The Synchronisation of Frequency, Phase and Time in Telecom Networks

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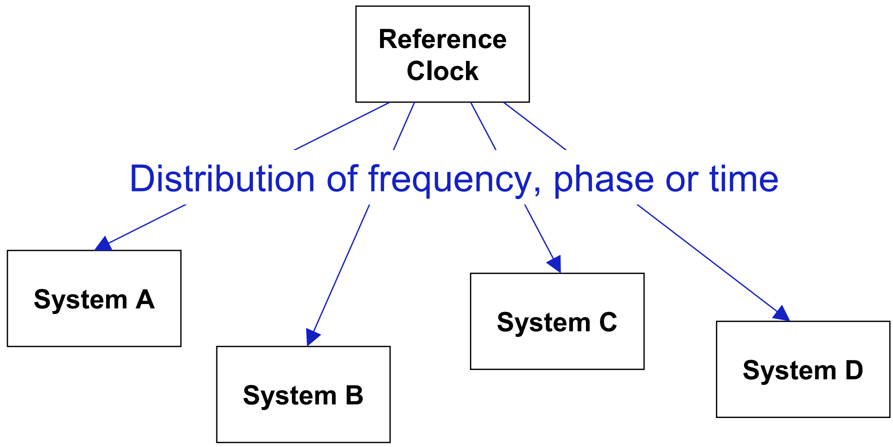
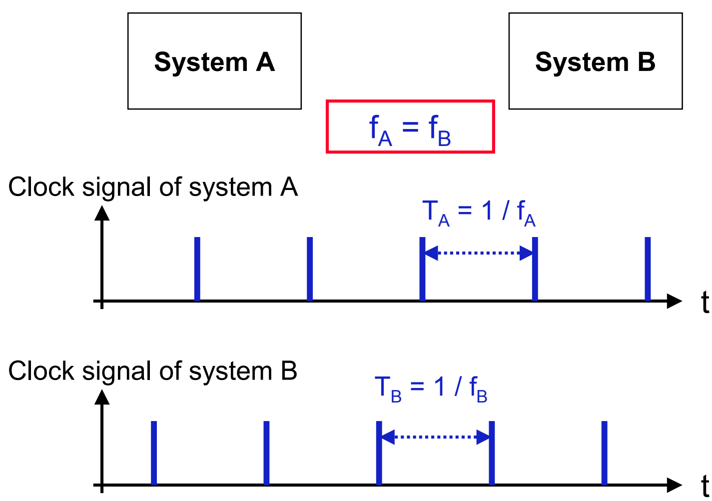
1. Introduction

