Synchronization in Packet-based Networks (SyncE & IEEE1588-2008)

Christian Schmutzer

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Agenda

• Motivation for Synchronization in Packet-based Networks
• Frequency and Time Synchronization Overview
• Synchronization Support in Cisco Products
• Deployment Considerations for
  – Industrial Solutions
  – Smart Grid
  – High Frequency Trading
  – Service Providers
• Summary and Conclusion
Motivation for Synchronization in Packet-based Networks
There are two “Things” to synchronize

Frequency and Time
Why do we need to synchronize Frequency?

Frequency Applications

- Avoid Slips on TDM Interfaces (E1/T1, …)
- Make Synchronous Networks work (SONET/SDH)
- 2G an 3G Radio Access Network (RAN) Deployments

RAN … Radio Access Network; TDM … Time Division Multiplexing; 
SONET … Synchronous Optical Network; SDH … Synchronous Digital Hierarchy
Why do we need to synchronize Time?

Time Applications – Mobile Network LTE TDD

1. Ex: Application requirement from 3GPP: ±3μs between BS (WCDMA/LTE TDD)
2. Ex: Network objective: ≤ ±1.5μs from common reference

WCDMA … Wideband Code Division Multiple Access; LTE … Long Term Evolution; TDD … Time Division Duplex
Why do we need to synchronize Time?

Time Applications – Y.1731 Performance Management

NEs must be synchronized (ToD) for one-way delay

ToD … Time of Day; NE … Network Element; MEP … Maintenance End Point
Why do we need to synchronize Time?

Time Applications – Industrial Ethernet

- Traditional Scan-based control operation subject to large input-output jitter
  - Part resolution = 122 msec jitter
  - Maximum speed = 1/122 = ~8 parts/sec
  - Maximum ppm = 8*60 = 480 parts/sec

- Time-based control greatly reduces jitter and maximizes conveyor belt output
  - Part resolution = 12.4 msec jitter
  - Maximum speed = 1/12.4 = ~80 parts/sec
  - Maximum ppm = 80*60 = 4,800 parts/sec

### Jitter or Delay Source

<table>
<thead>
<tr>
<th></th>
<th>Delay</th>
<th>Jitter (Scan-based)</th>
<th>Jitter (Time-based)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>0.2 msec</td>
<td>10 msec</td>
<td>0</td>
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<tr>
<td>Input Network</td>
<td>1 msec</td>
<td>1 msec</td>
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<tr>
<td>Controller</td>
<td>10 msec</td>
<td>100 msec</td>
<td>0</td>
</tr>
<tr>
<td>Output Network</td>
<td>1 msec</td>
<td>1 msec</td>
<td>0</td>
</tr>
<tr>
<td>Output</td>
<td>0.2 msec</td>
<td>10 msec</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>12.4 msec</td>
<td>122 msec</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Rockwell, IEEE
Why you don’t want to rely on GNSS only

Global Navigation Satellite System (GNSS) – aka GPS, COMPASS, Galileo, …

• Reasons for using GPS
  – nearly available everywhere
  – A GPS disciplined oscillator can provide time accurate to within 100ns

• Reasons for not using GPS
  – see statement on www.pnt.gov, from Nov 3rd, 2010
    GPS should not be used as the unique reference in any critical civilian system
  – Reliability (very weak satellite signal)
  – Attacks (jamming and spoofing)
  – Cost of installation
  – Local Distribution (Splitters, Amplifiers, …)
Frequency Synchronization Overview
Frequency – Closer Look

Frequency = 1 / T [Hz]

Interval T [sec]

- Typical External Timing Interfaces
  - 2,048 kHz
  - E1/T1 Framed
  - 10 MHz
- Sine or Square Waves possible

Typically BITS
Pins 1&2 = External Timing Input
Pins 4&5 = External Timing Output

Line Interfaces
1GE, 10GE, …
Two clocks are **frequency synchronized** if the frequency of the two clocks have a common denominator.

Two clocks are called **plesiochronous** if the difference in their common denominator is bounded.

The difference in **position of rising edges** of the clocks is called **phase offset**.

Two common frequencies which have constant phase offset are **phase-locked and implicitly frequency synchronized**.
Frequency Distribution

Physical or Packet Layer distributing Frequency

SEC … Synchronous Equipment Clock; EEC … Ethernet Equipment Clock; SSM … Synchronous Status Messaging
ESMC … Ethernet Synchronous Messaging Channel; PTP … Precision Time Protocol
Physical Layer Frequency Distribution

- The timing signal is typically implemented as a periodic digital signal.
- Rate: 8 kHz to 100’s of MHz
**Significant Instants – Physical Distribution**

Timing Signal and Noise

- **Timing signal**
- **Significant instants**
- **Timing jitter at wander**
- **Rate**: 8 kHz to 100's of MHz

Example: 25 MHz signal

Source: ITU-T G.8260 (201007)
Packet-based Frequency Distribution

Adaptive Clock Recovery (ACR) or IEEE1588 Precision Time Protocol (PTP)

- Three key steps:
  - **Generation**: from physical signal to packet
  - **Transfer**: timing events (frame or packet flow) transmission over packet network
  - **Recovery**: from packet-based signal to physical signal
Significant Instants Packet-based Distribution

Source: ITU-T G.8260 (201007)

Rate: typical 1-64 Hz

- Timing signal could either be
  - periodic (e.g., CES) or
  - aperiodic (e.g., NTP, PTP) with

- Additional information (e.g., timestamps) defining the ideal position in time of the significant instant relative to a master time scale.

CES … Circuit Emulation Service; NTP … Network Time Protocol
Typical Router/Switch Architecture

Packet Delay Variation (PDV): $\text{prop\_time\_pkt\#n} \neq \text{prop\_time\_pkt\#m}$

Asymmetry: $\text{prop\_time} \neq \text{prop\_time}$
Equipment Packet Delay Variation

Traffic Load & QoS

- Each equipment will have its own PDV (and asymmetry) signature.

