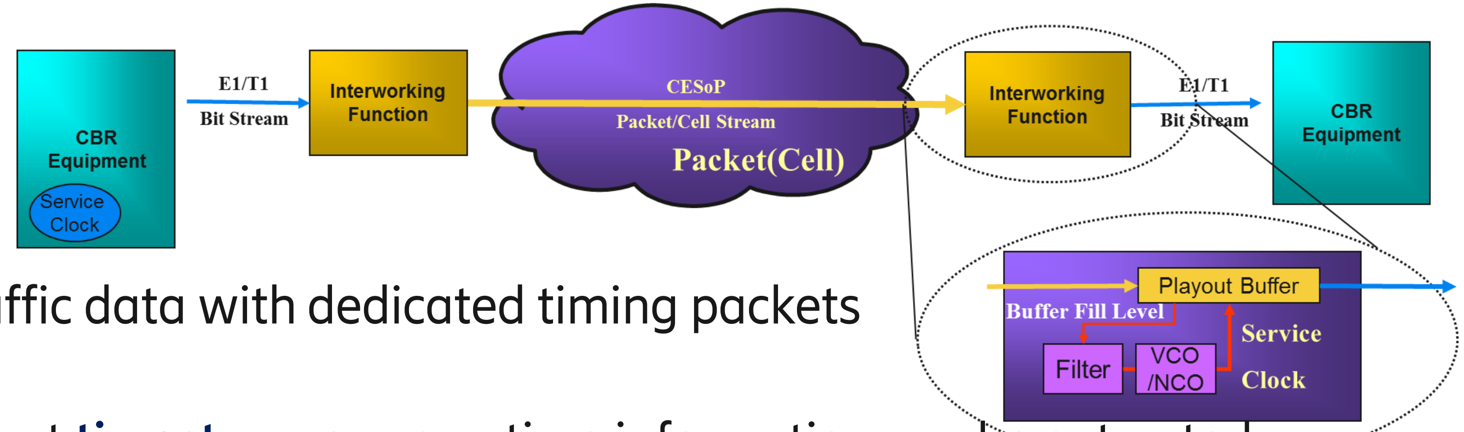
If a clock supports both the QL TLV and the extended QL TLV, it should set the SSM code and the enhanced SSM code according to table 11-7/11-8, and send both the QL TLV and the extended QL TLV.

Note: ePRC SSM code (0x23) recently added (G.8264 Amd1, February 2018)

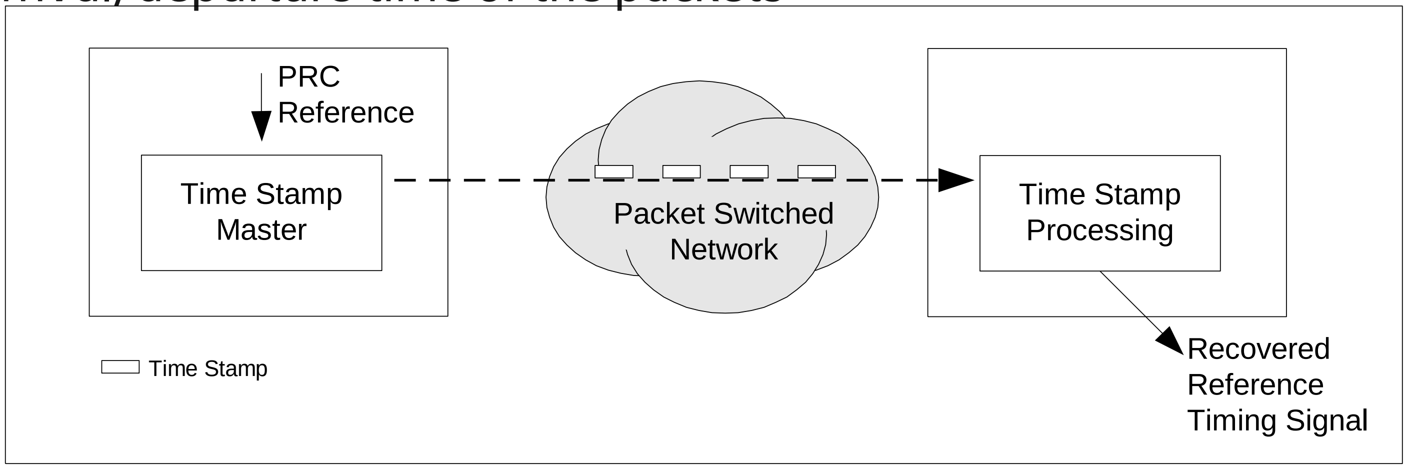
3. FREQUENCY SYNC VIA PACKETS

INTRODUCTION

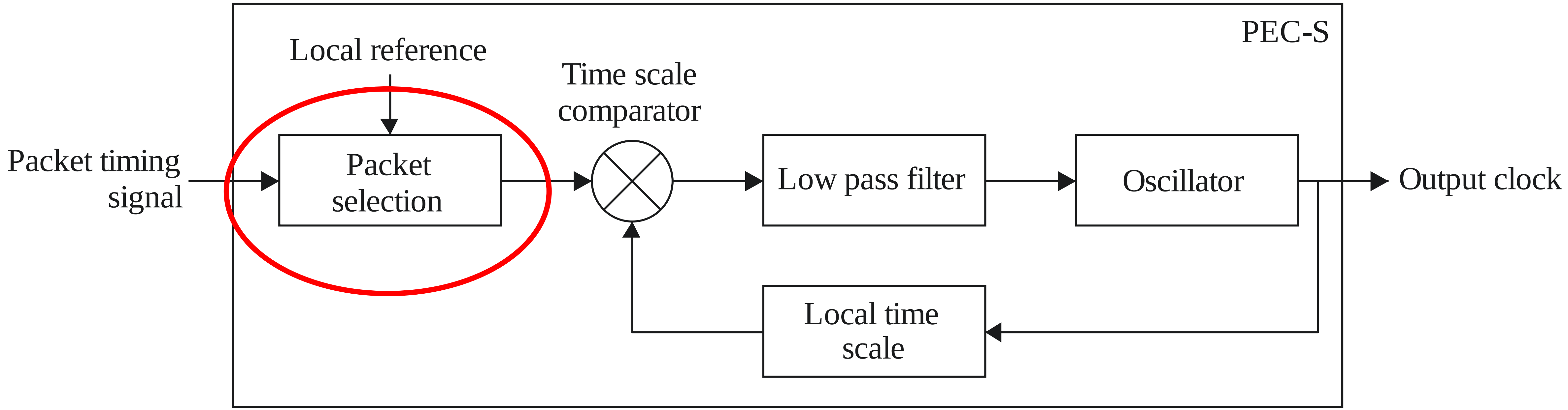
- Timing carried via packets was originally used to receiver the service timing (e.g., 2 Mbit/s service carried over packet networks); known as “Circuit Emulation”
  - Service clock adjusts based on buffer fill level / **packet arrival rate, PDV** influences wander at the network output



