Distribution of Timing: Basic principles and Sync over the Physical Layer

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WSTS Tutorial

Contents

Credits:

- Figures in slides 6, 9, 15 taken from book «Synchronous Ethernet and IEEE 1588 in Telecoms: Next Generation Synchronization Networks» (Wiley, 2013, ISBN: 978-1-848-21443-9)

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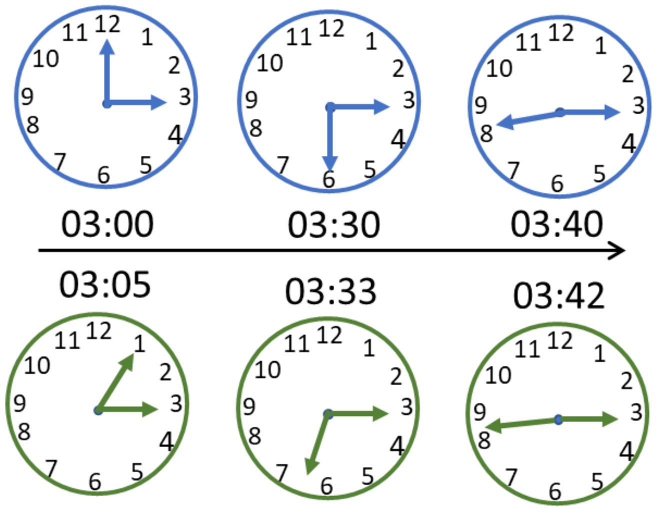
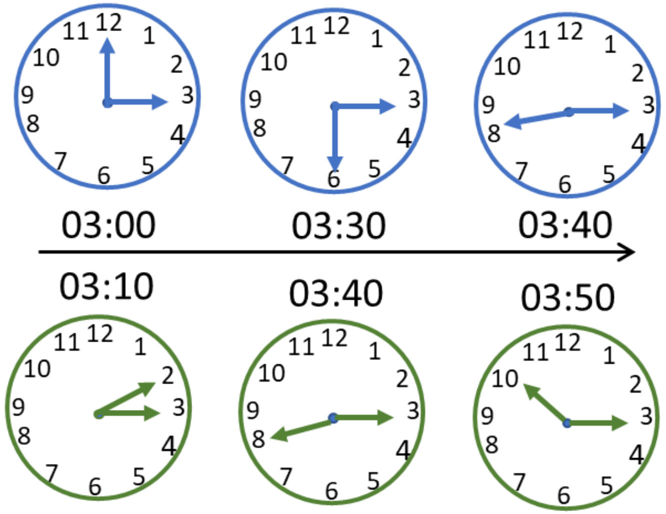
1. General

Time vs Frequency

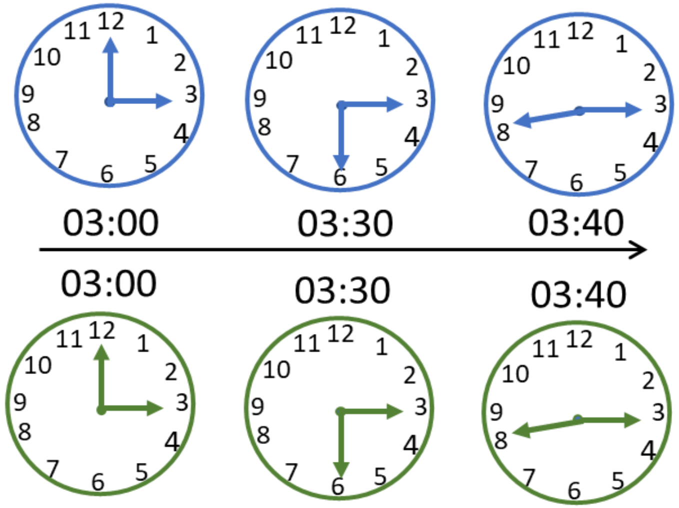
Not Synchronized



Frequency Synchronized (Syntonized)