**X-axis:** number of observed packets  
**Y-axis:** packet delay from the minimum delay observed during measurement
Packet-based Timing Slave Recovery

Three major Tasks

1. Classify the packets
2. Select the “good” packets depending on network conditions
3. Process the “good” packets to recover clock

Packet-based timing Flow

Reference Clock

Packet master

Packet Slave

Recovered Clock

XO ... Oscillator; PLL ... Phase Locked Loop
Clock Selection inside the Network Element

SETS - Synchronous Equipment Timing Source

Network Element (NE)

- SETG … Synchronous Equipment Timing Generator (PLL - Phase Locked Loop)
- Three Selector table to control
  - System Frequency
  - Output Interface Frequency
### Quality Level & Traceability

#### Quality Level Comparison

<table>
<thead>
<tr>
<th>SSM QL</th>
<th>G.781</th>
<th>ESMC</th>
<th>PTP Clock Class</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Option I</td>
<td>Option II</td>
<td>Option I</td>
</tr>
<tr>
<td>0001</td>
<td>QL-PRS</td>
<td></td>
<td></td>
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<tr>
<td>0000</td>
<td>QL-STU</td>
<td></td>
<td></td>
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<tr>
<td>0010</td>
<td>QL-PRC</td>
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<td></td>
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<td>0111</td>
<td>QL-ST2</td>
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<tr>
<td>0011</td>
<td></td>
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<td>0100</td>
<td>QL-SSU-A</td>
<td>QL-TNC</td>
<td></td>
</tr>
<tr>
<td>0101</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0110</td>
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<tr>
<td>1000</td>
<td>QL-SSU-B</td>
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<tr>
<td>1001</td>
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<td>1101</td>
<td>QL-ST3E</td>
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<td>1010</td>
<td>QL-ST3</td>
<td>QL-ECC2</td>
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<td>QL-ECC1</td>
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<td>1100</td>
<td>QL-SMC</td>
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<td>1110</td>
<td>QL-PROV</td>
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<tr>
<td>1111</td>
<td>QL-DNU</td>
<td>QL-DUS</td>
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</table>
Quality Level & Traceability
Determining the best available Clock

What clock signal shall I use?

QL-Disabled Mode
1. External commands
2. Signal Failure
3. Local Priority (per interface)

QL-Enabled Mode
1. External commands
2. Quality level
3. Signal Failure
4. Local Priority (per interface)

References: ITU-T G.871 / G.8261 and Telcordia GR-253-CORE
QL … Quality Level
Physical Signal Re-Generation

Frequency Distribution

• Deliver recovered Clock to External Timing Interface
• For example:
  – E1/T1, 2,048kHz, 2,048kbps/1,544kbps

![Physical Timing Chain Diagram]

- Reference Clock
- PSN
- Packet-based timing Flow
- G.823/G.824/G.8261/G.8265
- SEC/EEC for timing distribution
- Clock stability quantities
- Physical layer timing interface
Frequency Accuracy

Reference signal (e.g. 10 MHz signal)

Received or recovered signal

1ns Phase offset

1 second observation period

Frequency offset = \Delta \text{Time} / \text{Time}

= 1 \text{ ns} / 1 \text{ second}

= 1 \times 10^{-9} = 1 \text{ ppb}

Frequency accuracy is a long-term measurement based on the \textit{average} phase accumulation over time.

Other examples:
• 50 µs / 1 second = 50 \times 10^{-8} = 0.05 \text{ ppb} = 50 \text{ ppm}
• 1 µs / 100 seconds = 1 \times 10^{-5} = 10 \text{ ppb}
Frequency Distribution Metric (Wander)

Calculations based on Phase Error Measurements

- **TIE (Time Interval Error)**
  - Phase Difference measured in ns
  … indicates Accuracy at certain Moment

- **MTIE (Maximum TIE)**
  - Largest Peak-to-Peak TIE for a particular Observation Interval
  … indicates Accuracy & Stability

- **TDEV (Time Deviation)**
  - Route Mean Square of Bandpass filtered TIE (statistical representation of TIE variance)
  … indicates Systematic Effects

TIE and MTIE

Phase Error and “Peak to Peak” Detection

Peak-Peak Detection for each Observation Interval $\tau$

MTIE does start at 8ns due to TIE transient at $T=30$ sec

TIE and TDEV

Statistical Measure & Spectral Content of Wander

• For TDEV of $\tau = X$ sec you normally need TIE measurement for around $3*X$ sec

Source: [http://users.rcn.com/wpacino/jitwtutr/jitwtutr.htm](http://users.rcn.com/wpacino/jitwtutr/jitwtutr.htm)
Validating Frequency Distribution

Typical Test Setup

Masks per G.823/G.824/G.8261
Time Synchronization Overview
Time – A closer Look
Time = Phase + Time of Day

*13:38:54.805 UTC Mon Apr 2 2012

Time of Day (TOD) Information
(serial interface on the RJ45 connector)

1PPS Pulse → Phase
(analog signal on the DIN connector)
Time of Day Formats

- Many different Formats available
  - NTP
  - Cisco
  - ISO8601
  - NMEA
  - UBX
- ...
Time Distribution

Packet Layer distributing Phase & Time of Day

Time Source ToD & 1PPS

Recovered Time ToD & 1PPS

See also ITU-T G.8260
Introduction to IEEE1588-2008

• Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

• Precision Time Protocol (PTP) is, like NTP, a Two Way Time Transfer protocol (TWTT).

• PTP has been designed to obtain accuracies down to the nanoseconds … if every elements are correctly implemented.

• IEEE 1588 has been originally specified for plug-and-play time synchronization solution.

• Original interest for telecom because dedicated standard and “precision” marketing.
IEEE Std 1588-2008 Clocks

- OC has unique PTP port, either slave or master (defines clock state).
- As network intermediate nodes, BC and TC aim correcting delay variations, in both directions (asymmetry).

Reference Clock

Ordinary Master

Slave

Master

Boundary Clock

Transparent Clock

Ordinary Slave

Recovered Clock

PTP
PTP v2 Messages and Transmission

- A set of event messages consisting of:
  - Sync
  - Delay_Req
  - Pdelay_Req
  - Pdelay_Resp

- Mappings: L2 Ethernet, IPv4, IPv6 (others possible)

- Transmission modes: either unicast or multicast (can be mixed)

- Variable rate and timeout values

- Various TLVs and flexible TLV extensions

- A set of general messages consisting of:
  - Follow_Up
  - Delay_Resp
  - Pdelay_Resp_Follow_Up
  - Announce
  - Signaling
  - Management

- Mappings: L2 Ethernet, IPv4, IPv6 (others possible)

- Transmission modes: either unicast or multicast (can be mixed)

- Variable rate and timeout values

- Various TLVs and flexible TLV extensions
**TWTT Protocol Basics**

**Basic PTP Message Exchange**

Master time = \( T_M \)

Slave time = \( T_S = T_M + \text{offset} \)

Offset = \( T_S - T_M \)

\[ \text{Delay - Offset} = B = t_4 - t_3 \]

\[ t_1, t_2 \]

\[ t_1, t_2, t_3 \]

\[ t_1, t_2, t_3, t_4 \]

\[ \text{Delay} = \frac{(t_2 - t_1) + (t_4 - t_3)}{2} \]

\[ \text{Offset} = \frac{((t_2 - t_1) - (t_4 - t_3))}{2} \]
Physical Signal Re-Generation