- 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**



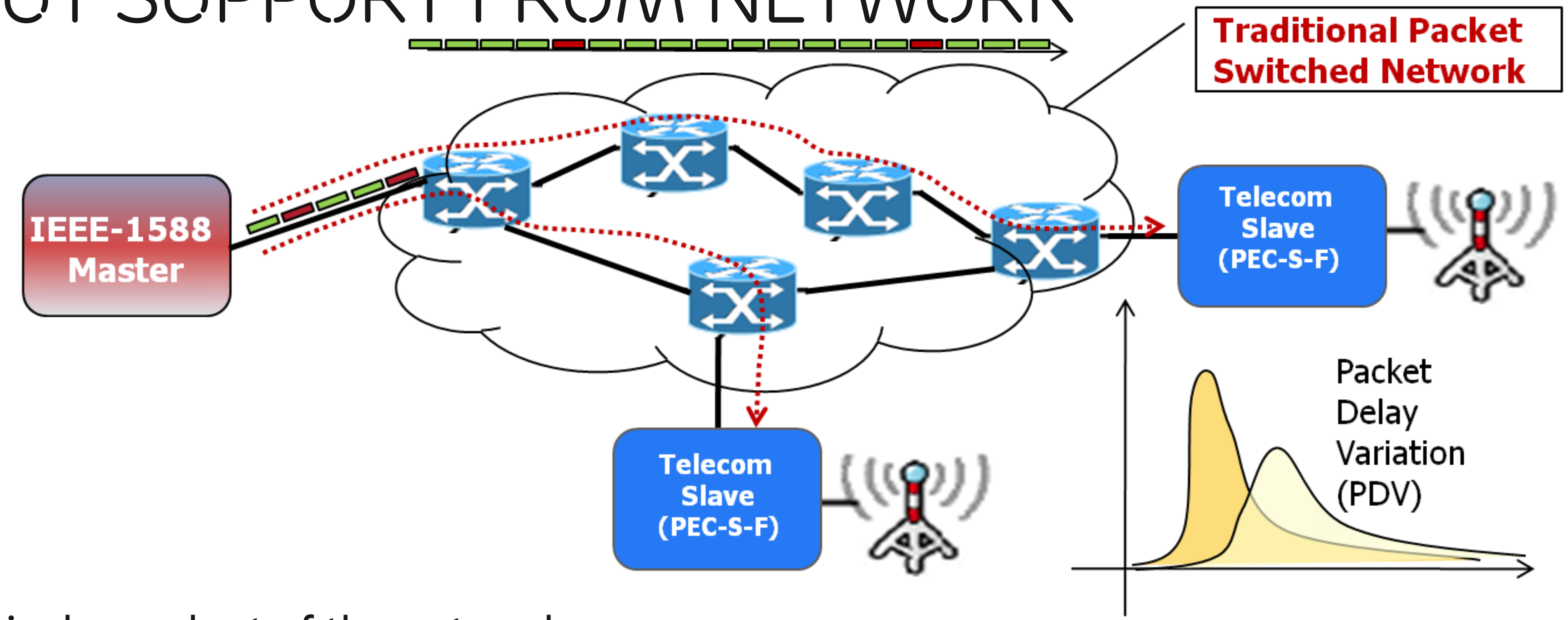
PACKET-BASED EQUIPMENT CLOCK



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

- 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



- Performance is dependent of the network
  - The clock recovery algorithm is adaptive in nature, therefore performance is impacted by packet delay variation
- The quality of the clock delivered to the application depends on several factors
  - Quality of the oscillator at the slave, packet delay variation of the network, number of timing packets per second
- ITU-T Recommendations for IEEE-1588 for Frequency Sync targeting wireless backhaul applications
  - 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.8261.1 (Packet Delay Variation Network Limits applicable to Packet Based Methods), and G.8260 (metrics)

BACK UP SLIDE: G.8265.1 - PTP OPTIONS AND CONFIGURABLE ATTRIBUTES

- One-way versus two-way mode
  - Both one-way and two-way modes are supported in the Frequency Profile
- Unicast versus Multicast mode
  - Only Unicast mode is allowed in the Frequency Profile
  - Unicast Message negotiation is used
- One-step versus two-step clock mode
  - Both one-step and two-step clocks are supported in the Frequency Profile
- PTP mapping
  - IEEE1588-2008 annex D - Transport of PTP over User Datagram Protocol over Internet Protocol Version 4 is supported in the Frequency Profile
  - IEEE1588-2008 annex E - Transport of PTP over User Datagram Protocol over Internet Protocol Version 6 is supported in the Frequency Profile
- PTP Message rates
  - Sync /Follow-up – min rate: 1 packet every 16 seconds, max rate: 128 packets per second
  - Delay_Request/Delay_Response – 1 packet every 16 seconds, max rate: 128 packets per second
  - Announce – min rate: 1 packet every 16 seconds, max rate: 8 packets per second, default: 1 packet every 2 seconds
  - Signaling messages – no rate is specified

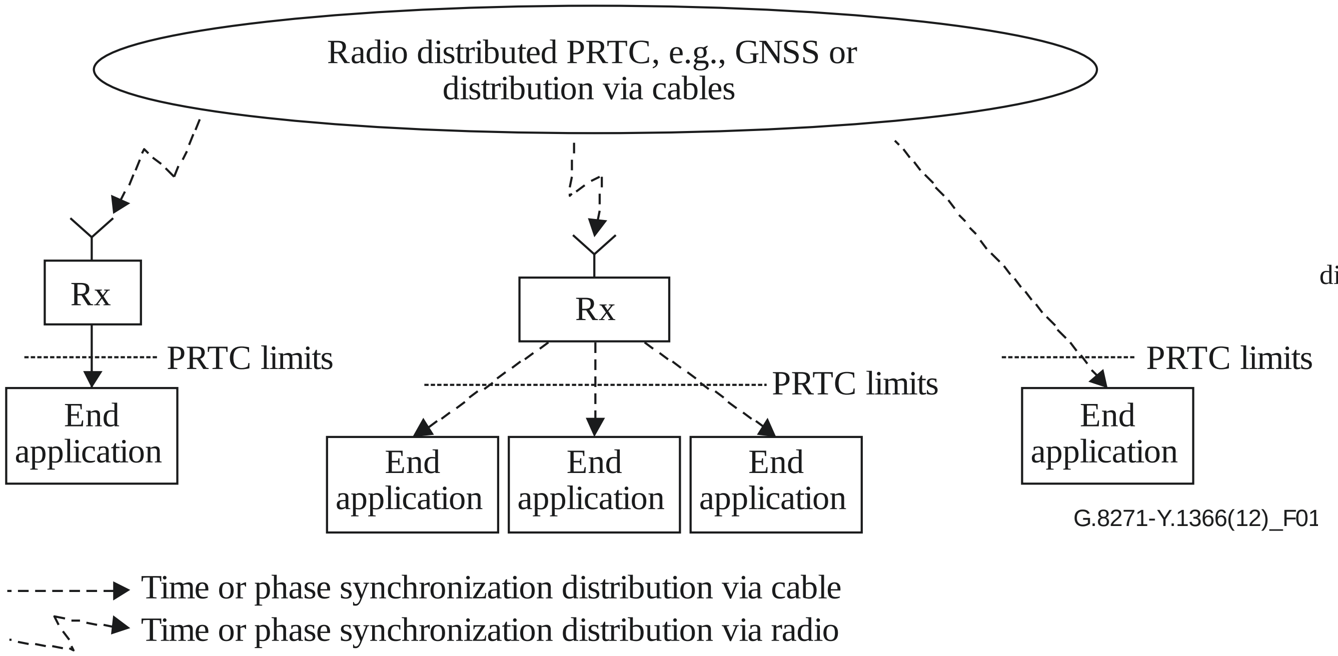
BACK UP SLIDE: G.8265.1 - ALTERNATE BMCA