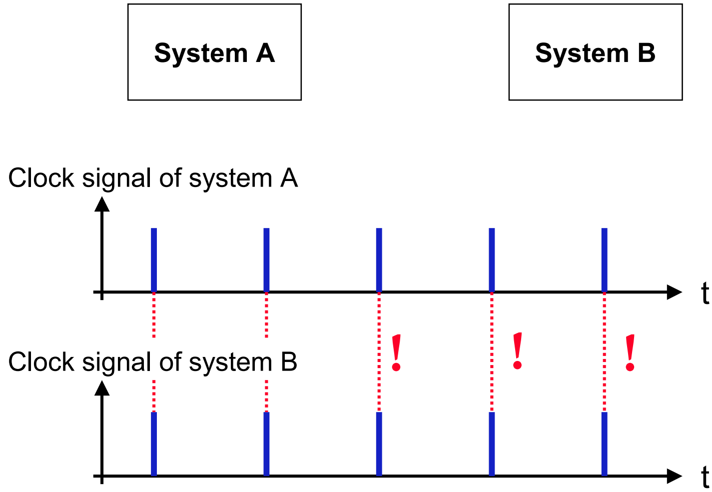
Network Synchronisation



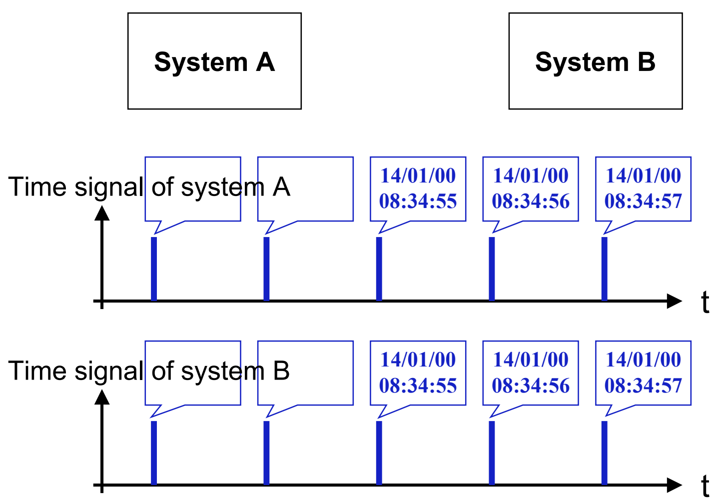
Frequency synchronisation



Phase synchronisation



Time synchronisation



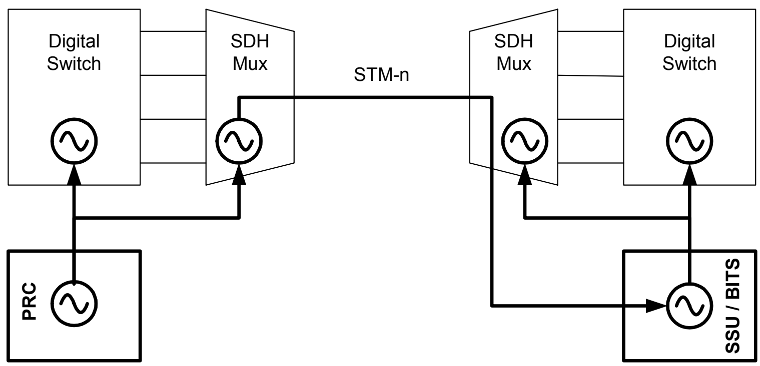
Examples

- Frequency synchronisation:
  - Digital Telephony
  - SDH transport networks
- Phase synchronisation:
  - 3G Mobile Networks (TD-CDMA, TD-SCDMA)
  - DVB-T
- Time synchronisation:
  - NTP (RFC 1305)
  - PTP (IEEE 1588)

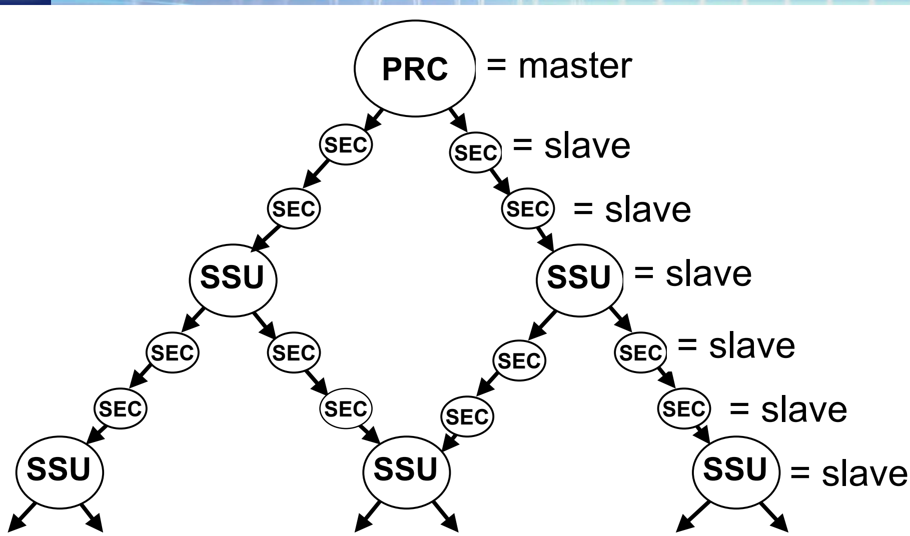
2. Frequency Synchronisation:

Digital Telephone and SDH Transport Networks

Synchronisation carried by STM-n Signals



Master-slave synchronisation



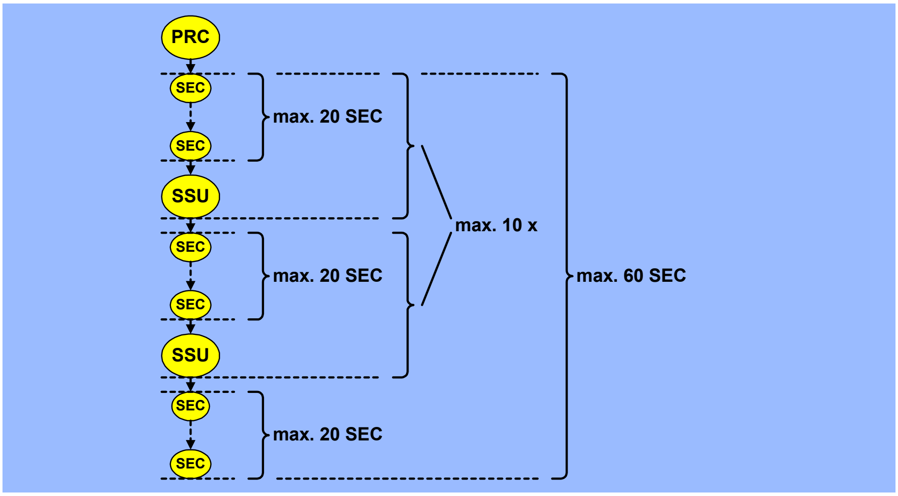
Master-slave synchronisation

- A designated master clock is used as a reference frequency generator.
- The frequency generated by the master clock is disseminated to all other clocks which are slaved to the master clock.

The control of jitter and wander

- SDH requires that jitter and wander be kept below tight network limits.
- This is achieved by inserting narrow-bandwith SSUs in the synchronisation chain (SEC bandiwth is relatively wide).
- Narrow-bandwith SSUs attenuate jitter and wander components that lie outside the SSU bandwith.

SDH synchronisation reference chain



SDH synchronisation reference chain

- For SDH (not SONET!) see ITU-T G.803 or ETSI EN 300 462-2
- The ITU-T/ETSI synchronisation reference chain meets the network limits on jitter and wander:
  - Not more than 60 SECs in a chain
  - Not more than 20 SECs between two SSUs
  - Not more than 10 SSUs in the chain

3. Phase Synchronisation:

3G Mobile Networks

(e.g. TD-CDMA, TD-SCDMA)

UMTS in a nutshell

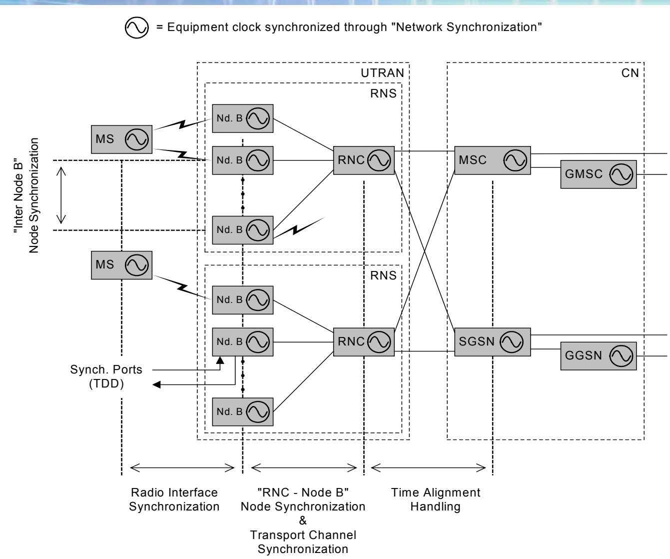
Three terrestrial Radio Access Network types:

- UTRAN-FDD (W-CDMA)
  - All environments
- UTRAN-TDD 3.84 Mcps (TD-CDMA)
  - Indoor picocells and outdoor microcells
- UTRAN-TDD 1.28 Mcps (TD-SCDMA)
  - All environments
  - Adopted by China

Abbreviations

CN	Core Network
GGSN	Gateway GPRS Support Node (a gateway router)
GMSC	Gateway MSC
HLR	Home Location Register
HSS	Home Subscriber Server
CS-MGW	Circuit Switched Media Gateway
MS	Mobile Station
MSC	Mobile Switching Center
PSTN	Public Switched Telephone Network
RNC	Radio Network Controller
SGSN	Serving GPRS Support Node (a router)
VLR	Visitor Location Register

