Intro To Timing
Synchronization Fundamentals
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Draft-V3
Network Synchronization

SSU/TimeHub

TimeProvider

Wireless Base Station

Access (CES/PWE)
Telecom Synchronization

• Synchronization in telecommunications networks is the process of aligning the time scales of digital transmission and switching equipment so equipment operations occur at the correct time and in the correct order.

• Synchronization is especially critical for real time services, such as voice and video.

• The impacts of poor synchronization are:
  - Call setup, takedown, and management problems
  - Degraded speech quality and audible clicks
  - Degraded data traffic throughput
  - Freeze-frames and audio pops on video transmissions
  - Call disconnects during mobile call hand-off
  - Partial or complete traffic stoppage
Synchronization Requirements

Frequency Synchronization

Phase Synchronization

Time Synchronization
Stratum Levels

- Performance levels, or **stratum**, are specified by ANSI and Telcordia.
- Telecom networks should always be traceable to Stratum 1 – the office’s Primary Reference Source.
- Holdover is the ability of a system to maintain frequency accuracy if its Stratum 1 reference timing has been lost.
- A slip, a measure of a synchronization error, it is a frame (193 bits) shift in the time difference between two signals.

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Clock Type</th>
<th>Accuracy</th>
<th>1st HO Slip</th>
<th>Pull-In</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cesium/GPS</td>
<td>$1 \times 10^{-11}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Rubidium</td>
<td>$1.6 \times 10^{-8}$</td>
<td>~ 14 days</td>
<td>$1.6 \times 10^{-8}$</td>
</tr>
<tr>
<td>3E</td>
<td>Precision Quartz</td>
<td>$1 \times 10^{-6}$</td>
<td>~ 48 hours</td>
<td>$1 \times 10^{-6}$</td>
</tr>
<tr>
<td>3</td>
<td>Transport</td>
<td>$1 \times 10^{-6}$</td>
<td>minutes</td>
<td>$1 \times 10^{-6}$</td>
</tr>
<tr>
<td>4</td>
<td>CPE</td>
<td>$3.2 \times 10^{-6}$</td>
<td>N/A</td>
<td>$3.2 \times 10^{-6}$</td>
</tr>
</tbody>
</table>
Clocks

Warm up – initialization/time/no output

Acquire – valid reference

Locked – normal state/time/takes on the quality of input reference

Holdover – output/drift

Free run – time will return to nominal rate of oscillator
Primary Reference Source

Equipment that provides a timing signal whose long-term accuracy is maintained at $1 \times 10^{-11}$ (stratum 1) or better with verification to coordinated universal time (UTC) and whose timing signal may be used as the basis of reference for the control of other clocks.

- ANSI T1.101
Timing Signal Generator

- Timing distribution inside the office
- Holdover
- Redundancy - No single-point of failure
- Filtering (FLL vs. PLL)
Building Integrated Timing Supply, BITS
The Heartbeat of the Network

Virtually every NE connects to and is dependent on the sync infrastructure
SONET Mapping

**Synchronous –**

- T1 tributary mapped in has the clock of the SONET network
- Frequency offset results in slips if SONET network and T1 network are not plesiochronous.
- Slip buffers used to compensate for frequency offset
- Loss or corruption of data

**Asynchronous –**

- T1 tributary mapped maintains the source clock of the T1 network
- Frequency offset between T1 network and SONET network generates VT1.5 pointer movements but to slips
- Frequency offset justified by bit-stuffing
- VT1.5 pointers = jitter
SONET

Other Specific Modes

• **Loop Timing** for SONET Terminals
• **Through Timing** for Uni-Path Switched Rings/IXC/Regeneration applications
• **Internal Timing** for Point-To-Point applications

**Line Timing**

**PRS&TSG External Timing**

**TSG External Timing**

Primary Timing  Secondary Timing  Input connection point
Frequency-lock loop control of direct digital synthesizer in SSU provides mechanism to filter short-term instability on cascaded timing signals.