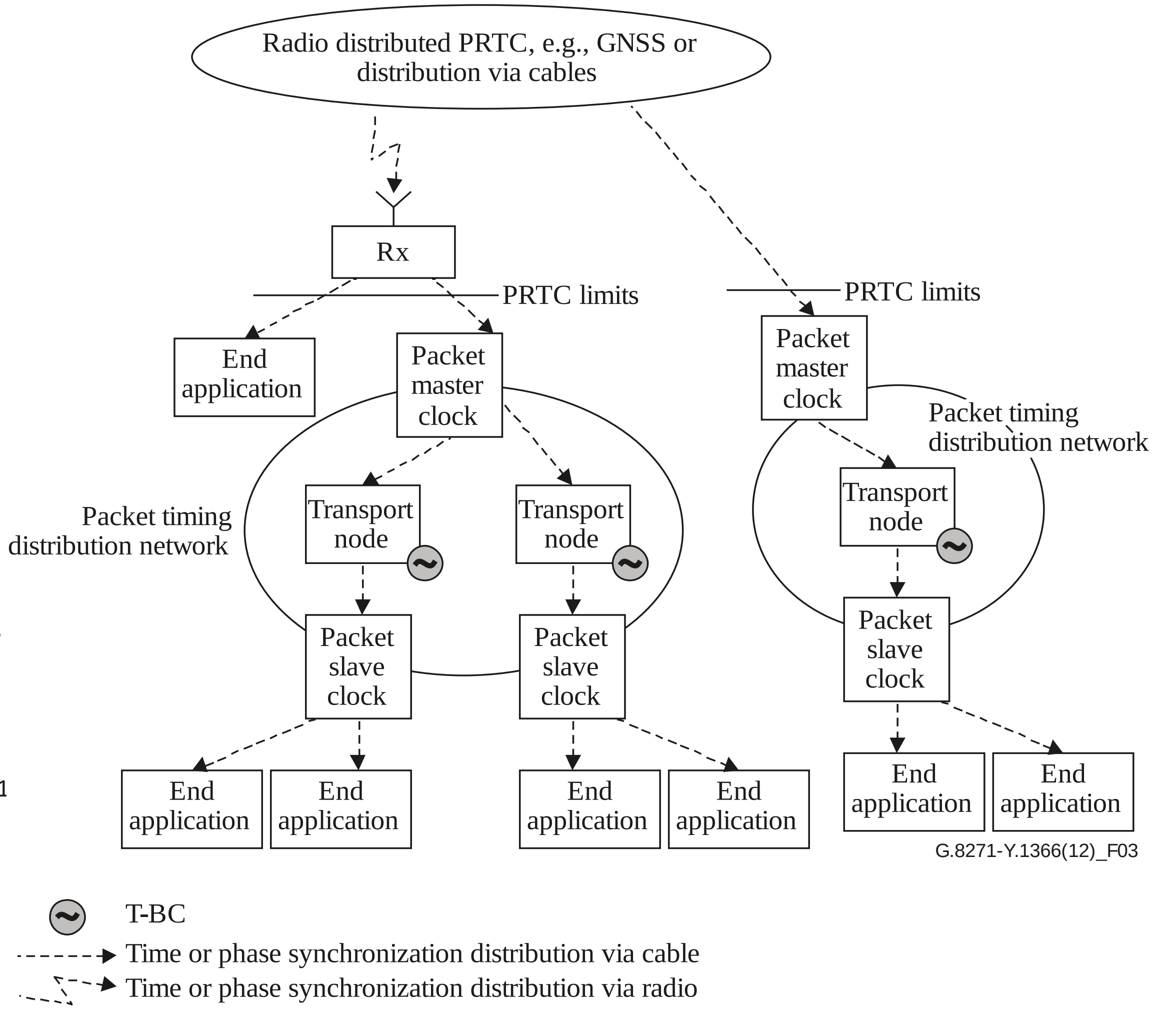
- The alternate BMCA in G.8265.1 is static, each master is isolated by a separated PTP domain that is done through the unicast communication
  - Grandmasters do not exchange Announce messages.
  - Masters are always active
  - Slaves are always slave-only clocks
- The Master selection process is based on the Quality Level (QL)-enabled mode per ITU-T Recommendation G.781
  - Quality Level (QL)
    - The Clock Class attribute in the Announce messages in PTP is used to carry the SSM QL value
    - Master with the highest Quality Level that is not in a failure condition will be selected
    - In case of Masters with similar QL, the Master with the highest Priority is selected.
  - Priority
    - Each master has a priority value that is locally maintained in the Telecom slave.
  - Packet Timing Signal Fail (PTSF)
    - PTSF-lossSync, PTSF-lossAnnounce, PTSF-unusable
- G.8265.1 introduces the concept of a Telecom Slave
  - Consists of one or multiple PTP slave-only ordinary clock instances

4. TIME SYNC DISTRIBUTION

INTRODUCTION

—Distributed vs. packet-based

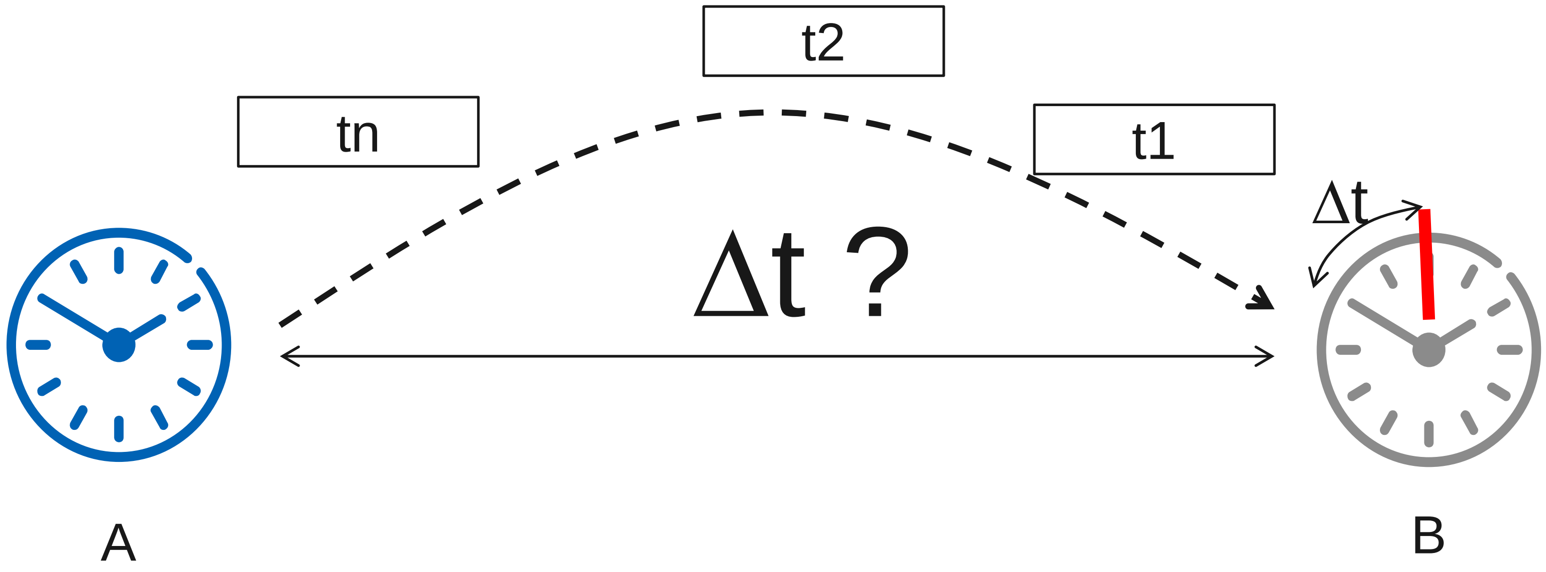




(From ITU-T G.8271)