Synchronisation Issues, overview



Network Synchronisation

- What: distribution of a common frequency to all equipment clocks
- Why: equipment clocks control the symbol timing of digital signals and the frequency of RF
- How: slave all equipment clocks to one or several reference clocks via a synchronisation distribution network

Frame synchronisation issues

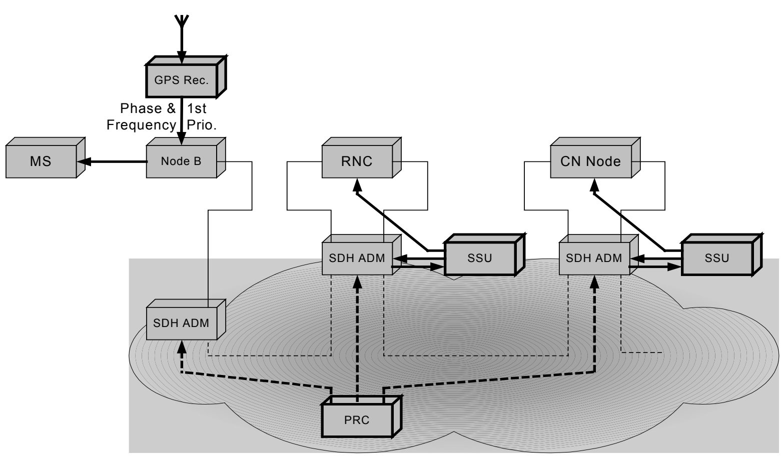
- What: Synchronisation of frame structures
- Why: Performance optimization (handover, delay, jitter on user signals, etc.)
- Where
  - Between Core Network node (MSC, SGSN) and RNC
  - Between RNC and Node B
  - Between neighbouring Node Bs (Intercell Synchronization)
  - Between Node B and Mobile Station
- How:
  - With protocol procedures
  - For Intercell Synchronisation: with GPS receivers (phase synchronization)

Synch. performance requirements

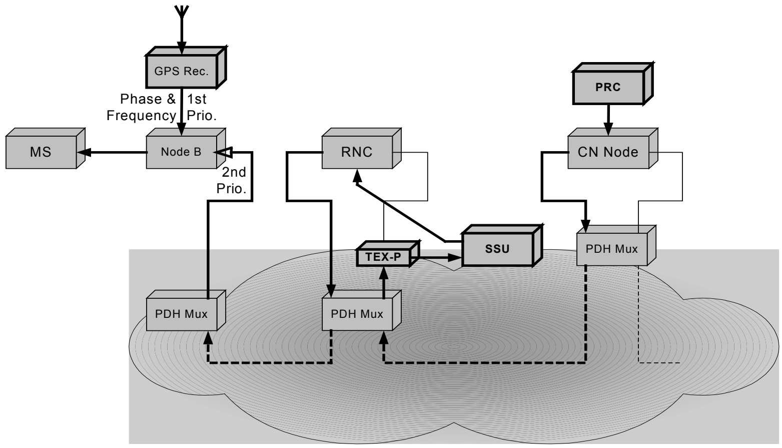
Summary:

- The UMTS network is a synchronous network
- All interfaces except the Iu radio interface require a frequency accuracy of 1E-11
- The Iu radio interface requires a frequency accuracy of 5E-8
- In UMTS-TDD, the Node B requires not only frequency synchronisation (5E-8), but also phase synchronisation (1.25 µs) for optimum performance