Time/Phase/Frequency Synchronized



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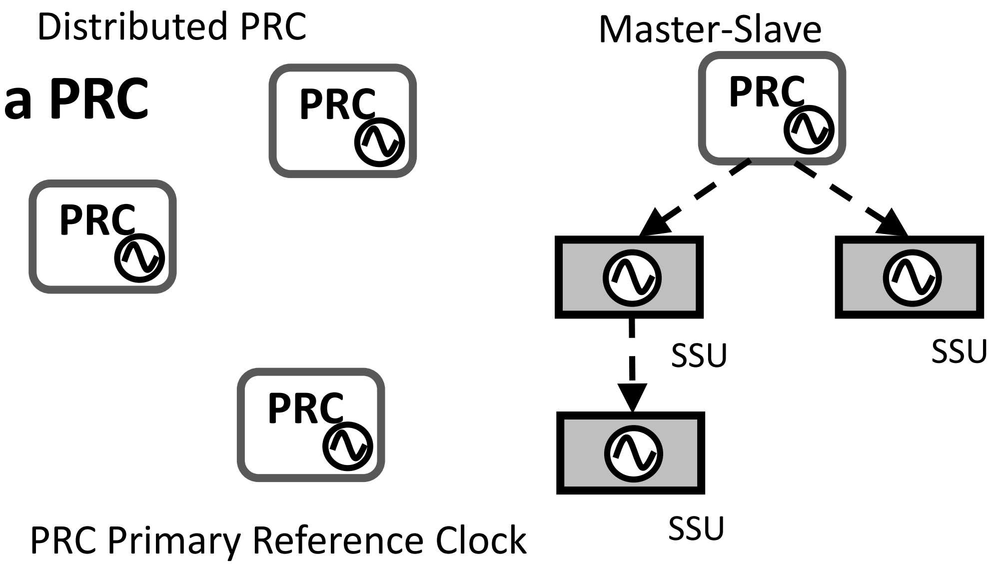
Master-Slave vs. Plesiochronous

- Original focus in Telecom is **Frequency synchronization.** Basic concepts defined 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*

- **Telecom networks were originally synchronized to a PRC**
  - **PRC** were originally based on Cesium technology
  - Increased use of GNSS-based sync leading to a mix of «Distributed PRC» and «synchronized mode»
  - Renewed interest on Mutually Synchronized mode fo time synchronization



PRC Primary Reference Clock
SSU Synchronization Supply Unit

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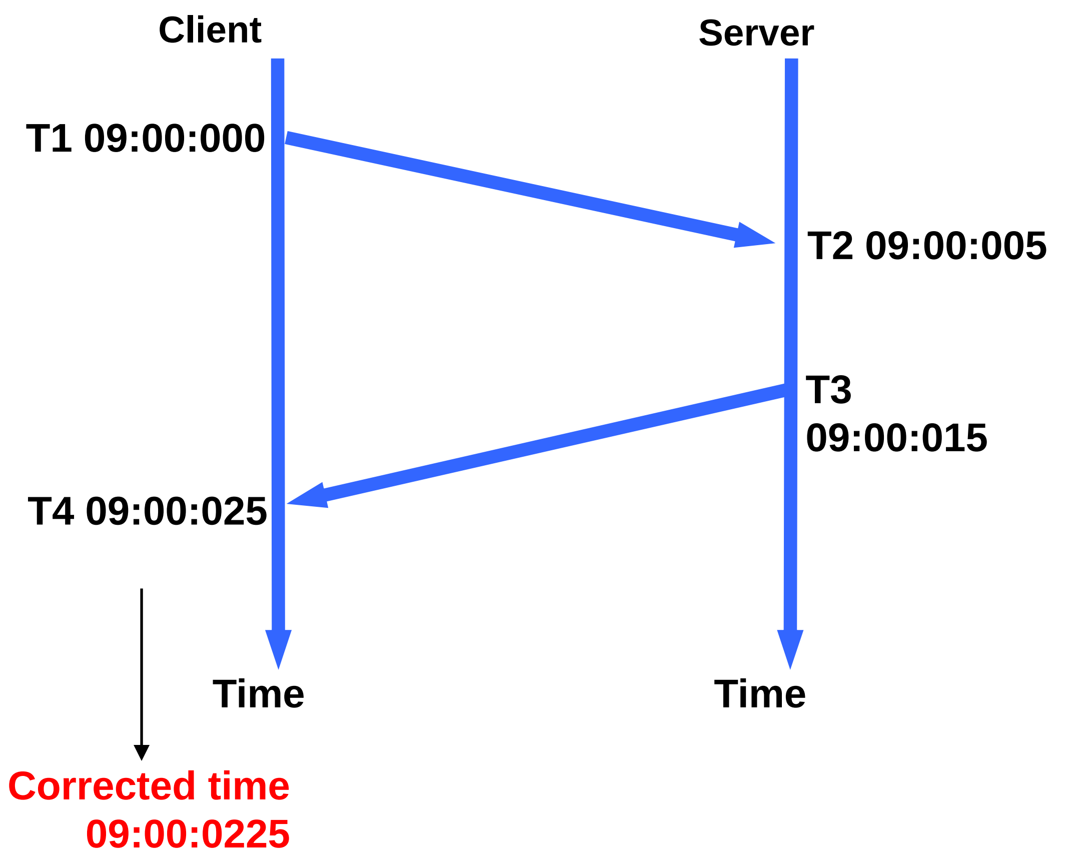
Timing Protocols