Time Distribution

• Deliver recovered Clock to External Timing Interface
• For example:
  – Time of Day (RJ48C, RS232/RS422)
  – Phase (DIN, 1PPS)
Phase Synchronization Accuracy

Reference A
(E.g., 1 PPS)

Reference B
(or recovered from A)

Phase error (accuracy)

Phase accuracy requirement defines the maximum deviation relative to the reference

+0.5 µs

- 1 µs
Typical Test Setup

Evaluating Impact of Hop Count & Network Load

Master

Traffic Generator 402-2

Simulated Network Load

Packet Network

Slave

Traffic Generator 402-3

PTP Session

Hop 1

Hop 2

Hop 3

Hop 4

Hop n

ToD

1PPS

E1

Frequency Counter or Oscilloscope

Frequency Verification

Phase Verification

ANT-20

10MHz

1PPS

PTP Session

Frequency Verification

RS422 Console

1PPS

E1
Synchronization Support in Cisco Products
### Cisco Industrial Ethernet Products

<table>
<thead>
<tr>
<th>Hardware</th>
<th>SW Version</th>
<th>Supported Clock Modes</th>
<th>PTP Transport Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>IE3000 Rockwell Stratix 8000</td>
<td>12.2(46)SE1</td>
<td>Boundary Clock E2E Transparent Clock “Forward Mode”</td>
<td>IPv4 Multicast</td>
</tr>
<tr>
<td>IE3010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE2000 Rockwell Stratix 5700</td>
<td></td>
<td></td>
<td>IPv4 Multicast</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hardware</th>
<th>SW Version</th>
<th>Supported Clock Modes</th>
<th>PTP Transport Options</th>
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<tr>
<td></td>
<td></td>
<td>Boundary Clock E2E Transparent Clock “Forward Mode”</td>
<td></td>
</tr>
</tbody>
</table>

1) Configure “passthrough” to enable PTP on Expansion Modules
2) PTP Packets are not processed by the Switch, treated as normal IP Packets

E2E … End 2 End
P2P … Peer 2 Peer

- IE3000 Rockwell Stratix 8000
- IE3010
- IE2000 Rockwell Stratix 5700

- Hardware is IEEE1588-2008 ready
- Software Support to be added in the future

- Cisco Models ending with “-E”
- Rockwell Models with “P”
# Cisco Smart Grid Products

<table>
<thead>
<tr>
<th></th>
<th>CGS2520</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hardware</strong></td>
<td>Both Copper only and SFP Model</td>
</tr>
<tr>
<td><strong>SW Version</strong></td>
<td>12.2(58)EY</td>
</tr>
</tbody>
</table>
| **Supported Clock Modes** | Boundary Clock  
|                   | E2E Transparent Clock  
|                   | P2P Transparent Clock  
|                   | “Forward Mode” 1) |
| **PTP Transport Options** | Layer 2  
|                  | IPv4 Multicast |

1) PTP Packets are not processed by the Switch, treated as normal IP Packets
High Frequency Trading

Support for
1. PONG
2. ERSPAN type3

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Nexus 3000</th>
<th>Nexus 5500</th>
<th>Nexus 7000</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW Version</td>
<td>NX-OS 5.0(3)U2(2)</td>
<td>NX-OS 5.2(1)N1(1)</td>
<td>NX-OS 5.2</td>
</tr>
<tr>
<td>Supported Clock Modes</td>
<td>Boundary Clock</td>
<td>Boundary Clock</td>
<td>Boundary Clock</td>
</tr>
<tr>
<td>PTP Transport Options</td>
<td>IPv4 Multicast</td>
<td>IPv4 Multicast</td>
<td>IPv4 Multicast</td>
</tr>
</tbody>
</table>
PONG

Determining Network Latency from CLI

```bash
switch(config)# pong source 001b.54c2.9a41 destination 001b.54c2.9a43 vlan 1 count 2
```

### Packet No. 1

<table>
<thead>
<tr>
<th>Hop</th>
<th>Switch-id</th>
<th>Switching time (sec, nsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>01b-54-c2-9a-42</td>
<td>0 4800</td>
</tr>
<tr>
<td>2</td>
<td>01b-54-c2-9a-43</td>
<td>0 5920</td>
</tr>
<tr>
<td>3</td>
<td>01b-54-c2-9a-42</td>
<td>0 4848</td>
</tr>
<tr>
<td>4</td>
<td>01b-54-c2-9a-41</td>
<td>0 6488</td>
</tr>
</tbody>
</table>

Round trip time: 0sec 22056 nsec

### Packet No. 2

<table>
<thead>
<tr>
<th>Hop</th>
<th>Switch-id</th>
<th>Switching time (sec, nsec)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>01b-54-c2-9a-42</td>
<td>0 4792</td>
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<td>2</td>
<td>01b-54-c2-9a-43</td>
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<td>3</td>
<td>01b-54-c2-9a-42</td>
<td>0 4816</td>
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<tr>
<td>4</td>
<td>01b-54-c2-9a-41</td>
<td>0 7120</td>
</tr>
</tbody>
</table>

Round trip time: 0sec 22640 nsec
ERSPAN Type III

Determining Network Latency using a Latency Analyzer

Latency = TS3-TS1, TS3-TS2, TS2-TS1

IEEE1588 derived TimeStamp
## Cisco SP Product Portfolio

### Physical Layer Frequency Distribution (SyncE)

<table>
<thead>
<tr>
<th>Traffic Interfaces</th>
<th>ASR9000</th>
<th>Cisco7600</th>
<th>ASR903</th>
<th>ME3600X/3800X</th>
<th>MWR2941/ASR901</th>
</tr>
</thead>
<tbody>
<tr>
<td>STM-1/4/16/64</td>
<td>E1/T1</td>
<td>E1/T1</td>
<td>E1/T1</td>
<td>E1/T1</td>
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<tr>
<td>OC-3/12/48/192</td>
<td>STM-1/4</td>
<td>STM-1/4</td>
<td>STM-1</td>
<td>STM-1</td>
<td>1GE</td>
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<tr>
<td>1GE²</td>
<td>OC-3/12</td>
<td>OC-3/12</td>
<td>OC-3</td>
<td>OC-3</td>
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<tr>
<td>10GE (LAN &amp; WAN)</td>
<td>10GE (LAN &amp; WAN)</td>
<td>10GE (LAN &amp; WAN)</td>
<td>10GE (LAN only)</td>
<td>10GE (LAN only)</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>External Timing Interfaces</th>
<th>ASR9000</th>
<th>Cisco7600</th>
<th>ASR903</th>
<th>ME3600X/3800X</th>
<th>MWR2941/ASR901</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input/Output 2048kHz/2048kbps/44kbps/10MHz³</td>
<td>Input/Output 2048kHz/2048kbps/154kbps/10MHz</td>
<td>Input/Output 2048kHz/2048kbps/154kbps/10MHz</td>
<td>Input/Output 2048kHz/2048kbps/154kbps</td>
<td>Input/Output 2048kHz/2048kbps/154kbps/10MHz⁴</td>
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</tr>
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</table>