TWO-WAYS TIME TRANSFER

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



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

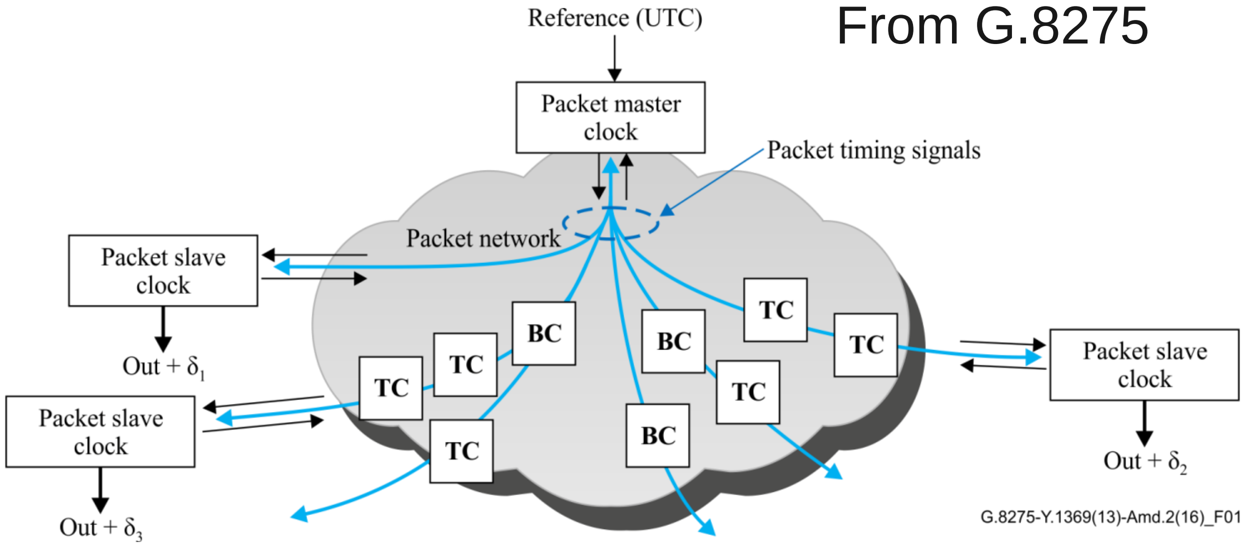
TIME SYNCHRONIZATION ARCHITECTURE (TELECOM PERSPECTIVE)

— General network topology for time/phase distribution from a packet master clock PRTC to a telecom time slave clock (T-TSC)

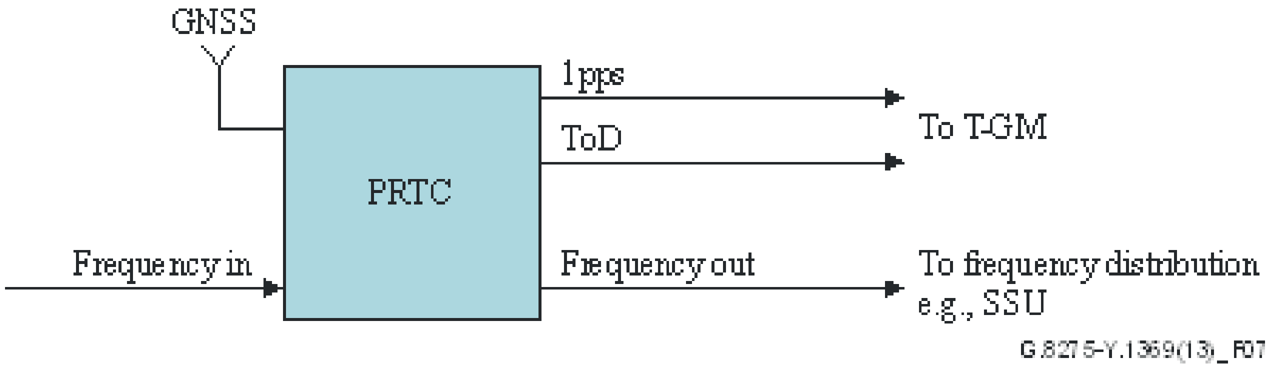
— The synchronization flow is from the master to slave, although the timing messages will flow in both directions.

— Individual nodes are T-BCs or T-TCs in the case of full support from the network