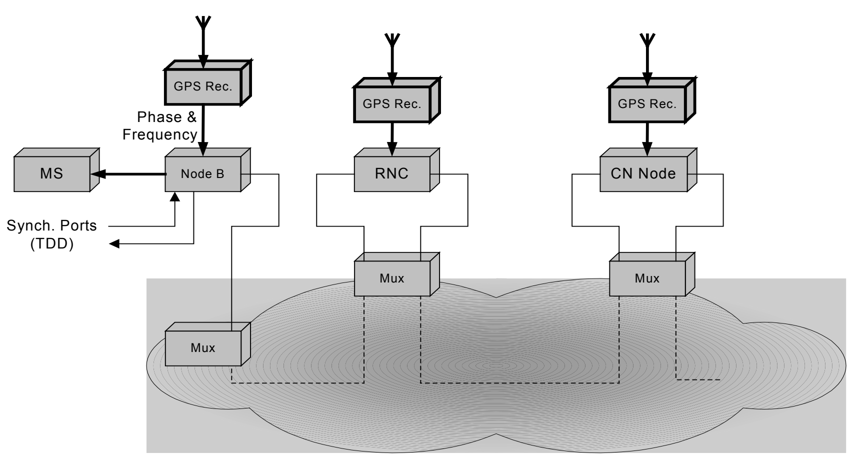
TDD, trusted SDH/SONET transport network



TDD, trusted PDH network



TDD, Leased Lines



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4. Phase Synchronisation:

Digital Broadcasting

What is DVB-T?

- DVB (Digital Video Broadcasting) = digital television broadcasting system standardized by ETSI and CENELEC under the leadership of the European Broadcasting Union (EBU)
- DVB uses a variety of transmission channels:
  - DVB-T = DVB via terrestrial radio
  - DVB-S = DVB via satellite
  - DVB-C = DVB via cable
  - Others ...

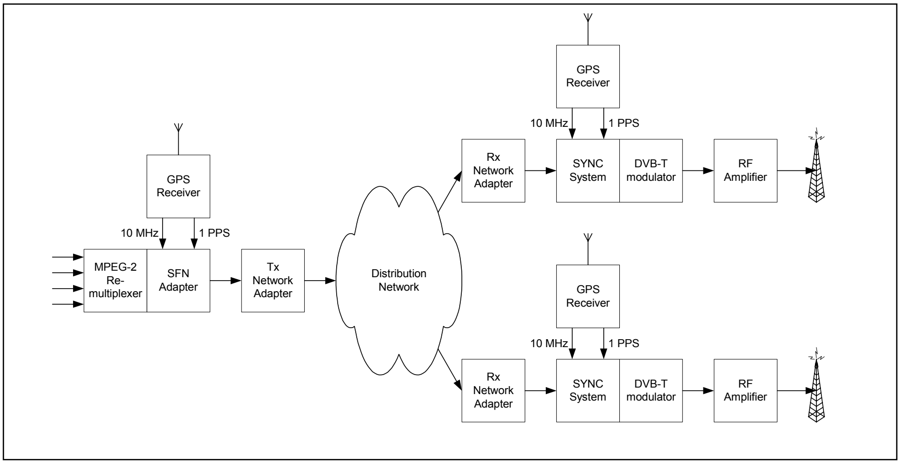
What is DVB-T?

- In DVB-T, video (television) programs are created in the broadcaster's studio, transported to the transmitter stations via some kind of transport network, and transmitted over UHF or VHF television radio spectrum using a cellular network called "Single Frequency Network" (SFN).
- SFNs are based on the OFDM (Orthogonal Frequency Division Multiplexing) modulation technique.

DVB-T: Synchronisation

- Each studio and each transmitter station requires a GPS-receiver with 10 MHz and 1 PPS outputs.
- In the studio, the GPS-receivers drives the "SFN Adapter".
- In the transmitter station, the GPS-receiver drives the "Synchronisation System".
- No accuracy specification in the standards
- GPS is explicitly mentionned in the standards as synchronisation source