<table>
<thead>
<tr>
<th>SSM</th>
<th>ASR9000</th>
<th>Cisco7600</th>
<th>ASR903</th>
<th>ME3600X/3800X</th>
<th>MWR2941/ASR901</th>
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<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>IOS XR 3.9</td>
<td>IOS 15.0(1)S</td>
<td>IOS 15.1(2)EY</td>
<td>IOS 15.0(1)MR</td>
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</tr>
</tbody>
</table>

1) SyncE is not supported with 1GE Copper SFPs      3) 10MHz on RSP440 only    4) 10MHz on ASR901 only
2) SyncE in+out support on Fiber SFPs and 1GE Copper Interface Module   5) ME3600X-24CX only

---

ITU-T G.8262 Compliance today
## Cisco SP Product Portfolio

### Packet Layer Frequency & Time Distribution (IEEE1588)

<table>
<thead>
<tr>
<th></th>
<th>ASR9000</th>
<th>Cisco7600</th>
<th>ASR903</th>
<th>ME3600X-24CX</th>
<th>MWR2941</th>
<th>ASR901</th>
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</thead>
<tbody>
<tr>
<td><strong>Hardware</strong></td>
<td>RSP440 &amp; 2nd Gen Linecards</td>
<td>SIP-400 SYNCE-SPA</td>
<td>All Interfaces</td>
<td>All Interfaces</td>
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<tr>
<td><strong>SW Version</strong></td>
<td>IOS XR 4.2.0</td>
<td>IOS 15.0(1)S</td>
<td>IOS XE 3.5</td>
<td>IOS 15.2(4)S</td>
<td>IOS 12.4(19)MR2 ²</td>
<td>IOS 15.1(2)SNG³</td>
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<tr>
<td><strong>Supported Clock Modes</strong></td>
<td>Ordinary Master</td>
<td>Ordinary Master</td>
<td>Ordinary Master</td>
<td>Ordinary Master</td>
<td>Ordinary Slave</td>
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<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IPv4 Mixed Multicast</td>
<td>IPv4 Mixed Multicast</td>
<td>IPv4 Mixed Multicast</td>
<td>IPv4 Mixed Multicast</td>
<td>IPv4 Mixed Multicast</td>
</tr>
</tbody>
</table>

1) MWR2941 only 2) First release to support PTP on MWR2941 3) First Release to support PTP on ASR901

ITU-T G.8265.1 Telecom Profile planned
External Timing Interfaces

Frequency and Time

ASR901

ME3600X/ME3800X

2048kHz
2048kbps / 1544kbps

1PPS

ToD

ASR9000 RSP-440

ASR903 RSP1

10MHz
ASR9000 Synchronization Architecture

- **Frequency Selection**
  - PTP Stack and Servo Algorithm
  - Encoder

- **Ingress Linecard**
  - RSP0
  - DTI/UTI
  - BITS #0
  - BITS #1
  - 10MHz
  - 1PPS
  - ToD
  - PTP Packets
  - ETH

- **Egress Linecard**
  - RSP1
  - DTI/UTI
  - BITS #0
  - BITS #1
  - 10MHz
  - 1PPS
  - ToD
  - PTP Packets
  - ETH

- **Hardware based Time Stamping**
  - MAC
  - NPU
  - DPLL
  - N:2

- **Prim & Sec**
  - 2x

- **Distributed PTP Packet Generation**
  - CPU
  - ETH
  - ETH
ASR903 Synchronization Architecture

Centralized PTP Packet Generation

Ingress Interface Module (IM)

PTP Packets

Egress Interface Module (IM)

PTP Packets

Hardware based Time Stamping

sets

PTP

10MHz

1PPS

ToD

10MHz

1PPS

ToD

RSP0

Frequency Selection

PTP Stack and Servo Algorithm

RSP1

sets

PHY

PHY

PHY

ETH

ETH

CPU

DPLL

N:2

PHY

PHY

PHY

ETH

ETH

CPU

DPLL

N:2

1pps

ToD

1pps

ToD

1pps

ToD

2x

2x

PTP Packets

Centralized PTP Packet Generation

PTP Stack and Servo Algorithm

Frequency Selection

PHY

ETH

N:2

CPU

DPLL

PTP Packets

ETH

ETH

CPU

DPLL

PTP Packets

ETH

ETH

CPU

DPLL

PTP Packets

ETH

ETH

CPU

DPLL

PTP Packets

ETH

ETH

CPU

DPLL

PTP Packets

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PTP Packets

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PTP Packets

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ETH

CPU

DPLL

PTP Packets

ETH

ETH

CPU

DPLL

PTP Packets

ETH

ETH

CPU

DPLL

PTP Packets

ETH

ETH

CPU

DPLL

PTP Packets
Deployment Consideration
# IEEE1588-2008 Profiles

## Application specific Parameter Definition

<table>
<thead>
<tr>
<th></th>
<th>IEEE1588 Default Profiles</th>
<th>ITU G.8265.1 Telecom Profile</th>
<th>Frequency</th>
<th>IEEE C37.238 Power Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Segment</strong></td>
<td>Industrial Solutions</td>
<td>2G Mobile RAN</td>
<td></td>
<td>Smart Grid</td>
</tr>
<tr>
<td></td>
<td>High Speed Trading</td>
<td>3G Mobile RAN</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Profile ID / Version</strong></td>
<td>00-19-A7-00-01-00 / v1.0</td>
<td>00-19-A7-00-01-00 / v1.0</td>
<td></td>
<td>1C-12-9D-00-00-00 / v1.0</td>
</tr>
<tr>
<td></td>
<td>00-19-A7-00-02-00 / v2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PTP Modes</strong></td>
<td>One-way &amp; two-way</td>
<td>One-way &amp; two-way</td>
<td></td>
<td>Two-way</td>
</tr>
<tr>
<td></td>
<td>One-step &amp; two-step</td>
<td>One-step &amp; two-step</td>
<td></td>
<td>One-step &amp; two-step</td>
</tr>
<tr>
<td><strong>PTP Transport</strong></td>
<td>IPv4 &amp; Layer 2 Multicast</td>
<td>IPv4 Unicast Negotiation</td>
<td></td>
<td>Layer 2 Multicast</td>
</tr>
<tr>
<td><strong>Master Selection</strong></td>
<td>BMCA</td>
<td>Alternate BMCA</td>
<td></td>
<td>BMCA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• QL (Clock Class)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• PTSF</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Local Priority</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Path Delay Mechanism</strong></td>
<td>Delay request/response</td>
<td>Delay request/response</td>
<td></td>
<td>Peer-to-Peer</td>
</tr>
<tr>
<td></td>
<td>Peer-to-Peer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Management Option</strong></td>
<td>Mgmt Message per Clause 15</td>
<td>not specified</td>
<td></td>
<td>IEEE C37.238 MIB</td>
</tr>
<tr>
<td><strong>Node Types</strong></td>
<td>Ordinary Master/Slave, Boundary and Transparent</td>
<td>Ordinary Master and Slave</td>
<td></td>
<td>Ordinary Master/Slave, Boundary and Transparent</td>
</tr>
</tbody>
</table>