Most effective with long time constant made possible by Rubidium oscillator because of its exceptional stability.
Synchronization Integrity Impaired

**TDM Timing Issues –**

- **Short-term instability –**
  - Jitter
  - Wander
  - Phase Transients
  - MTIE & TDEV

- **Long-term accuracy –**
  - Frequency Offset
  - Phase & Frequency

- **What you see –**
  - Bit-errors
  - Slips
  - Pointer activity
  - Holdover & Clock Alarms

**Packet Timing Issues –**

- Packet Jitter (PDV)
- Asymmetry
  - time/phase for time transfer
- Latency or Delay
- Packet Loss
  - MinTDEV
  - MRTIE

Poor synchronization is the most common, non-obvious, cause of service degradation
Network Time Protocol (NTP)

• Internet protocol for synchronizing system clocks, via time stamps, over a packet network

• Uses Universal Coordinated Time (UTC) as reference from GPS constellation

• IP Client/Server architecture
  ▪ Time stamps delivered via LAN/WAN

• Developed in 1985 at U of Delaware
  ▪ Air traffic control was one of first applications
  ▪ Widely employed in information technology domain, e.g. every PC

• **Telecom NEs with NTP clients include softswitches, routers, IP transport, and mobile switching centers**
Network Time Protocol (NTP)

Network Synchronization (Frequency)
- Free Run
- Loop/Line
- External

Timing (Time of Day)
- Free Run
- Client/Server (LAN/WAN)
- External

Stratum 0 (Source that is UTC traceable)
- Stratum 1 (Stratum 1 gets time directly from Stratum 0 source)
- Stratum 2
- Stratum 3
- Stratum 4

Frequency Accuracy
- Most Accurate
- Least Accurate

Distance (number of hops) from Stratum 1
Carrier Class NTP

Enterprise NTP

- **Best Effort** Delivery
- Accuracy — 10s of seconds (WAN)
- Enterprise Implementation
- Traceability is Not Assured
- Not secure or authenticated – spoofing
- Not designed for mission critical applications

Telecom NTP

- **High Performance**, **High Accuracy**
- **UTC** Traceable
- **Five Nines** Availability and Reliability
- Security and Authentication
- Management and Monitoring
- Suitable for mission-critical applications

Enterprise/Data Center NTP

- **Best Effort** Delivery
- Accuracy — 10s of seconds (WAN)
- Enterprise Implementation
- Traceability is Not Assured
- Not secure or authenticated – spoofing
- Not designed for mission critical applications
Carrier-Class Timing Architecture

SSU-2000 w/PackeTime
NTP SERVER BLADES

EDGE ROUTER
Switch Complex
IP Microwave
MSPP
IP Transport
Data Servers
Other NTP Client
Changing Landscape of Telecommunications
Networks are Transitioning to IP
Network Sync Must Transition Too
# Frequency Delivery Strategies

<table>
<thead>
<tr>
<th>Synchronization Strategies</th>
</tr>
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<tbody>
<tr>
<td><strong>E1/T1 Circuit(s)</strong></td>
</tr>
<tr>
<td>Strategy based on use of legacy PDH systems. This method is only applicable to TDM networks.</td>
</tr>
<tr>
<td><strong>Adaptive Clock Recovery</strong></td>
</tr>
<tr>
<td>A vendor specific book-end solution used to support TDMoIP services. ACR methods are not industry standard compliant.</td>
</tr>
<tr>
<td><strong>GPS Radio</strong></td>
</tr>
<tr>
<td>Good performance, supporting wide range of applications. Cost, vulnerability and maintenance issues limit wide scale use.</td>
</tr>
<tr>
<td><strong>Synchronous Ethernet</strong></td>
</tr>
<tr>
<td>An end-to-end solution that mirrors, and is a substitute for, the physical layer frequency distribution schemes of SONET/SDH.</td>
</tr>
<tr>
<td><strong>IEEE 1588-2008 (PTP)</strong></td>
</tr>
<tr>
<td>Layer 2/3 time transfer technology that can deliver frequency and time. Alternative to SyncE for frequency distribution.</td>
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# Time/Phase Delivery Strategies

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IEEE 1588-2008 Profiles

IEEE 1588-2008 ...

- 2008 defined for all applications ... barrier to interoperability
- profiles define application related features from the full specification, enabling interoperability

Default Profile
Defined in Annex J. of 1588 specification
LAN/Industrial Automation Application (v1)

Power Profile
Defined by IEEE PSRC (C37.238)
Substation LAN Applications

Telecom Profile
Defined by ITU-T (G.8265.1)
Telecom WAN Applications

1588™
IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems
IEEE Instrumentation and Measurement Society
Sponsored by the Technical Committee on Sensor Technology (TC-9)
IEEE 1588™ Standard (Revision of IEEE Std 1588-2002)
31 July 2008
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What is IEEE 1588?