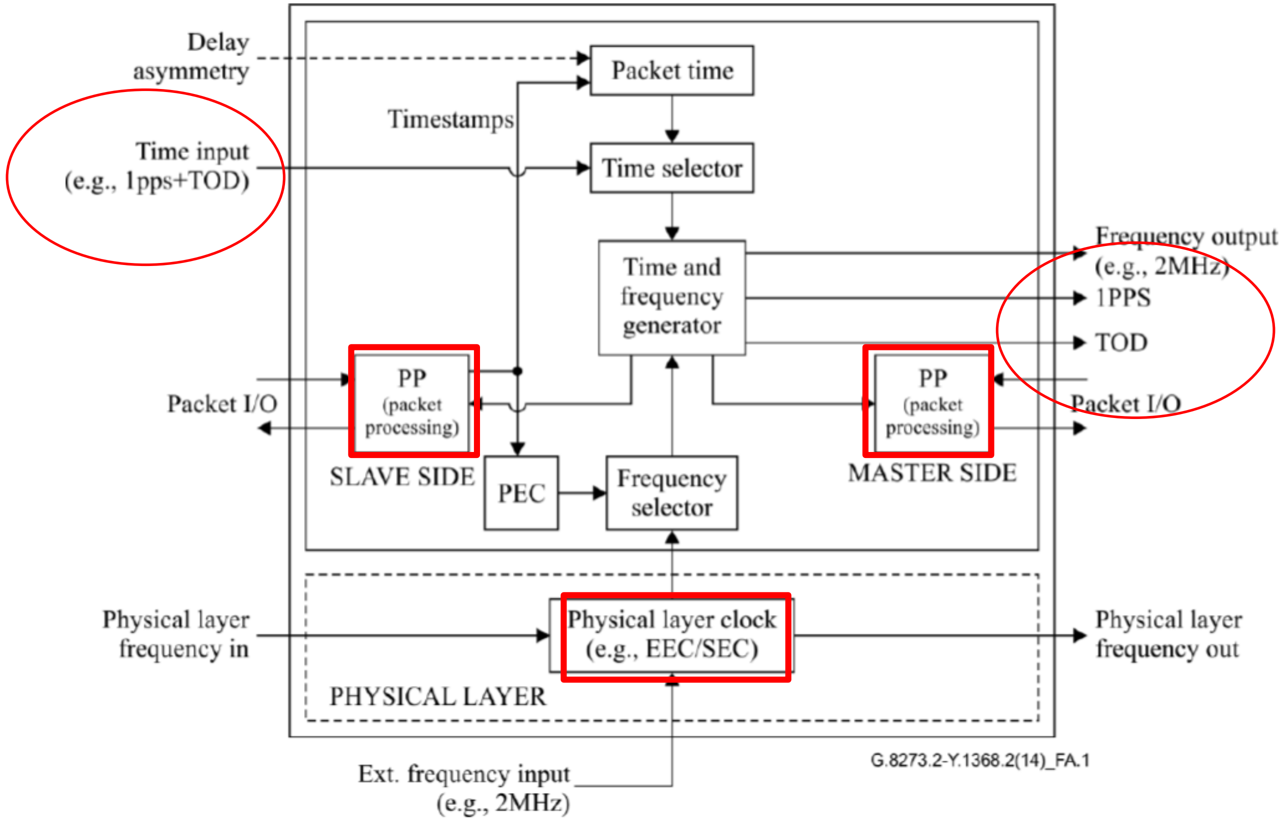
From G.8275

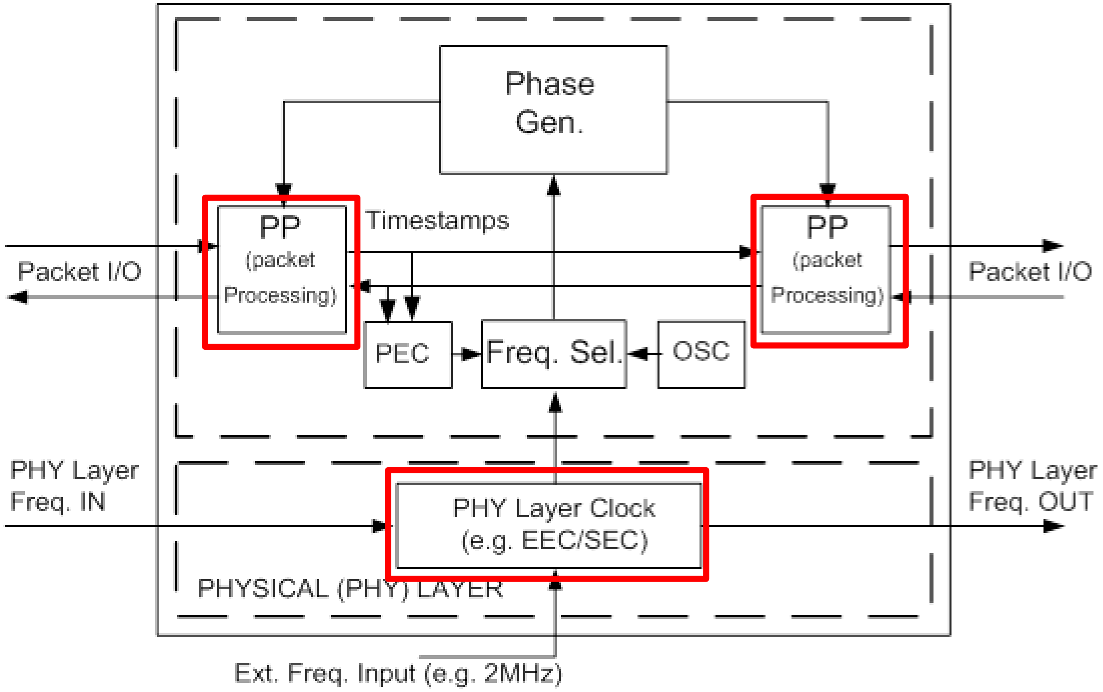


— Primary Reference Time Clock (PRTC) is the master of the time synchronization network (G.8272). ePRTC (enhancedPRTC) recently defined (G.8272.1)



T-BC AND T-TC CLOCK MODELS

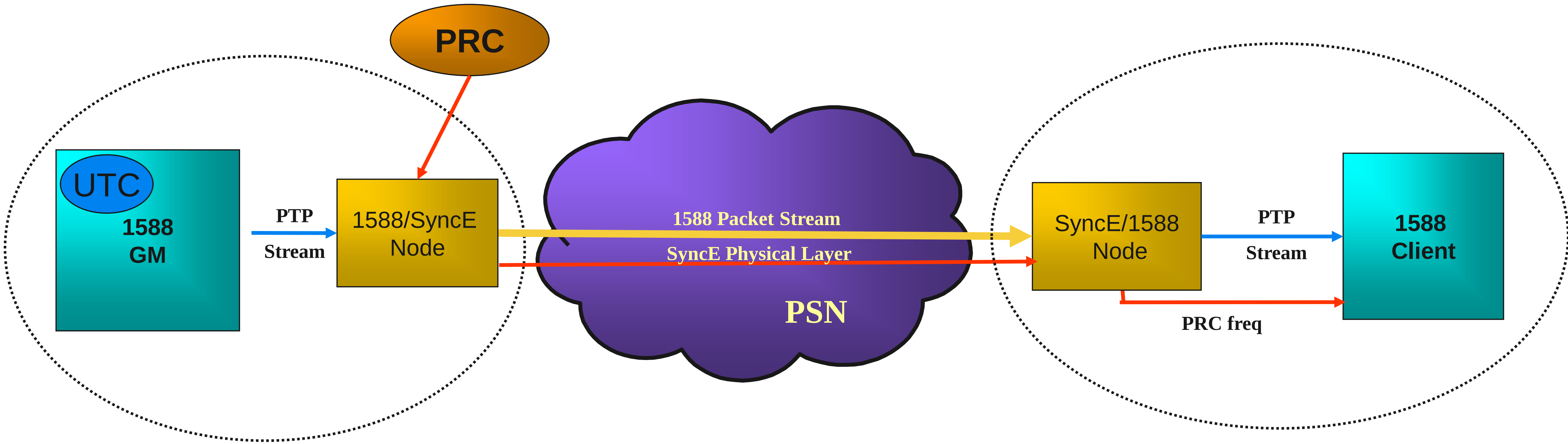




- **G.8273.2** and **G.8273.3** provide models for the Telecom Boundary and Transparent Clocks
- **Frequency sync via physical layer** initially considered

COMBINED PTP-SYNCE

—SyncE as “frequency assistance” to 1588

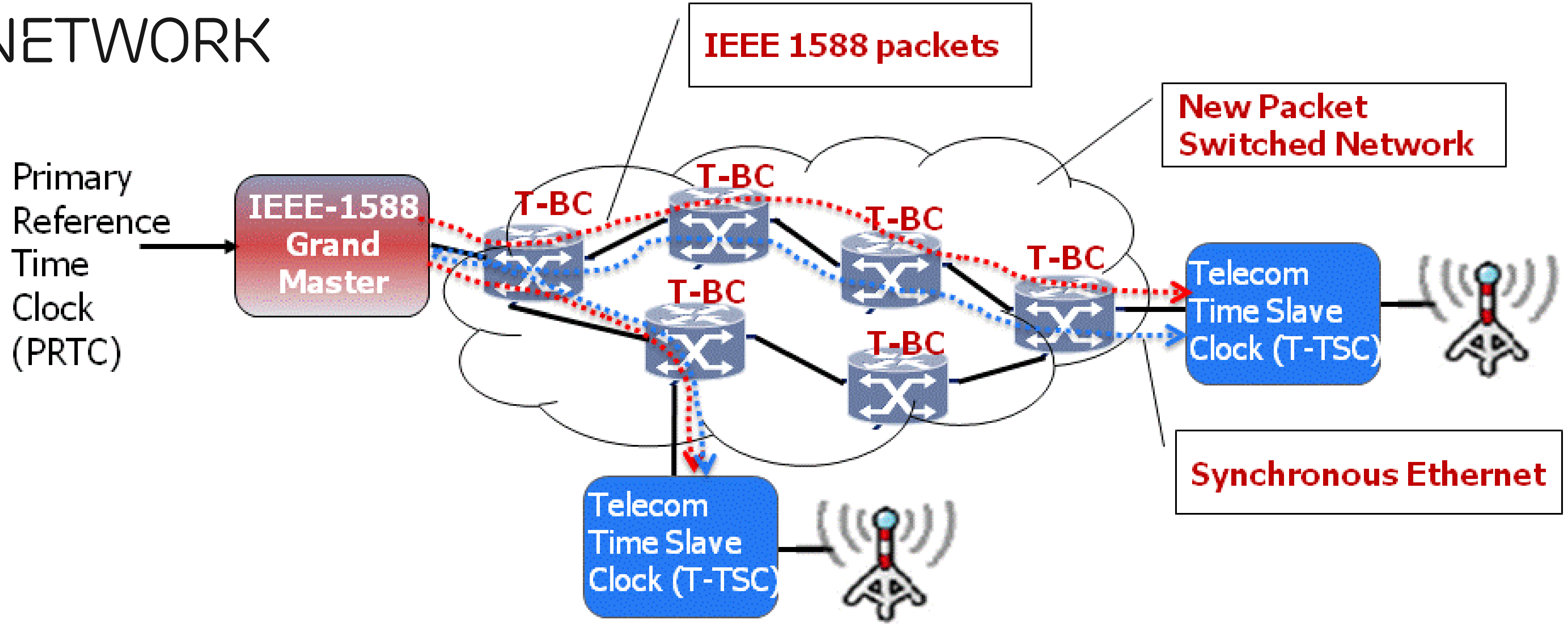


—Gives immediate “frequency lock” to 1588 client

—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 SUPPORT FROM NETWORK



— Telecom Boundary Clocks (T-BCs) and Telecom Transparent Clocks (T-TCs) can be used to overcome packet delay variation