**BMCA** … Best Master Clock Algorithm   **QL** … Quality Level   **PTSF** … Packet Timing Signal Fail
# IEEE1588-2008 Profiles

**Application specific Parameter Definition**

<table>
<thead>
<tr>
<th></th>
<th>IEEE1588 Default Profiles</th>
<th>ITU G.8265.1 Telecom Profile Frequency</th>
<th>IEEE C37.238 Power Profile</th>
</tr>
</thead>
</table>
| **Goals** | • Plug & Play Deployment  
            • CIP Sync  | • Based on ITU-T G.8265 Architecture  
            • Interoperability with SONET/SDH & SyncE  
            • WAN Operation  
            • Fixed Arrangement  | • Performance Parameter Mapping for  
                               o IEC61850  
                               o C37.118  
                               o IRIG-B  |
| **Application** | • Migrate Motion Control Systems from Scan or Event based to a Time based to improve Throughput  | • Frequency Distribution in Service Provider Packet Networks  | • Time Distribution to IED without Distance Limitations  
                               • Timestamping of SCADA Data  
                               • IRIG-B replacement  |
| **Status** | • In force  | • In force  | • In force  |

**Time Distribution in Service Provider Networks (i.e. LTE TDD)**

**ITU G.8275.1 Telecom Profile Time**

In force

In force

In force

In development
Deployment Consideration for High Frequency Trading
Typical Execution Venue Architecture

Providing Timing as a Service
Time Services are already evolving

**Timing Overlay Network**

- GM Clock with GPS Input
- L2 Switch (Fan-out)
- L2 Switches
- Server w/ PTP Clients
- IE 3000 For Time Distribution
- Boundary Clock

**Data Network**

- L2 Switches
- Server w/ PTP Clients
- Boundary Clock

**Integrated Network**

- GM Clock with GPS Input
- Nexus 3000 With Time Distribution
- Nexus 7000 With Time Distribution
- Nexus 3000 With Time Distribution
- Server w/ PTP Clients
- Boundary Clock

---

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Precision timing is fundamental for today's DC infrastructure. This session describes why a sub-microsecond timing solution is needed for today's financial trading application and data center fabric, and how to design and implement IEEE1588v2 Precision Time Protocol (PTP), a distributed nanosecond accuracy timing synchronization protocol with Nexus switches. The session also shows some examples on how the network infrastructure and application can benefit from this nanosecond accuracy timing solution.

Thursday 14th June, 8.00am, 90 min
Deployment Consideration for Industrial Solutions
Plantwide Network Architectures

Cisco Convergence Plantwide Ethernet (CPwE) Architecture
Machine Solutions – CPwE 2.2

E2E Transparent Clock – Cisco IE3000 & Rockwell Stratix 8000

Diagram showing Layer 2 Switched Ring, GPS Antenna, and various clock configurations, including GrandMaster Clock, Slave Clock, and E2E Transparent Clock.
Cisco IE3000 E2E Transparent Clock