- 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

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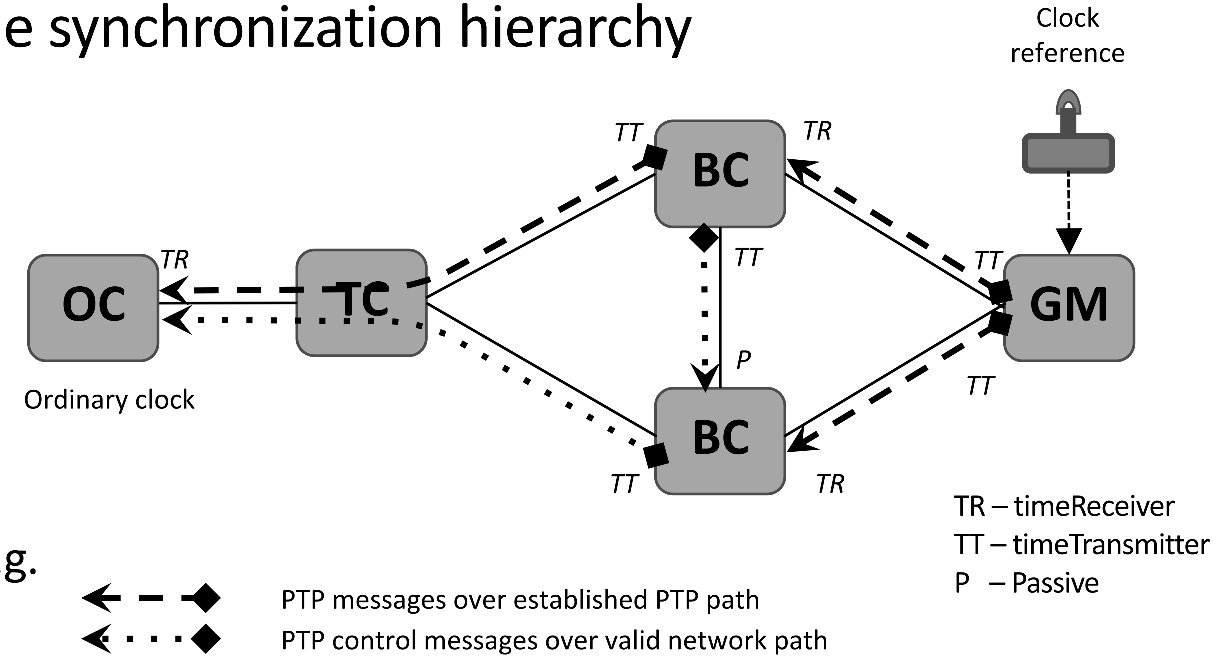
IEEE 1588-2008/2019

- The Grandmaster "reference clock" sends a series of time-stamped messages
- timeReceiver process timestamps and synchronize to the Grandmaster.
- Frequency can be recovered from an accurate time of day reference (but physical layer can also be used)
- Best Master Clock Algorithm is used to define the synchronization hierarchy
- Accuracy is possible by means of:
  - Proper packet rate
  - Hardware time-stamping (eliminate software processing delays)
  - Timing support in the network (e.g. transparent clocks, boundary clocks)
- New features in 2019:
  - Addition of special ports to allow some technologies (e.g. WiFi and EPON) to use their inherent timing support
  - New optional features (e.g. cumulative rate ratio, performance monitoring)
  - High accuracy profile
  - Security options



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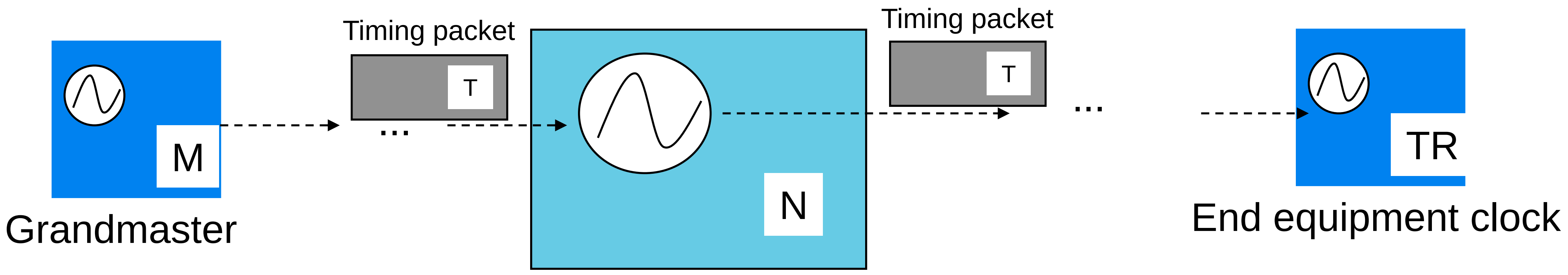
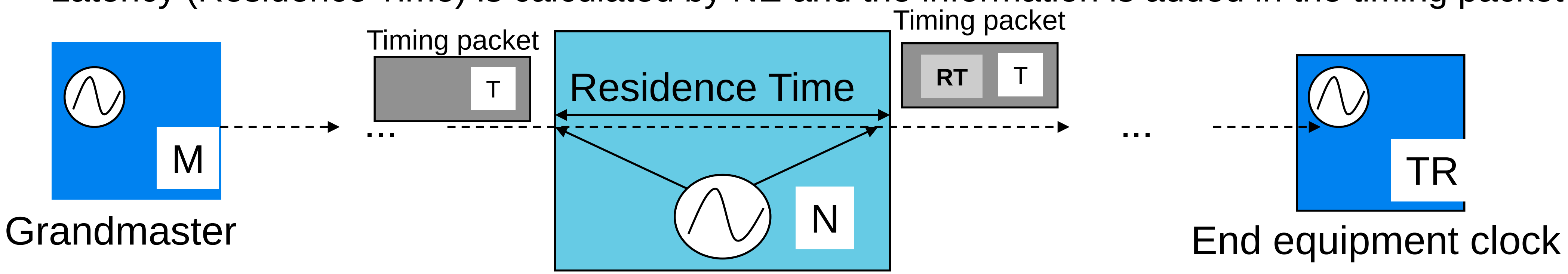
Timing Support