DVB-T: Synchronisation

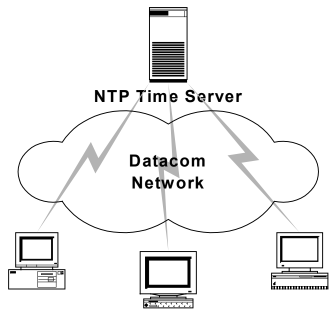


5. Time Synchronisation:

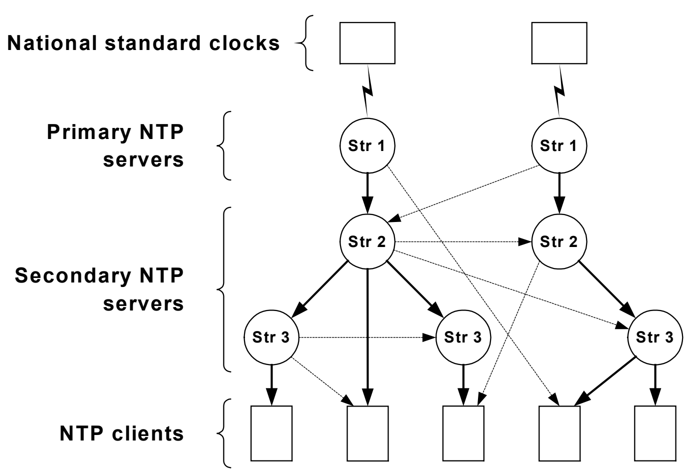
Network Time Protocol (NTP)

What is NTP?

- NTP is a system for the distribution of time to computers via a datacommunications network
- NTP is an IETF (Internet Engineering Task Force) standard (RFC1305)



NTP System Architecture



NTP System Architecture

- Hierarchical master-slave tree topology with NTP servers (root and nodes) and NTP clients (leaves)
- « Stratum Levels » indicate hop count from the root
- Stratum 1 server (root) synchronized by wire or radio to a national standard clock, or caesium clock calibrated with reference to a national standard clock
- Multiple Stratum 1 servers possible
- Active paths: used to discipline the local clocks
- Backup paths: time-stamps are exchanged but not used to discipline the local clocks

NTP System Architecture

- Self-organizing tree configuration, based on minimum-weight spanning tree algorithm
- Each slave synchronises to « least distant » server

  d = l + s + 0.5 x p, where

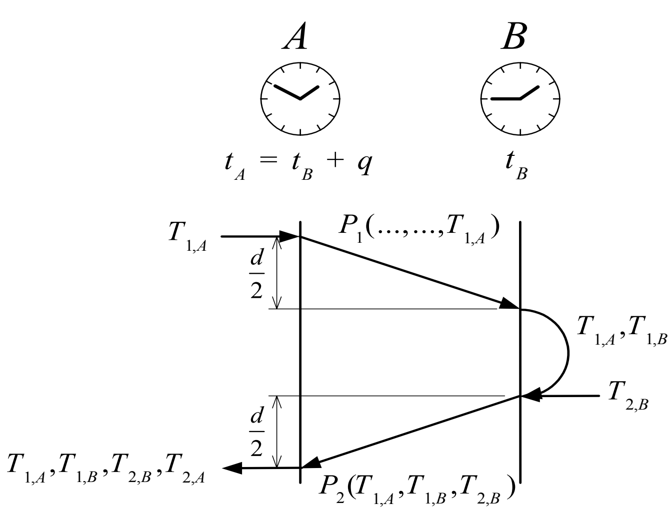
  d = distance
  l = scaled stratum level of the distant server
  s = slave clock's time dispersion[1]
  p = propagation delay[1]
  Note 1: measured by the slave
- No timing loops
- If all primary servers fail, one of the secondary servers becomes the master (free running clock)

NTP Protocol Stack

NTP	Application Layer
UDP	Transport Layer
IPv4 or IPv6	Network Layer
...	Data Layer
...	Physical Layer

NTP = Network Time Protocol
UDP = User Data Protocol
IPv4 = Internet Protocol Version 4
IPv6 = Internet Protocol Version 6

Two-Way Time Transfer



Two-Way Time Transfer

t_A = time scale of clock *A*

t_B = time scale of clock *B*

q = time offset of clock *A* relative to clock *B*

d = roundtrip packet delay

$P_1(\ldots)$ = first NTP packet

$P_2(\ldots)$ = second NTP packet

$T_{1,A}$ = transmit time of P_1 on timescale t_A

$T_{1,B}$ = receive time of P_1 on timescale t_B

$T_{2,B}$ = transmit time of P_2 on timescale t_B

$T_{2,A}$ = receive time of P_2 on timescale t_A

Two-Way Time Transfer

Calculating Clock Offset and Roundtrip delay:

$$T_{1,B} = T_{1,A} - q + \frac{d}{2}$$

$$T_{2,A} = T_{2,B} + q + \frac{d}{2}$$

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$$q = \frac{(T_{2,A} - T_{2,B}) + (T_{1,A} - T_{1,B})}{2}$$

$$d = (T_{2,A} - T_{2,B}) - (T_{1,A} - T_{1,B})$$

6. Time Synchronisation:

Precise Time Protocol (PTP)

What is PTP?