Configuration Example

```
interface gig 1/1
  no ptp enable

ptp mode e2etransparent

Global PTP Configuration
```

```
Ordinary Master (GM)

interface gig 1/1
  no ptp enable

Interface PTP Parameters

Default=enabled
```

```
Ordinary Slave
```

```
Announce

Sync

Follow-Up

Residency Time 1

Residency Time 2

Del-req

TC

Follow-Up

Del-Resp

Ordinary Slave
Cisco IE3000 Boundary Clock

Configuration Example

Ordinary Master (GM)
- Announce (GM dependent)
- Sync (GM dependent)
- Follow-Up (1 per Sync)
  - Del-req (1 every $2^5=32$ sec)
  - Del-Resp (1 per Del-Req)

Ordinary Slave
- Announce (1 every $2^1=2$ sec)
- Sync (1 every $2^0=1$ sec)
- Follow-Up (1 per Sync)
  - Del-req (Slave dependent)
  - Del-Resp (1 per Del-Req)

Interface PTP Parameters for Slave Ports
- interface gig 1/1
- ptp sync limit <50..500000000>
- ptp delay-req interval <1..6>
- ptp announce timeout <2..10>

Interface PTP Parameters for Master Ports
- interface gig 1/1
- ptp announce interval <0..4>
- ptp sync interval <1..1>

Global PTP Configuration
- ptp domain <0..255>
- ptp mode boundary
- ptp priority1 <0..255>
- ptp priority2 <0..255>

PTP enabled per default

Default=50000

Default=128

Default=0, user-defined up to 127
Cisco IE3000 Expansion Modules

All PTP Packets to be passed to Base Module

Per default PTP is only enabled on the Base Module Ports

Enables PTP for Expansion Module Ports
Deployment Consideration for Smart Grid
Wire Area Measurement System (WAMS)

• Why WAMS?
  – Provide accurate measurement of grid state across broad regions of the transmission grid
  – Provides added grid monitoring and (eventually) real time protection & control using Phasor Measurement Units (PMUs)
  – Remediates frequency oscillations, disturbances before they cascade

• Drivers for Change
  – Variable Energy Resources
  – More cross-utility communication and control required among interchange authorities
  – Eventual closed loop control

• Characteristics
  – Low Latency
  – High Bandwidth: 120 samples/sec
Timing Requirements

Today fulfilled by using IRIG-B or 1PPS

• General Applications (<1msec)
  – Sequence of Events
  – Digital Fault Recorder (DFR)

• High Precision Timing (<10usec)
  – Synchrophasors (C37.118)
  – Sampled Values (IEC 61850-9-2)
  – Distributed DFR Events

• IEC 61850-5-2003
  – Class T1: Events = ±1msec
  – Class T2: Syncrocheck ±0.1msec
  – Class T3: Samples Values ±25usec
  – Class T4: Samples Values ±4usec
  – Class T5: Samples Values ±1usec
Migrating from IRIG-B to IEEE1588-2008

CGS2520 with Transparent Clock as per IEEE C37.238 Power Profile

- **PTP Message Transport**
  - Layer 2 (Ethertype 0x88F7)
- **PTP Domain**
  - 0
- **Path Delay Mechanism**
  - Peer to Peer Transparent Clock
- **Clock Type**
  - Two Step
- **PTP Packet Priority**
  - COS = 0
- **Slave Performance**
  - <1usec for up to 16 hops

1) With Peer Delay Request Mechanism

RTU … SCADA Remote Terminal Unit; DFR … Digital Fault Recorder
Peer to Peer Transparent Mode

**Master Time**
- Master time = \( T_M \)

**Slave Time**
- Slave time = \( T_S = T_M + \text{offset} \)

**Residency Time (rt)**
- \( t_1 \) to \( t_2 \)

\[
mPD1 = \frac{(pt_2 - pt_1) + (pt_4 - pt_3)}{2}
\]

\[
mPD2 = \frac{(pt_2 - pt_1) + (pt_4 - pt_3)}{2}
\]

\[
\text{Offset} = \frac{(t_2 - t_1) - (t_4 - t_3)}{2}
\]

\[
\text{Offset} = t_2 - t_1 - mPD2 - \text{correctionField}
\]

\[
\text{correctionField} = mPD1 + \text{rt}
\]
Migrating from IRIG-B to IEEE1588-2008

CGS2520 with Boundary Clock

RTU … SCADA Remote Terminal Unit; DFR … Digital Fault Recorder

Power Profile compliant

Global PTP Configuration
- ptp profile power
- ptp mode boundary pdelay-req

PTP Port Configuration
- inter gig 1/1
- ptp pdelay-req interval <-5..5>

Not Power Profile compliant

Global PTP Configuration
- no ptp profile power
- ptp mode boundary delay-req

IPv4 Multicast Transport

Layer 2 Transport
IEEE C37.238 Power Profile (cont’d)

• Two mandatory TLVs
  – ORGANIZATION_EXTENSION IEEE_C37_238 TLV
    Communicates: Grandmaster ID, GrandmasterTimeInaccuracy, NetworkTimeInaccuracy
  – ALTERNATE_TIME_OFFSET_INDICATOR TLV

• IEEE C37.238 MIB
  – Time Error Estimate
  – Traceability
  – Grandmaster ID

• Mapping of C37.238 Performance Parameters into
  – IEC61850 Parameters
  – C37.118 Parameters
Deployment Consideration for Service Providers
# Applications driving Synchronization Needs

<table>
<thead>
<tr>
<th>Technology</th>
<th>Frequency Read: better than…</th>
<th>Phase or Time Synchronization Read: less than…</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GSM</strong></td>
<td>Macro BS: ±50 ppb</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Pico BS: ±100 ppb</td>
<td></td>
</tr>
<tr>
<td><strong>WCDMA (and LTE) FDD</strong></td>
<td>WideArea BS: ±50 ppb</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Medium/LocalArea BS: ±100 ppb</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Home BS: ±250 ppb</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OBSAI: ±16 ppb</td>
<td></td>
</tr>
<tr>
<td><strong>WCDMA TDD</strong></td>
<td>WideArea BS: ±50 ppb</td>
<td>± 2.5 µs between base stations</td>
</tr>
<tr>
<td></td>
<td>LocalArea BS: ±100 ppb</td>
<td></td>
</tr>
<tr>
<td><strong>TD-SCDMA</strong></td>
<td>WideArea BS: ±50 ppb</td>
<td>± 3 µs between base stations</td>
</tr>
<tr>
<td></td>
<td>LocalArea BS: ±100 ppb</td>
<td></td>
</tr>
<tr>
<td><strong>LTE TDD</strong></td>
<td>WideArea BS: ±50 ppb</td>
<td>± 3 µs between base stations</td>
</tr>
<tr>
<td></td>
<td>LocalArea BS: ±100 ppb</td>
<td>May range from ±0.5µs to ±50µs</td>
</tr>
<tr>
<td><strong>CDMA2K</strong></td>
<td>Macro Cell BS: ±50 ppb</td>
<td>ToD (UTC) sync should be less than 3 µs and</td>
</tr>
<tr>
<td></td>
<td>Pico Cell BS and Femto Cell:</td>
<td>shall be less than 10 µs</td>
</tr>
<tr>
<td></td>
<td>±100 ppb</td>
<td></td>
</tr>
<tr>
<td><strong>WiMAX Mobile</strong></td>
<td>Up to ± 1 ppb</td>
<td>Usual values between ± 0.5µs and ± 5µs</td>
</tr>
<tr>
<td></td>
<td>Average target: ± 15 ppb</td>
<td></td>
</tr>
<tr>
<td><strong>LTE-Advanced Services</strong></td>
<td>±5 ppb (CoMP)</td>
<td>CoMP, relaying function, carrier aggregation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 0.5 µs [± 1 µs]</td>