- IEEE 1588 is a protocol that enables precise distribution of time and frequency over packet-based networks.
- IEEE 1588 was originally for a building/factory, and version-2008 contains enhancements for Telecommunication networks (Telecomm Profile).
- The “Server” clock sends a series of messages to slaves to initiate the synchronization process. Clients synchronize themselves to their Server.
- *Network equipment manufacturers are building slaves (clients) into their latest equipment, e.g. IP DSLAM, OLT, and eNodeB (LTE base stations).*
IP Sync & Timing with IEEE-1588

• Any service where synchronization over Ethernet is needed, such as:
  ▪ Wireless Ethernet backhaul (base station synchronization), below
  ▪ Packet PRS - primary reference over IP (IP equivalent of derived OC-N)
  ▪ Enterprise applications requiring synchronization
Extra slides that may be of use
How Is Precision Possible?

- **Message Exchange Technique**
  - Frequent “Sync” messages broadcast between master & slaves, and
  - delay measurement between slaves and master

- **Hardware-Assisted Time Stamping**
  - Time stamp leading edge of IEEE 1588 message as it passes between the PHY and the MAC
  - Removes O/S and stack processing delays

- **Best Master Clock (BMC) Algorithm**
IEEE 1588-2008 Traffic Impact

Message Packet Sizes

- Signaling (request) 96 bytes (54)
- Signaling (ACK/NACK) 98 bytes (56)
- Announce message 106 bytes (64)
- Sync message 86 bytes (44)
- Follow_Up message 86 bytes (44)
- Delay_Req(uest) 86 bytes (44)
- Delay_Resp(ONSE) 96 bytes (54)

In-band Traffic Rate

Using the following typical values:

- Announce interval 1 per second
- Sync interval 64 per second
- Lease duration 300 seconds
- Delay_Req(uest) 64 per second
- Delay_Resp(ONSE) 64 per second

Peak traffic transmitted in one second:

\[(96 \times 3) + (98 \times 3) + 106 + 64 \times (86 + 96 + 86)\]

= 17840 bytes

= 0.017% of Fast Ethernet (100mbps)

= 0.00166% of GigE

() 1588 only message size in bytes
Introducing IEEE 1588 Elements

- **Ordinary Clocks**
  Grandmaster & Slave (client)

- **Boundary Clock**
  Regenerates PTP message, eliminating earlier path delays
  (Switch with a built-in clock)

- **Transparent Clock**
  Adjusts the *correction field* in the *sync* and *delay_req* event messages
  (Switch with ability to measure packet residence time)

- **Management Node**
  Human/programmatic interface to PTP management messages
On-Path Support

- **Transparent Clock**, Switch not a Clock
  - Measures 1588 packet delay inside the switch (residence time)
  - Modifies (adds) residence time to the *correction field* in the 1588 message
  - Limited to non-encrypted networks
  - *Correction field* must be accurate

- **Boundary Clock**, Switch with built-in clock
  - Internal clock synchronized via 1588 to the upstream master
  - Regenerates 1588 messages
  - Slave on 1 port, master on other ports
  - Interrupts the Sync flow
  - The burden of holdover, reliability and traceability is on the boundary clock
IEEE 1588-2008 Message Overview

The Grandmaster (Server) sends the following messages:

- **Signaling** (2 types)
  - Acknowledge TLV (ACK)
  - Negative Acknowledge TLV (NACK)
- **Announce** message
- **Sync** message
- **Follow_Up** message
- **Delay_Resp** (onse)

The Slave (Client) sends the following messages:

- **Signaling** (3 types)
  - Request announce
  - Request sync
  - Request delay_response (onse)
- **Delay_Req** (uest)

Message Headers entering the PHY are the “on-time” marker
IEEE 1588 Routing Options

Multicast
- Grandmaster broadcasts PTP packets to a Multicast IP address
- Switches/Routers...
  - With IGMP snooping, forwards multicast packets to subscribers
  - Else traffic broadcast to all ports
- Multicast Sync Interval; Default Profile:
  - 0.5 Hz, 1Hz & 2 Hz (1 packet/2 seconds up to 2 packets/second)

Unicast
- Grandmaster sends PTP packets directly to PTP slaves
- Switches/Routers forward PTP packets directly to slaves
- Unicast Sync Interval; Telecom Profile:
  - User defined Sync interval up to 128Hz
  - Many subscribers supported
## SLA for PTP Flow

<table>
<thead>
<tr>
<th>Bandwidth Capacity</th>
<th>Maximum Loading</th>
<th>Intermittent Congestion</th>
<th>QoS</th>
<th>Hop Count</th>
<th>Switch Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum 1GigE (Core)</td>
<td>80% Average</td>
<td>100% load for less than 100s</td>
<td>Highest Priority</td>
<td>Frequency (10 hops)</td>
<td>Hardware Forwarding</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time (5 hops)</td>
<td>QoS</td>
</tr>
</tbody>
</table>

### Jitter (Highest Priority Traffic QoS)

250 us to 10 ms  PTP client algorithms use only a fraction of total packets, the ones with the best quality (low PDV). Packets with high PDV are not used. So high jitter can be tolerated if the distribution of the jitter includes sufficient high quality packets.
SyncE Overview

What is Synchronous Ethernet?
- Schema that transports frequency at the Ethernet physical layer
- Implemented in the IP transport element hardware, i.e. SyncE enabled
- End to End scheme similar to SONET, synch traceable to office PRS
- All switches must be SyncE enabled to transport synchronization
- ITU-T G.8261, G.8262 and G.8264 define Synchronous Ethernet
SyncE Overview

How is SyncE different from normal Ethernet?