Timing packets are terminated and regenerated by Node N



e.g. **IEEE 1588 Boundary Clock**, NTP Stratum Clock

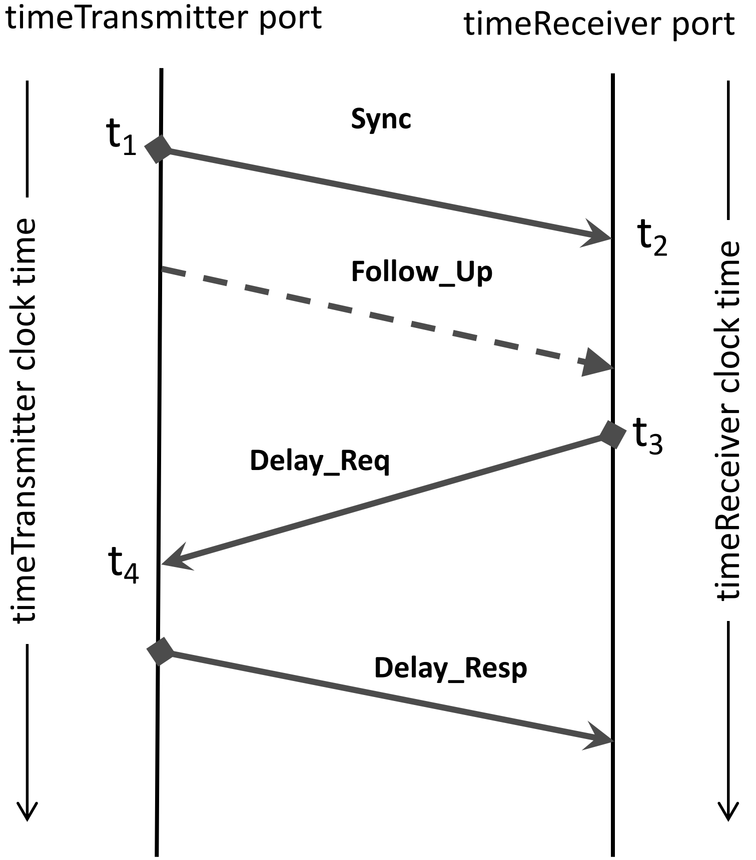
Latency (Residence Time) is calculated by NE and the information is added in the timing packet



e.g. **IEEE 1588 Transparent Clock**

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

PTP Time Transfer Technique



Timestamps known by

one-step clock	two-step clock
t_1, t_2	t_2
	t_1, t_2
t_1, t_2, t_3	t_1, t_2, t_3
t_1, t_2, t_3, t_4	t_1, t_2, t_3, t_4

Offset:

(timeReceiver clock error and one-way path delay)

$Offset_{SYNC} = t2 – t1$

$Offset_{DELAY\_REQ} = t4 – t3$

We assume path symmetry, therefore

Mean Path Delay = [(t2 - t1) + (t4 - t3)] ÷ 2

timeReceiver Clock offset = [(t2 - t1) - (t4 - t3)] ÷ 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.