— Synchronous Ethernet is used for frequency and IEEE 1588 is used for phase synchronization

— ITU-T recommendations (**G.827x**) to address time and phase applications

  — **G.8275.1**, PTP (telecom profile for phase/time synchronization with full timing support from the network), **G.8275** (Architecture), **G.8271** (Time and phase synchronization aspects of packet networks), **G.8271.1** (Network limits for time synchronization in Packet networks), **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), **G.8273.3** (Timing characteristics of telecom transparent clocks)

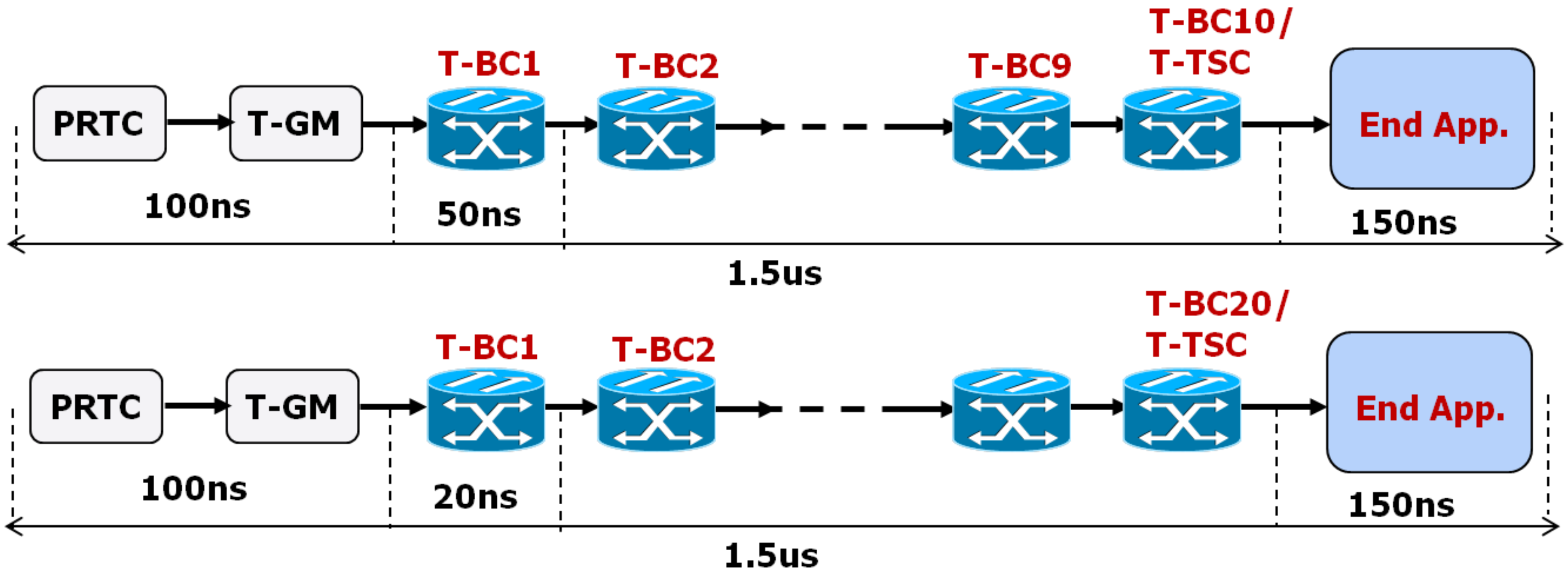
G.8275.1 PTP OPTIONS AND CONFIGURABLE ATTRIBUTES

- Two types of Ordinary clocks: T-GM (Telecom Grand master, master clock only) and T-TSC (Telecom Slave clock, Slave-Only Ordinary Clock)
- Boundary clock will be used on the first profile, transparent clocks will be added in future version
- One-step and two-step clocks are allowed
- PTP mappings
  - The default mapping for the Time/phase profile is agreed to be IEEE1588-2008 annex F - Transport of PTP over Ethernet
- Multicast mode
  - For the Ethernet mapping, both the forwardable multicast address 01-1B-19-00-00-00 and the non-forwardable multicast address 01-80-C2-00-00-0E must be used for all PTP messages'
  - The default Ethernet multicast address to be used depends on the operator
- PTP Message types and rates
  - Sync message, Follow-up, Announce, Delay_Request, and Delay_Response
  - Fixed packet rate of 16 packets per second for Sync, Delay_Req and Delay_Resp messages for the case where physical layer frequency support (e.g. Synchronous Ethernet) is used
  - Fixed packet rate of 8 packets per second for Announce message

G.8275.1 - ALTERNATE BMCA

- The alternate BMCA in G.8275.1 is based on the default BMCA specified in IEEE 1588
  - It has provisions to allow a manual network planning
- The alternate BMCA allows
  - Multiple Grand Masters
  - Per-port Boolean attribute notSlave.
    - masterOnly is TRUE -> the port is never placed in the SLAVE state
    - masterOnly is FALSE -> the port can be placed in the SLAVE state
  - Per-port attribute localPriority to be used as a tie-breaker in the dataset comparison algorithm
    - Using different values than their default value allows building manually the synchronization network topology
  - The clock attribute priority1 is static
  - The clock attribute priority2 is configurable
  - the clock attributes clockAccuracy and offsetScaledLogVariance must be set to specific values defined in G.8275.1

G.8271.1 ARCHITECTURE



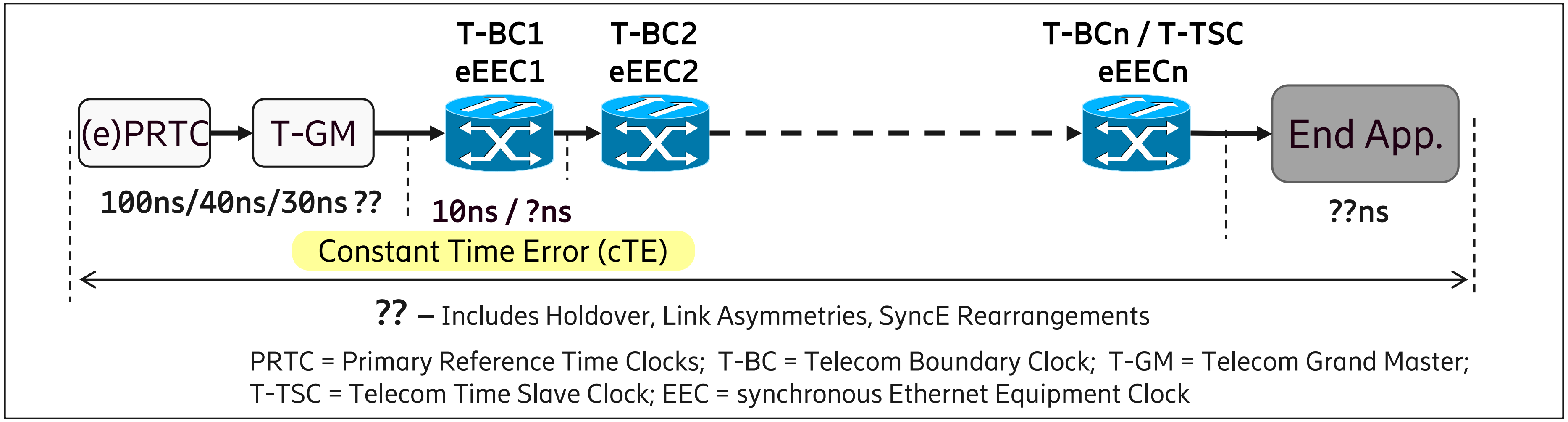
- G.8273.2 defines the T-BC and T-TSC specifications
- The network limit of 1.5us also accounts for other sources of noise (e.g. holdover, link asymmetries, syncE rearrangements)
- Four classes of Telecom Boundary Clock (T-BC) and Telecom Time Slave Clock (T-TSC). Reference chains with class A and B have been fully studied.