Standard Ethernet PHY (Physical Layer)

- Rx uses the incoming line time. Tx uses the built-in 100ppm clock
- *No relationship between the Rx & Tx*

SyncE PHY (Physical Layer)

- Rx disciplines the internal oscillator (4.6ppm)
- Tx uses the traceable clock reference, creating end-end scheme
- As with SONET the PRS provides the reference
- SyncE and standard Ethernet switches cannot be mixed
• Extra slides that may be of use.
### Commonly Used Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary clock</td>
<td>A boundary clock is a clock with more than a single PTP port, with each PTP port providing access to a separate PTP communication path. Boundary clocks are used to eliminate fluctuations produced by routers and similar network elements.</td>
</tr>
<tr>
<td>Clock</td>
<td>A device providing a measurement of the passage of time since a defined epoch. There are two types of clocks in 1588: boundary clocks and ordinary clocks.</td>
</tr>
<tr>
<td>Clock timestamp point</td>
<td>1588 requires the generation of a timestamp on transmission or receipt of all 1588 Sync and Delay_Req messages. The point in the outbound and inbound protocol stacks where this timestamp is generated is called the clock timestamp point.</td>
</tr>
<tr>
<td>Direct communication</td>
<td>The communication of PTP information between two PTP clocks with no intervening boundary clock is termed a direct communication.</td>
</tr>
<tr>
<td>External synchronization</td>
<td>It is often desirable to synchronize a single clock to an external source of time, for example to a GPS system to establish a UTC time base. This synchronization is accomplished by means other than those specified by 1588 and is referred to as external synchronization.</td>
</tr>
<tr>
<td>Epoch</td>
<td>The reference time defining the origin of a time scale is termed the epoch.</td>
</tr>
<tr>
<td>Grandmaster clock</td>
<td>Within a collection of 1588 clocks one clock, the grandmaster clock, will serve as the primary source of time to which all others are ultimately synchronized.</td>
</tr>
</tbody>
</table>

# Commonly Used Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master clock</td>
<td>A system of 1588 clocks may be segmented into regions separated by boundary clocks. Within each region there will be a single clock, the master clock, serving as the primary source of time. These master clocks will in turn synchronize to other master clocks and ultimately to the grandmaster clock.</td>
</tr>
<tr>
<td>Message timestamp point</td>
<td>1588 Sync and Delay_Req messages contain a distinguished feature, the message timestamp point, serving as a reference point in these messages. When the message timestamp point passes the clock timestamp point, a timestamp is generated that is used by 1588 to compute the necessary corrections to the local clock.</td>
</tr>
<tr>
<td>Ordinary clock</td>
<td>A clock that has a single Precision Time Protocol (PTP) port in a domain and maintains the timescale used in the domain. It may serve as a source of time, i.e., be a master clock, or may synchronize to another clock, i.e., be a slave clock.</td>
</tr>
<tr>
<td>Preferred master clock set</td>
<td>1588 allows the definition a set of clocks that will be favored over those not so designated in the selection of the grandmaster clock.</td>
</tr>
<tr>
<td>PTP</td>
<td>PTP is an acronym for Precision Time Protocol, the name used in the standard for the protocol.</td>
</tr>
<tr>
<td>PTP domain</td>
<td>A PTP domain is a collection of one or more PTP sub domains. A sub domain is a logical grouping of 1588 clocks that synchronize to each other using the PTP protocol, but that are not necessarily synchronized to PTP clocks in another PTP sub domain. Sub domains provide a way of implementing disjoint sets of clocks, sharing a common network, but maintaining independent synchronization within each set.</td>
</tr>
</tbody>
</table>