- PTP stands for Precise Time Protocol
- PTP is an IEEE standard (IEEE 1588) with the following objectives:
  - Protocol for precise synchronisation of real-time clocks (Time of Day)
  - For Local Area Networks supporting multicast messaging including but not limited to Ethernet
  - Sub-microsecond accuracy, system-wide
  - Minimal network and local clock computing resources
  - Allow simple default systems without user administration

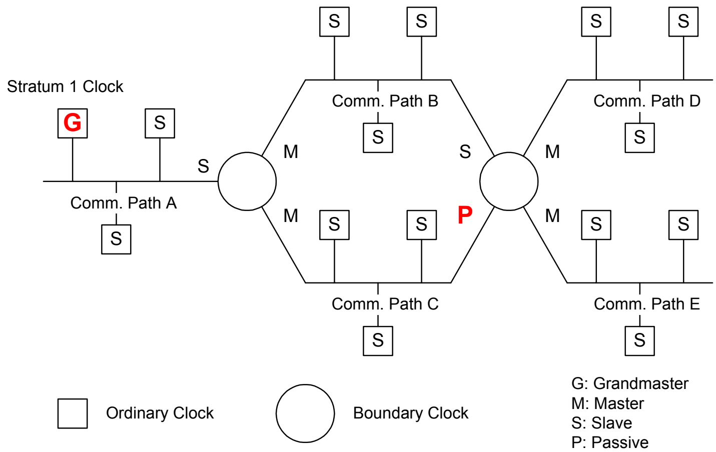
Elements of a PTP System

- Nodes:
  - Ordinary clocks: communicate with other clocks over a single communication path
  - Boundary clocks (optional): communicate with multiple sets of clocks using distinct communication paths
  - Administrative nodes (optional): for management purposes
- Communication paths:
  - Network segments allowing direct communication between clocks

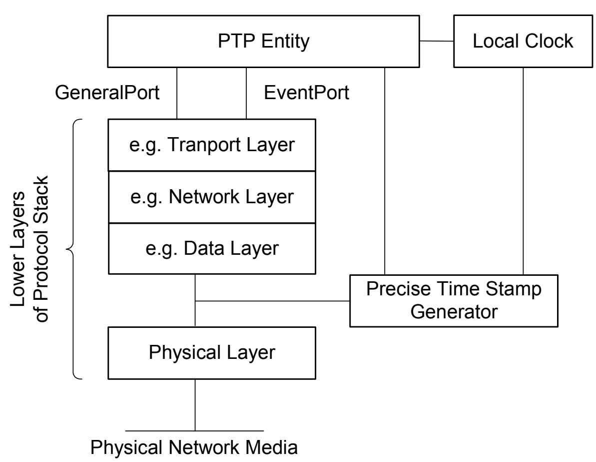
Clock Roles

- Master clock / clock port:
  - Clock used as the time source by all other clocks accessing a given communication path
- Grandmaster clock / clock port:
  - Best master clock in a system with multiple master clocks (multiple communication paths)
- Slave clock /clock port:
  - Clock which synchronises to a master or grandmaster clock
- Passive clock / clock port
  - Clock not used in order to prevent timing loops or to subdivide into disjoint clock trees

PTP System Architecture



PTP Clock 1



Best Master Clock (BMC) Algorithm

First Purpose: select the master clock

- Each clock publishes its properties via periodic Sync messages
- Automatic determination of the master clock (= the best clock)
- Determination of the local clock's and port's state (master, slave, disabled,etc.)

Second purpose: build a time distribution tree

- Master clock is the root
- Minimum number of boundary clock hops
- No timing loops

Clock Synchronisation Procedure

- Two-phase synchronisation:
- Phase 1: Offset measurement and correction
  - SYNC message (master -> slave)
  - FOLLOW UP message (master -> slave)
- Phase 2: Delay measurement and correction
  - DELAY REQUEST message (slave -> master)
  - DELAY RESPONSE message (master -> slave)

Thank you