- ***In contrast to NTP, it is the Grandmaster (equivalent to server in NTP) that initiates the protocol. It sends timing messages to timeReceivers.***

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)

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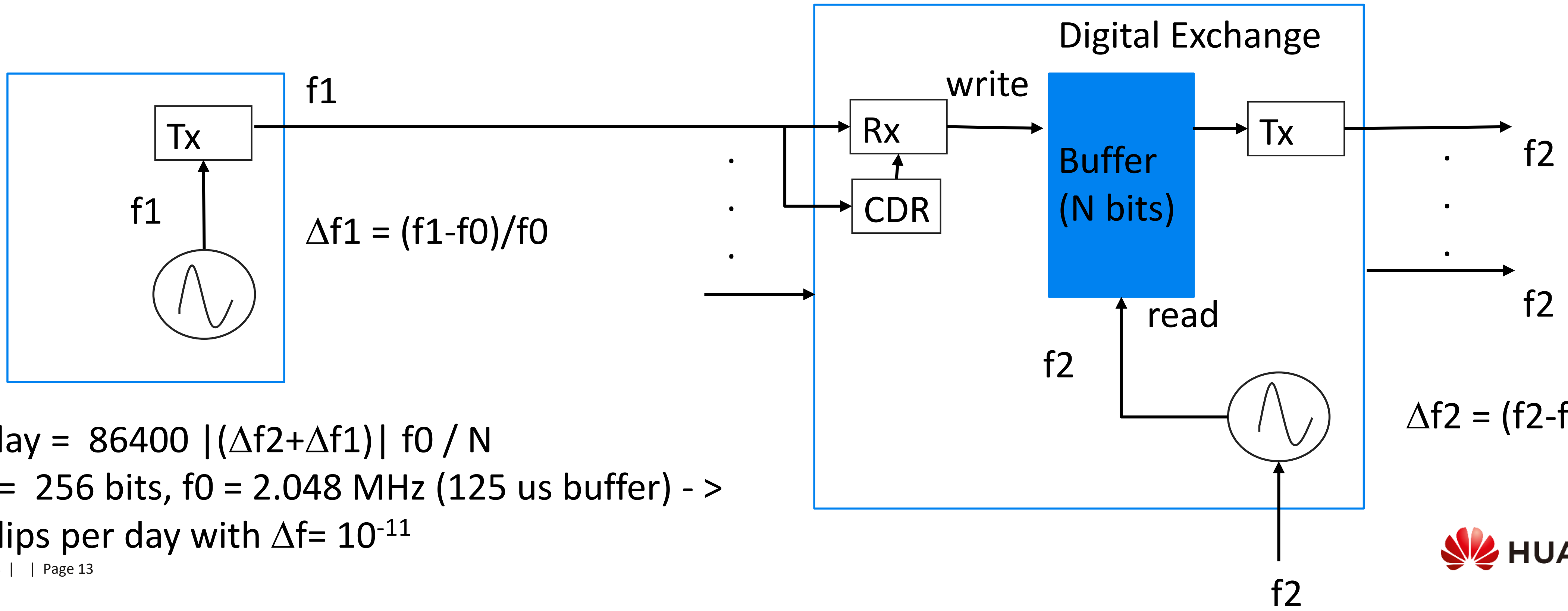
2. Frequency synchronization over the Physical layer

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 $|(\Delta f2+\Delta f1)|$ f0 / N

Ex.: N = 256 bits, f0 = 2.048 MHz (125 us buffer) - >

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

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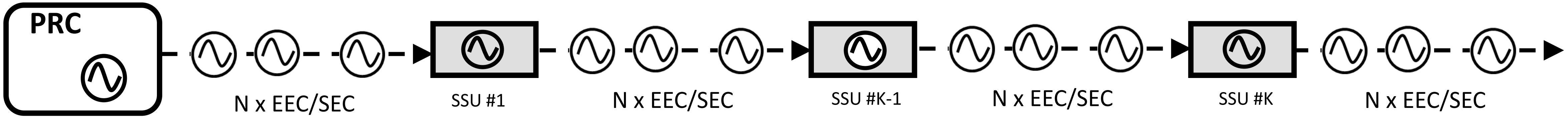
Basic principles

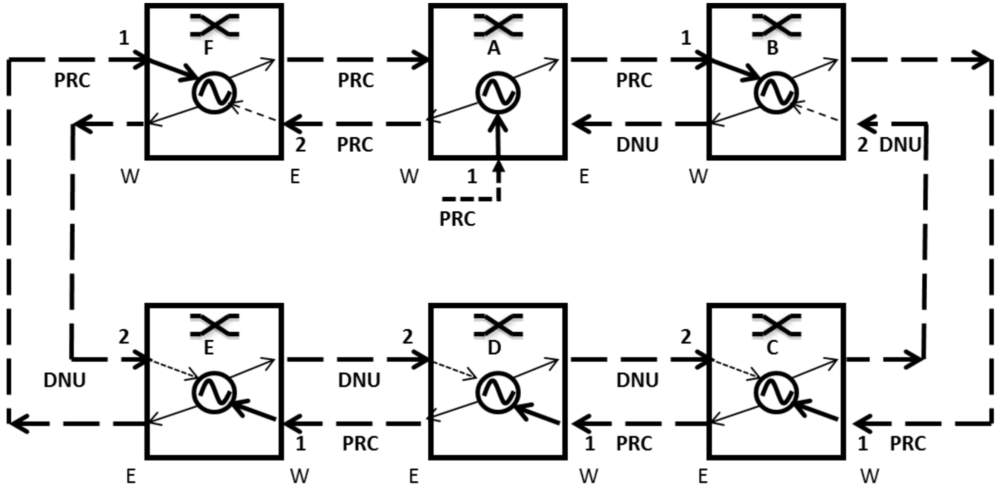
— G.803 specifies the reference chain as a combination of this clocks, that can guarantee to meet specified performance objectives