Commonly Used Terms

<table>
<thead>
<tr>
<th>Meanings of common terms used in IEEE 1588</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PTP message</strong></td>
</tr>
<tr>
<td><strong>Multicast communication</strong></td>
</tr>
<tr>
<td><strong>PTP port</strong></td>
</tr>
<tr>
<td><strong>Synchronized clocks</strong></td>
</tr>
</tbody>
</table>

http://ieee1588.nist.gov/terms.htm
### Synchronization Impact

<table>
<thead>
<tr>
<th>Application</th>
<th>Frequency</th>
<th>Phase</th>
<th>Need for Compliance</th>
<th>Impact of Non-compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTE (FDD)</td>
<td>16 ppb</td>
<td>N/A</td>
<td>Hand-off</td>
<td>Dropped calls</td>
</tr>
<tr>
<td>LTE (TDD)</td>
<td>16 ppb</td>
<td>± 1.5 μs Time difference</td>
<td>Time slot alignment</td>
<td>Interference, Bandwidth efficiency</td>
</tr>
<tr>
<td>LTE MBSFN</td>
<td>16 ppb</td>
<td>± 32 μs inter-cell Time difference</td>
<td>Coherent video signal from multiple eNodeB</td>
<td>Video service degradation</td>
</tr>
<tr>
<td>LTE-A MIMO/CoMP</td>
<td>16 ppb</td>
<td>± 0.5 μs inter-cell Time difference</td>
<td>Coordination of signals from multiple eNodeB</td>
<td>Slower throughput and Poor signal quality at edge of cells, Accuracy of LBS</td>
</tr>
</tbody>
</table>
# LTE Synchronization

<table>
<thead>
<tr>
<th>Application</th>
<th>Frequency (Air Interface)</th>
<th>Time /Phase</th>
<th>Why You Need to Comply</th>
<th>Impact of Non-compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTE (FDD)</td>
<td>50 ppb</td>
<td>N/A</td>
<td>Call Initiation</td>
<td>Call Interference Dropped calls</td>
</tr>
<tr>
<td>LTE (TDD)</td>
<td>50 ppb</td>
<td>+/- 1.5 µs Time difference</td>
<td>Time slot alignment</td>
<td>Packet loss/collisions Bandwidth efficiency</td>
</tr>
<tr>
<td>LTE MBSFN</td>
<td>50 ppb</td>
<td>+/- 32 µs inter-cell Time difference</td>
<td>Proper time alignment of video signal decoding from multiple BTSs</td>
<td>Video broadcast interruption</td>
</tr>
<tr>
<td>LTE-A MIMO/COMP</td>
<td>50 ppb</td>
<td>+/- 500 ns (0.5 µs) inter-cell Time difference</td>
<td>Coordination of signals to/from multiple base stations</td>
<td>Poor signal quality at edge of cells</td>
</tr>
<tr>
<td>WiMAX (TDD) includes Femtocell</td>
<td>2 ppm absolute, ~50 ppb between base stations</td>
<td>Typically 1 -8 µs</td>
<td>Time slot alignment</td>
<td>Packet loss/collisions Bandwidth efficiency</td>
</tr>
</tbody>
</table>
## Frequency and Time Specifications

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<thead>
<tr>
<th>Application</th>
<th>Frequency: Transport / Air Interface</th>
<th>Phase</th>
</tr>
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<tbody>
<tr>
<td>GSM / UMTS / W-CDMA</td>
<td>16 ppb / 50 ppb</td>
<td>+/- 1.5 µs</td>
</tr>
<tr>
<td>UMTS/ W-CDMA Femtocells</td>
<td>n/a / 200 - 250 ppb</td>
<td>+/- 3 - 10 µs</td>
</tr>
<tr>
<td>GSM, UMTS, LTE Network Interface</td>
<td>16 ppb / 50 ppb</td>
<td>+/- 1.5 µs</td>
</tr>
<tr>
<td>CDMA2000</td>
<td>16 ppb / 50 ppb</td>
<td>N/A</td>
</tr>
<tr>
<td>TD-SCDMA</td>
<td>16 ppb / 50 ppb</td>
<td>N/A</td>
</tr>
<tr>
<td>LTE (FDD)</td>
<td>16 ppb / 50 ppb</td>
<td>+/- 1.5 µs small cell, +/- 5 µs large cell</td>
</tr>
<tr>
<td>LTE (TDD)</td>
<td>16 ppb / 50 ppb</td>
<td>+/- 1-32 µs, implementation dependent</td>
</tr>
<tr>
<td>LTE MBSFN</td>
<td>16 ppb / 50 ppb</td>
<td>+/- 500 ns (0.5 µs), pre-standard</td>
</tr>
<tr>
<td>LTE-A CoMP (Network MIMO)</td>
<td>16 ppb / 50 ppb</td>
<td>+/- 1 - 8 µs, implementation dependent</td>
</tr>
<tr>
<td>WiMAX (TDD)</td>
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