</tr>
<tr>
<td><strong>Multi-Media Bcast SFN Service</strong></td>
<td>± 50ppb</td>
<td>± 1 µs</td>
</tr>
<tr>
<td><strong>DVB SFN</strong></td>
<td>Up to ± 1 ppb</td>
<td>General agreement: ± 1 µs</td>
</tr>
<tr>
<td><strong>TDM transmission</strong></td>
<td>G.823/G.824/G.8261</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Network Monitoring</strong></td>
<td>N/A</td>
<td>± 1 to 100 µs ToD synchronization for 10 µs to 1 ms measurement accuracy</td>
</tr>
</tbody>
</table>
ITU-T SG15 Q13 Work Plan

Definitions / terminology

Frequency: G.826x

Basic / Network requirements

Clocks

Methods

Profiles

Supplements

G.810
G.8260
(for synchronization in packet networks)

G.8271

G.8271.1
(NetwkJitter_time/phase)

G.8271.2
may be needed in future

G.8272
PTC

G.8273

G.8275
(Packet-architecture-time)

G.8261
SyncE NetwkJitter-Wander: Included in G.8261

G.8261.1
(NetwkJitter_frequency)

G.8262
(SyncE - EEC)

G.8263
(Packet Clock)

G.8264
(SyncE – incl. ESMC)

G.8265
(Packet-architecture-Frequency)

G.8265.1
(PTPprofileFrequency)

G.8265.m
(PTPprofileFrequency m)

G.8265.n
(PTPprofileTime/phase n)

G.8261

G.8262

G.8263

G.8264

G.8265

G.8265.1

G.8265.m

G.8265.n

G.8271

G.8271.1

G.8271.2

G.8272

G.8273

G.8275

PRTC … Primary Reference Time Clock, T-GM … Telecom Grandmaster; T-BC … Telecom Boundary Clock;
T-TC … Telecom Transparent Clock; T-TSC … Transparent Time Slave Clock;

G Suppl. x: Simulation of Transport of time over packet network
SyncE + End2End IEEE1588

SP Mobile 2G and 3G RAN Transport Evolution

BTS … Base Transceiver Station; BSC … Base Station Controller
**SyncE + End2End IEEE1588**

**SP Mobile 2G and 3G RAN Transport Evolution**

**ACCESS**
- **BTS/NodeB**
- **OC3/STM1 SONET/SDH/ATM**

**AGGREGATION**
- **BSC/RNC**
- **OC12/STM4 SONET/SDH/ATM**

**CORE**
- **SSU**
- **OC48/STM16 SONET/SDH/ATM**

**Traffic**
- **Sync**

**Sync**
- **Frequency Reference**

**BTS** … Base Transceiver Station; **BSC** … Base Station Controller
SyncE + End2End IEEE1588

SP Mobile 2G and 3G RAN Transport Evolution

BTS … Base Transceiver Station; BSC … Base Station Controller

Traffic

Sync

Access

Aggregation

Core

Sync

BTS/NodeB → RAN Traffic → BSC/RNC

OC3/STM1
SONET/SDH/ATM

OC12/STM4
SONET/SDH/ATM

SSU

Frequency Reference

BSC/RNC

Sync

Traffic

80
SETS Configuration Options
Cisco IOS XR

- Enabling Frequency Synchronization
  ```
  RP/0/RSP0/CPU0:201-14(config)#frequency synchronization
  ```

- Selecting SSM Option
  ```
  RP/0/RSP0/CPU0:201-14(config-freqsync)#quality itu-t option ?
  1  ITU-T QL option 1
  2  ITU-T QL option 2
  ```

- Selecting Generation 1 or 2 for Option 2
  ```
  RP/0/RSP0/CPU0:201-14(config-freqsync)#quality itu-t option 2 ?
  generation  ITU-T QL option 2 generation
  ```
  ```
  RP/0/RSP0/CPU0:201-14(config-freqsync)#quality itu-t option 2 generation ?
  1  ITU-T QL option 2, generation 1
  2  ITU-T QL option 2, generation 2
  ```
Chain of SyncE Clocks

Signaling upon Failure and Chain Convergence

Before the Failure (PRC traceable)

Restored Chain (SSU-S traceable)

You want to avoid/minimize Holdover of SECs!!
Node connected to SSU

Cisco IOS XR Configuration

interface TenGigE0/1/0/0
frequency synchronization
selection input
priority 20
wait-to-restore 0

Make SyncE Line a Nominated Source

Priority of External Input MUST be better (lower) than Line Interfaces

10GE (Te0/1/0/0)
Rsp0 / Sync0

clock-interface sync 0 location 0/RSP0/CPU0
port-parameters
bits-input e1 crc-4 sa8 hdb3

Timing Inputs

SSU

clock-interface sync 1 location 0/RSP0/CPU0
port-parameters
bits-output e1 crc-4 sa8 hdb3

interface GigabitEthernet0/2/0/32
frequency synchronization

Rsp0 / Sync1

1GE (Gi0/2/0/32)

ASR9006

Slot 3
Slot 2
Slot 1
Slot 0
RSP1
RSP0

SSU
Configurable Timers

Ensuring SETS Stability

- Hold-Off Timer dampens short Activations of Input Signal Fail
- Wait-to-Restore Timer does ensure Input is fault-free again

Reference: G.781, page 23
Node connected to SSU

Cisco IOS XR Verification

RP/0/RSP0/CPU0:201-14#show frequency synchronization selection
Thu Apr 14 13:22:44.065 UTC
Node 0/RSP0/CPU0:

Selection point: T4-SEL-C (2 inputs, 1 selected)
Last programmed 00:00:14 ago, and selection made 00:00:07 ago
Next selection points
SPA scoped : None
Node scoped : None
Chassis scoped: None
Router scoped : None
Used for local clock interface output

<table>
<thead>
<tr>
<th>S</th>
<th>Input</th>
<th>Last Selection Point</th>
<th>QL</th>
<th>Pri</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TenGigE0/1/0/0</td>
<td>0/RSP0/CPU0 T4-SEL-A 1</td>
<td>PRC</td>
<td>20</td>
<td>Locked</td>
</tr>
<tr>
<td></td>
<td>Sync0 [0/RSP0/CPU0]</td>
<td>0/RSP0/CPU0 T0-SEL-B 1</td>
<td>PRC</td>
<td>5</td>
<td>Available</td>
</tr>
</tbody>
</table>

Implicit Implementation:
External Input will never drive External Output
Node connected to SSU

Cisco IOS XR Verification

RP/0/RSP0/CPU0:201-14#show frequency synchronization selection
Thu Apr 14 13:22:44.065 UTC
Node 0/RSP0/CPU0:

==============
Selection point: T0-SEL-B (3 inputs, 1 selected)
Last programmed 00:00:15 ago, and selection made 00:00:07 ago
Next selection points
SPA scoped : None
Node scoped : T4-SEL-C
Chassis scoped: LC_TX_SELECT
Router scoped : None
Used for local line interface output

<table>
<thead>
<tr>
<th>S</th>
<th>Input</th>
<th>Last Selection Point</th>
<th>QL</th>
<th>Pri</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sync0 [0/RSP0/CPU0]</td>
<td>n/a</td>
<td>PRC</td>
<td>5</td>
<td>Locked</td>
</tr>
<tr>
<td></td>
<td>TenGigE0/1/0/0</td>
<td>0/1/CPU0 ETH_RXMUX 1</td>
<td>PRC</td>
<td>20</td>
<td>Available</td>
</tr>
<tr>
<td></td>
<td>Internal0 [0/RSP0/CPU0]</td>
<td>n/a</td>
<td>SEC</td>
<td>255</td>
<td>Available</td>
</tr>
</tbody>
</table>

External Input preferred due to local priority
SyncE + End2End IEEE1588

SP Mobile 2G and 3G RAN Transport Evolution

BTS … Base Transceiver Station; BSC … Base Station Controller
1st Telecom Profile: ITU-T G.8265.1

Frequency Distribution

• Supports Frequency Delivery, with no Network Assistance (to PTP)
  – Operation across managed Wide Area Networks (WANs)
  – Slave and Master only (End-to-End PTP) Model
  – IPv4 negotiated unicast transport (defined in IEEE1588-2008 as option),