Worst case scenario calculation purposes:
K=10 and N= 20, with limitation that total number of clocks is less than 60

PRC Primary Reference Clock
SSU Synchronization Supply Unit
SEC Synchronous Equipment Clock

— Clocks have been specified in ITU-T G.812 and G.813
— G.781 specifies the synchronization 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..)



SSM used in: SDH, SyncE (using ESMC), Sync over OTN (using OSMC)

ESMC: Ethernet synchronization messaging channel; OSMC: OTN synchronization messaging channel

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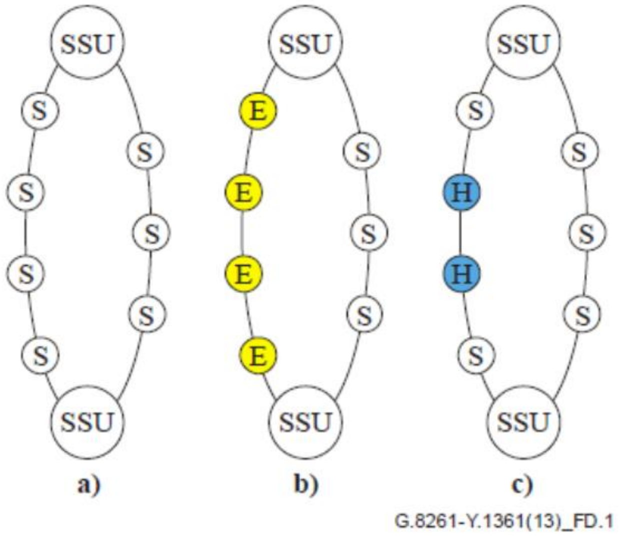
Synchronous Equipment Clock (SEC): Introduction

- SEC: A generic term representing the SDH equipment clock, the Ethernet equipment clock (EEC), and the OTN equipment clock (OEC)
- 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 802.3 (+/- 4.6 ppm 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 SEC (eSEC) is defined in G.8262.1
  - It also covers Optical Transport Network (OTN) equipment clock (OEC)
  - It does not transport Time
- All nodes must support SyncE: sync chain as per G.803
  - Cannot be transported transparently across network boundaries