T-BC Constant TE Classes	Maximum Constant Time Error (ns)
A	50
B	20

G.8273.2/Table 1 – T-BC Constant Time Error Classes

PRTC = Primary Reference Time Clocks
T-GM = Telecom Grand Master

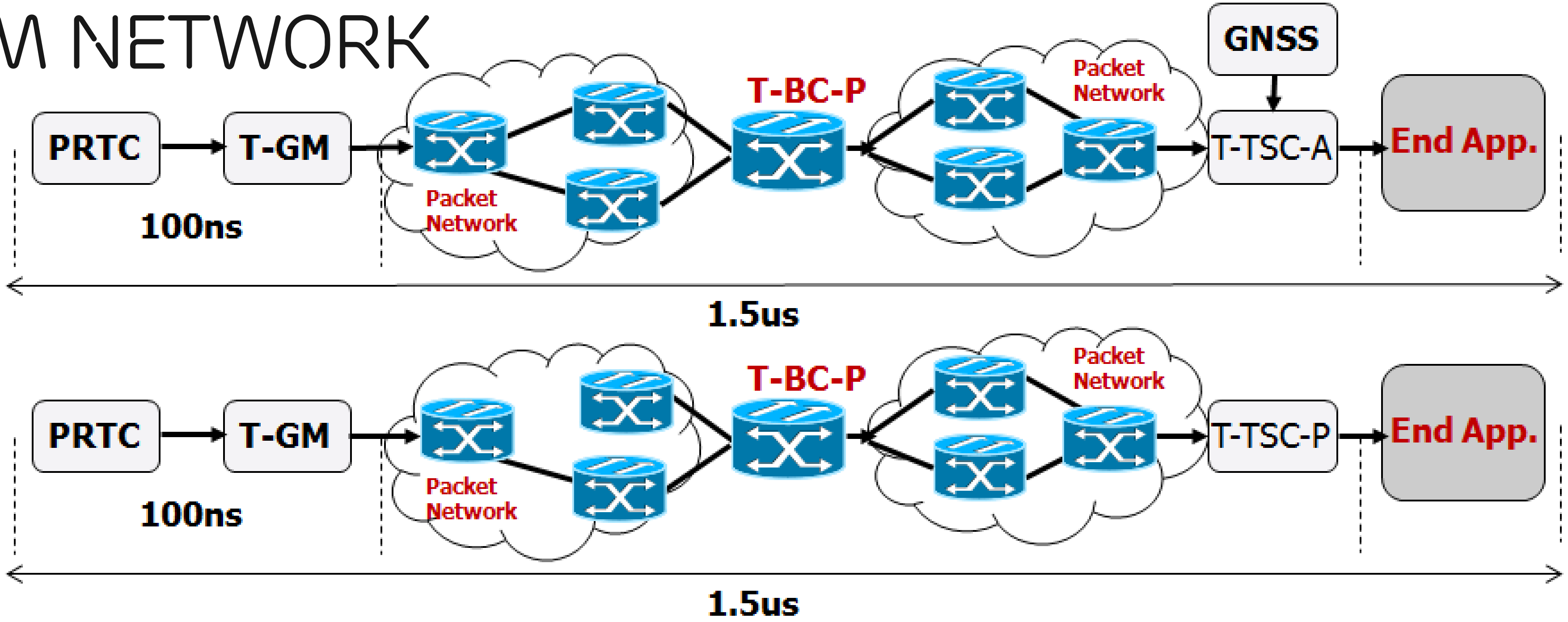
ITU-T TIME/PHASE NEW REQUIREMENTS



T-BC / T-TSC Class	Maximum cTE (ns)	n (Hops)
C	10	?
D	TBD	?

- T-BC/T-TSC Class C and eEEC have been recently Approved
- T-BC/T-TSC Class D – a new metric has been defined max|TE_L| to be less than 5ns

G.8275.2- ITU-T TIME/PHASE PROFILE – IEEE-1588 WITHOUT SUPPORT FROM NETWORK



- Assisted Partial Support Telecom Time Slave Clock (T-TSC-A)-based architecture where GNSS is co-located with the T-TSC-A
  - The local GNSS (e.g. GPS) can be used to measure the asymmetry of the network
  - PTP is used as a backup for GNSS failures
- Partial Support Telecom Time Slave Clock (T-TSC-P)-based architecture without the GNSS co-located with the T-TSC-A;
  - Number of nodes in the network not defined (yet?).
- Related ITU-T recommendations (G.827x) :
  - **G.8275.2** (Precision time Protocol Telecom Profile for time/phase synchronization with partial timing support from the network), **G.8275** (Architecture**), G.8271** (Time and phase synchronization aspects of packet networks), **G.8271.2** (Network limits for time synchronization in packet networks with partial timing), **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.8273.4** (Timing characteristics of partial timing support telecom boundary clocks and telecom time slave clocks)

GNSS= Global Navigation Satellite System

G.8275.2 PTP OPTIONS AND CONFIGURABLE ATTRIBUTES

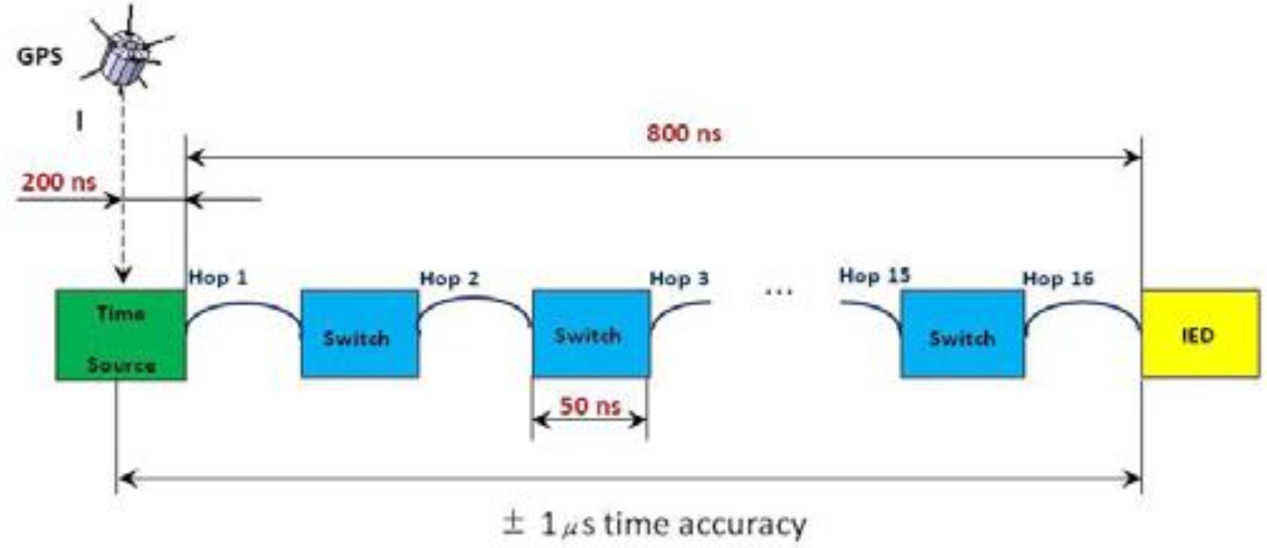
- Default PTP domain number is 44, range of {44 – 63}
- Two types of Ordinary clocks: T-GM (Telecom Grand master, master clock only) and T-TSC-P/T-TSC-A (Telecom Slave clock)
- Boundary clock are allowed on this profile
- One-step and two-step clocks are allowed
- Unicast mode only
- PTP mappings
  - IEEE1588-2008 annex D - Transport of PTP over User Datagram Protocol over Internet Protocol Version 4
  - IEEE1588-2008 annex E - Transport of PTP over User Datagram Protocol over Internet Protocol Version 6
- PTP Message types and rates
  - Sync /Follow-up – min rate: 1 packet per second, max rate: 128 packets per second
  - Delay_Request/Delay_Response – 1 packet per second, max rate: 128 packets per second
  - Announce – min rate: 1 packet per second, max rate: 8 packets per second
  - Signaling messages – no rate is specified
- Unicast Negotiation per G.8265.1