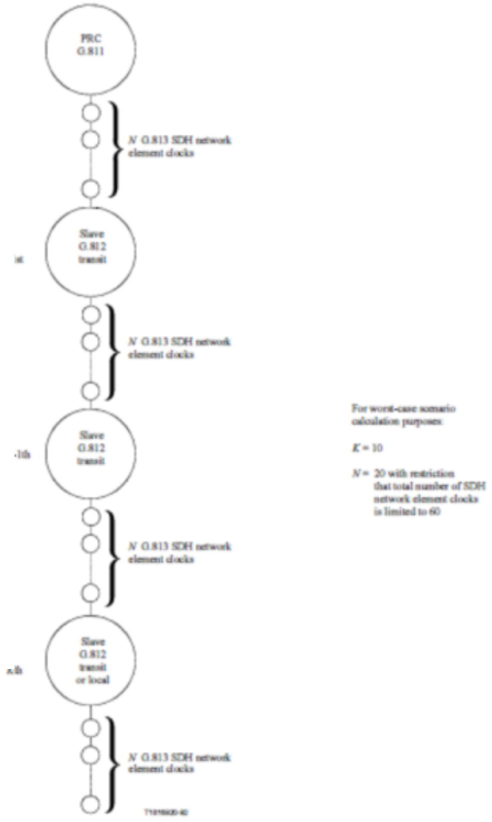


Figure 8-5/G.803 – Synchronization network reference chain

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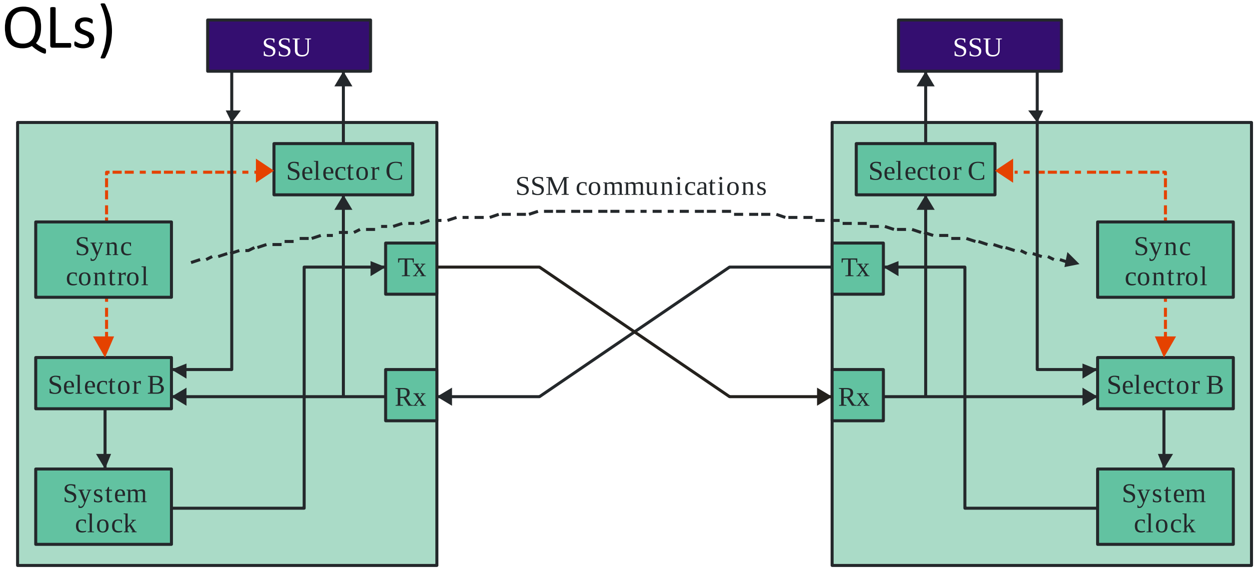
SSM (Synchronization Status Message) in SyncE

- 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 Quality Levels (QLs) over the OAM specific slow protocol (OSSP)
- Option 1 clock treated as G.813 option 1 (QL-SEC), Option 2 as an G.812 type IV clock (QL-ST3)



G.8264-Y.1364(14)_F11-1

- Two types of protocol message are defined
  - "heart-beat" message (once per second)
  - Event message generated immediately after a change in QL value
- SSM QL value is considered failed if no SSM messages are received after a five second period

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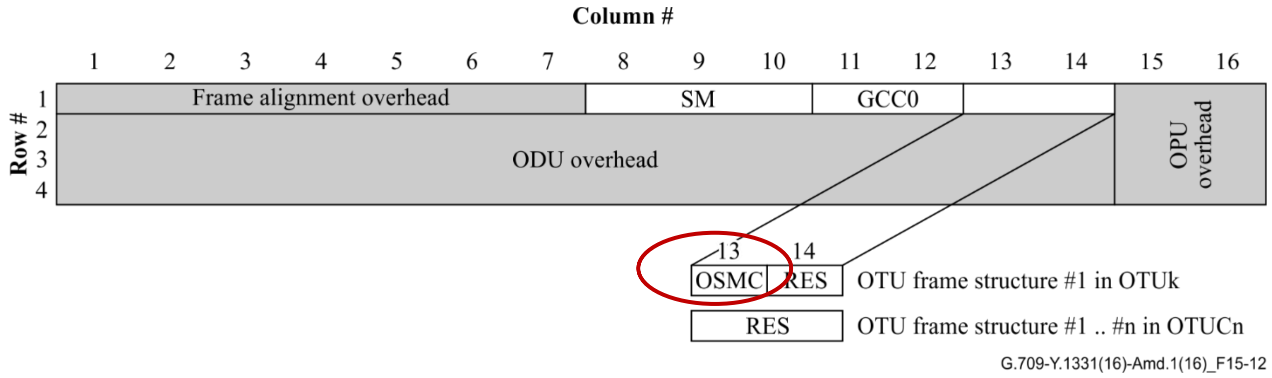
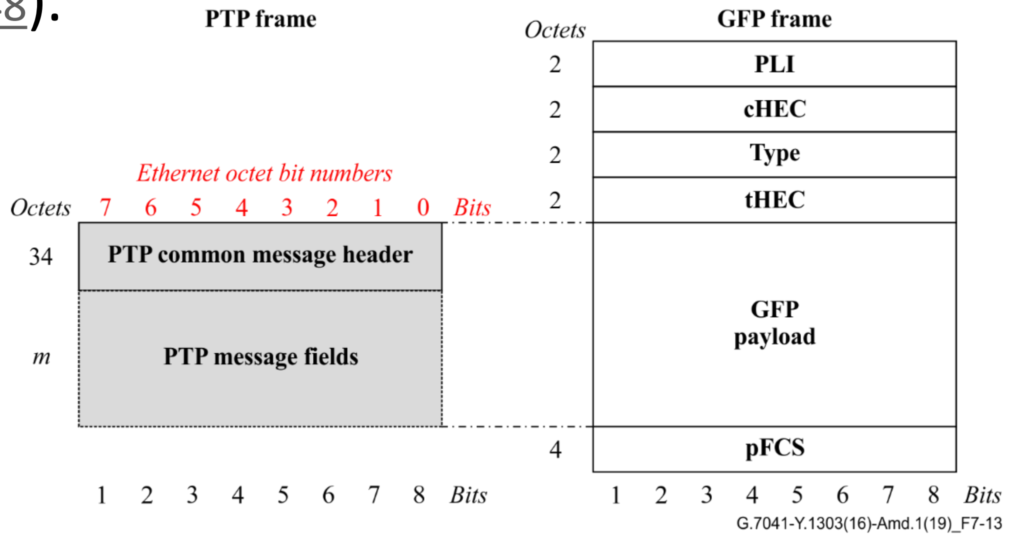
Synchronization over OTN (Optical Transport Network)

- OSMC (OTN synchronization messaging channel) is used to carry PTP and SSM messages
- Frequency synchronization can be carried over the physical layer, or via OTN clients (e.g., via SyncE)
- New Amendment to IEEE 1588 to support PTP over OTN has been published (IEEE 1588b-2022, https://ieeexplore.ieee.org/document/9895348).



- PTP over OTUk/FlexO, defined in G.7041 Clause 7.10
  - GFP-F mapping



The header of Generic Framing Procedure (GFP) frame does not have source and destination MAC/IP address.

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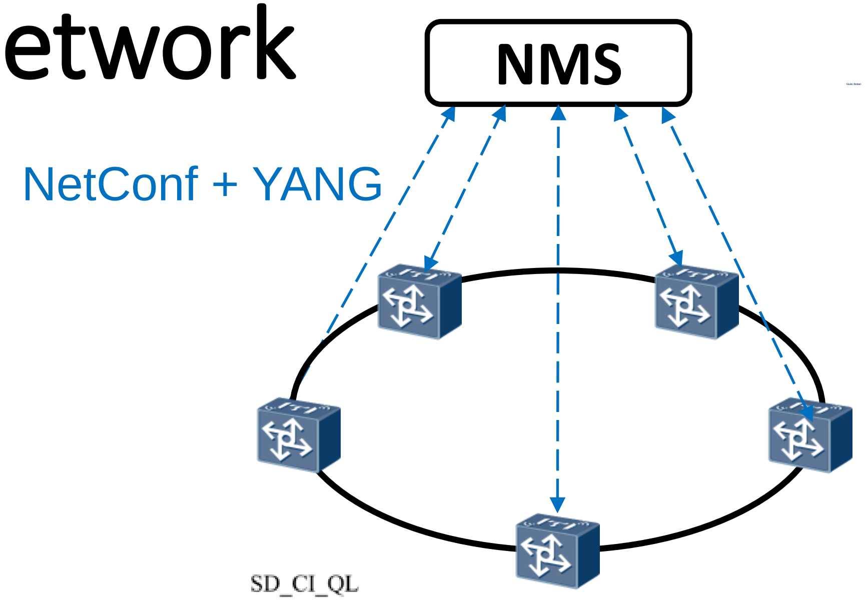
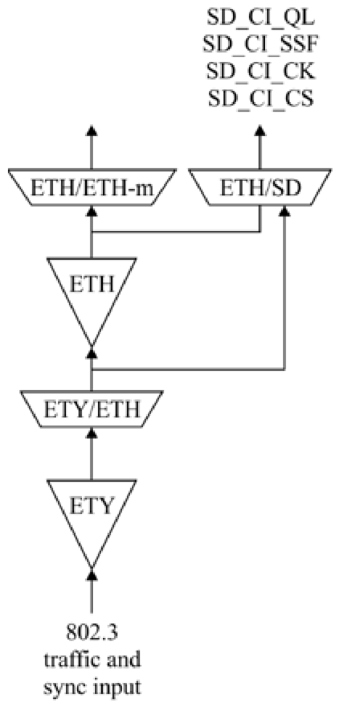
Managing Synchronization in the Network

- Managing the synchronization in the network is very important
- Management protocol between the equipment and Network management system (NMS) are important to be standardized to allow NMS to manage equipment from different vendors
- NetConf (IETF RFC 6241) + YANG (IETF RFC 6020) are suggested as management protocol
- ITU-T Recommendations are being updated to define new datasets and management objects
- ITU-T G.781 defines the synchronization layer functions for frequency synchronization based on the physical layer
  - It was updated to include physical layer (syncPHY) datasets





G.781(17)_F1.3

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Thank you!

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