G.8275.2 - ALTERNATE BMCA

- The alternate BMCA in G.8275.2 is based on G.8275.1 ABMCA
  - It has provisions to allow a manual network planning
- Signal Fail: defines 2 types of Packet Time Signal Fail (PTSF): PTSF-lossSync and PTSF-unusuable
- Several aspects regarding the setup of the protocol in the network are still for further study
  - Architectures that imply re-arrangements of the synchronization direction
  - Architectures that include clocks with multiple PTP ports
  - Ports not in Master state that provides synchronization services

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.

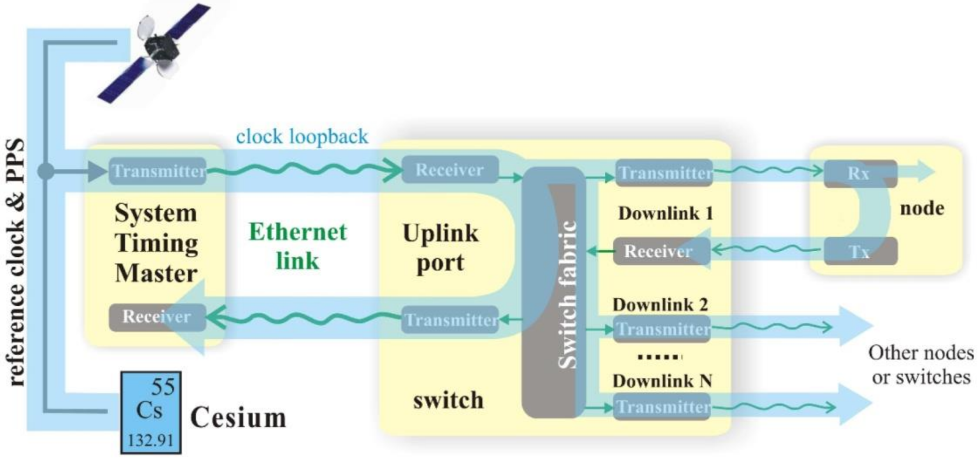


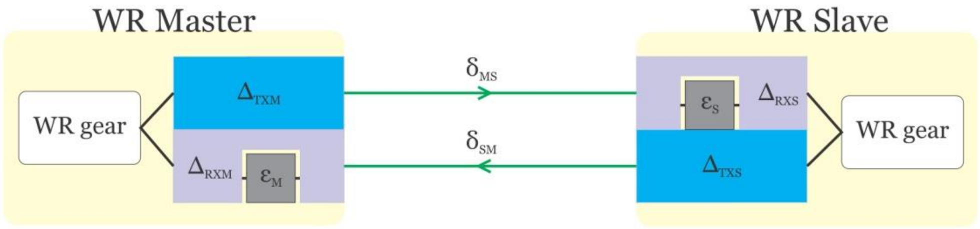
From Standard Profile for Use of IEEE Std 1588-2008 Precision Time Protocol (PTP) in Power System Applications, IEEE PES PSRC Working Group H7/Sub C7 Members and Guests, 2012 IEEE Conference

- IEEE C37-238: IEEE Standard Profile for Use of IEEE 1588™ Precision Time Protocol in Power System Applications (revised in 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

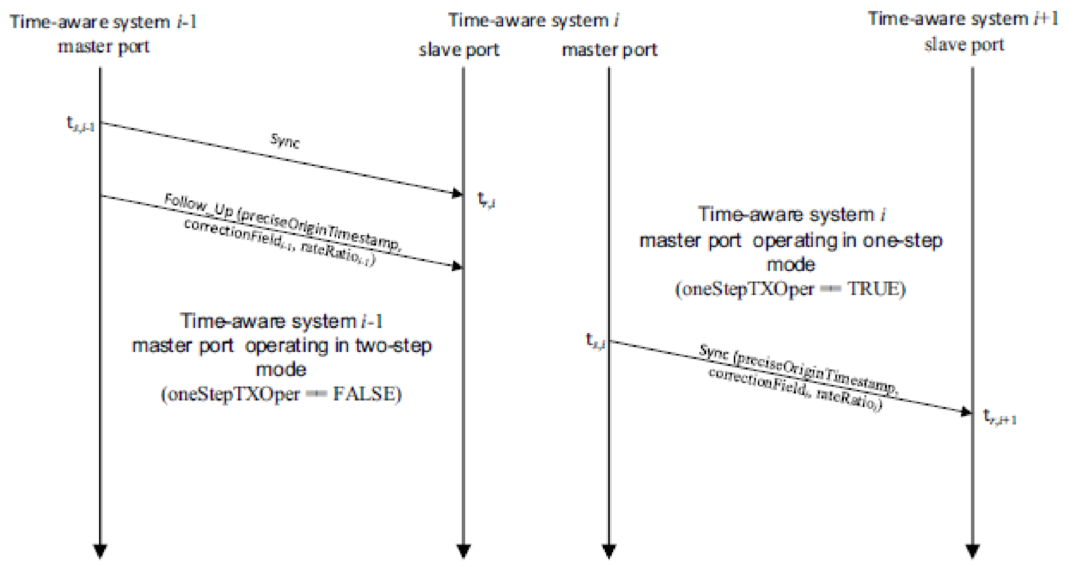
- PTP-based solution originally specified by the CERN targeting sub-ns accuracy, max(|TE|) < 1ns (typically, to support scientific applications); White Rabbit is the name of the project and of the related profile.
- Currently being specified as High Accuracy Default PTP Profile in the new Edition of the IEEE 1588 (J.5 in IEEE1588-201x)
- 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





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; Currently under revision: 802.1AS-REV (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).
- Latest revision expected to be compliant with the new Edition of IEEE1588



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

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 packet networks
- ITU T Recommendation G.8271.1, Network limits for time synchronization in Packet networks
- ITU T Recommendation G.8271.2, Network limits for time synchronization in packet networks with partial timing support
- 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
- ITU T Recommendation G.8273.3 , Timing characteristics of telecom transparent 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.Sup, Simulations of transport of time over packet networks

ITU-T RECOMMENDATIONS (PACKET SYNC – PHASE/TIME) WORK IN PROGRESS

- ITU T Recommendation G.8273.1 , Timing characteristics of Telecom Grandmaster clocks
- ITU T Recommendation G.8273.4 , Timing characteristics of assisted partial timing support slave clocks (APTSC)

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 (under definition (High Accuracy Default PTP Profile in Annex J.5);
  - WR-PTP = White Rabbit Profile defined in WR Spec
- TSN: IEEE 802.1AS

Silvana Rodrigues
Director of System Engineering, IDT Canada
Silvana.rodrigues@idt.com

Stefano Ruffini
ITSF Vice Chair & Expert - Ericsson Research
Stefano.ruffini@ericsson.com

Ericsson.com