• Seamless Interoperability with existing Networks
  – SONET/SDH (G.813)
  – SyncE (G.8262)
  – Quality Level for Traceability (G.781)

• Protection Scheme inline with Telecom Best Practices
  – Static master and slave port state
  – Clock selection (based on G.781 model) based on QL Values and Local Priorities
PTP Negotiation Message Exchange

Option to IEEE1588-2008, used by G.8265.1

G.8265.1 … PTP Telecom Profile for Frequency Synchronization

One Way Example!
Simplified Functional Model of G.8265.1

IEEE1588-2008 End2End Master/Slave Model

- **Telecom Grandmaster**
  - PTP port in master state
  - clockClass value (mapped to QL)

- **Telecom Slave**
  - PTP port in slave state
  - Frequency recovery from PTP Event messages
  - Track PTSF Announce, Sync and DelayResp flow
  - Select Packet Master based on clockClass (QL) and local priority
  - Unicast Negotiation Request messages

**PTP communication path** (IP source – IP dest. pair)
PTP Negotiation Message Exchange
Option to IEEE1588-2008, used by G.8265.1

- Slaves send requests to Master to establish PTP exchange

- Requests can be sent via multiple messages or by packing multiple TLVs in a single request message
- Messages include information on the desired message rates
- Master can grant, reject or proposes other values
- G.8265.1 Master needs to support both one- and two-way
- G.8265.1 Slave needs may use one-way or two-way

<table>
<thead>
<tr>
<th></th>
<th>One Way</th>
<th>Two Way</th>
</tr>
</thead>
<tbody>
<tr>
<td>Announce</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sync</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Delay_Response</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
## Quality Level

### Mapping between SSM/G.781 QL and the PTP clockClass Attribute

<table>
<thead>
<tr>
<th>SSM QL</th>
<th>G.781</th>
<th>ESMC</th>
<th>PTP Clock Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Option I</td>
<td>Option II</td>
<td>Option I</td>
</tr>
<tr>
<td>0001</td>
<td>QL-PRS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0000</td>
<td>QL-STU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0010</td>
<td>QL-PRC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0111</td>
<td>QL-ST2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0100</td>
<td>QL-SSU-A</td>
<td>QL-TNC</td>
<td></td>
</tr>
<tr>
<td>0101</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0110</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>QL-SSU-B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1101</td>
<td>QL-ST3E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1010</td>
<td>QL-ST3</td>
<td>QL-ECC2</td>
<td></td>
</tr>
<tr>
<td>1011</td>
<td>QL-SEC</td>
<td>QL-ECC1</td>
<td></td>
</tr>
<tr>
<td>1100</td>
<td>QL-SMC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1110</td>
<td>QL-PROV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1111</td>
<td>QL-DNU</td>
<td>QL-DUS</td>
<td></td>
</tr>
</tbody>
</table>

The default value should correspond to the holdover quality of the master.
Clock Selection Process

- The following parameters contribute to the master selection process:
  - Quality Level (in clockClass parameter)
  - Packet Timing Signal
  - Priority

- Leveraging Experience from SONET/SDH/SyncE PHY-layer Timing Chain Control (G.781)
ITU-T Telecom Slave

Source: ITU-T G.8265.1

Grandmaster1
PTP domain = x

Grandmaster2
PTP domain = x

GrandmasterN
PTP domain = x

Network

Slave-only OC
Instance 1

Slave-only OC
Instance 2

Slave-only OC
Instance N

SOOC instantiation

QL

PTSF

ENABLE_REQUESTING_UNICAST_ANNOUNCE

UNICAST_SYNC_DEL_RESP

timestamps

QL

PTSF

ENABLE_REQUESTING_UNICAST_ANNOUNCE

UNICAST_SYNC_DEL_RESP

timestamps

QL

PTSF

ENABLE_REQUESTING_UNICAST_ANNOUNCE

UNICAST_SYNC_DEL_RESP

timestamps

Selector

PTP timestamps for frequency recovery

Controller & Processing Block

GM#1, priority_GM#1
GM#2, priority_GM#2
GM#N, priority_GM#N

List of Grandmasters

Priority processing

QL from SOOCs

PTSF from SOOCs

QL processing

PTSF processing

Request

Announce

Request

Sync/Del_Resp

GM selection

Selected

Grandmaster

Selector

PTP timestamps from

SOOCs

ENABLE_REQUESTING_UNICAST_ANNOUNCE

UNICAST_SYNC_DEL_RESP

timestamps

ENABLE_REQUESTING_UNICAST_ANNOUNCE

UNICAST_SYNC_DEL_RESP

timestamps

ENABLE_REQUESTING_UNICAST_ANNOUNCE

UNICAST_SYNC_DEL_RESP

timestamps

ENABLE_REQUESTING_UNICAST_ANNOUNCE

UNICAST_SYNC_DEL_RESP

timestamps

Management

Information

Telecom Slave Model
ASR9000 PTP Master Example
Gateway between SyncE and IEEE1588

Interface PTP Configuration
- interface gi 0/1/0/10
- ipv4 address 2.205.209.2/30
- ptp
- profile Master

PTP has to be configured per port

Global PTP Configuration
- ptp
- clock domain <0..255>
- clock priority1 <0..255>
- clock priority2 <0..255>
- ptp profile Master
- announce interval <1..16>
- sync frequency <1..64>
- delay-request frequency <1..64>

Number of Del-req Messages per Second sent by the Master

Drive System Frequency by SyncE Line

PTP Master uses System Frequency

interface gi 0/0/0/4
- frequency synchronization
- selection input
- priority 10
- wait-to-restore 0

Interface Freq-Sync Configuration

Default = 0, user-defined up to 127
Priority must be lower value than on Slaves
Seconds between Announce Messages
Max. Sync Messages per Second to be granted
IEEE1588-2008 Cell Site Design Options

Ordinary Slave on Base Station vs Cell Site Router

- **“Legacy” Base Stations**
  - Frequency Recovery on Cell Site Router (CSR)
  - E1/T1 Clock is driven by CSR System Frequency

- **Ethernet Base Stations**
  - Need external Timing Interface to provide Frequency

- **Ordinary Slave implemented on Base Station directly**
- **CSR is part of the “RAN cloud” which is transparent to IEEE1588**
ASR901 PTP Slave Example

Recovering Frequency via IEEE1588

Global PTP Configuration

- ptp clock ordinary domain <0..255>
- priority1 <0..255>
- priority2 <0..255>

- clock-port ASR9000 slave
- sync interval -6
- delay-req interval -6
- transport ipv4 unicast interface Lo1588 negotiation clock source 2.205.209.2

Global IP Configuration

- interface Loopback1588
  ip address 15.88.0.231 255.255.255.255

IEEE 1588-2008 (PTP)

GM

Gi0/1/0/10
(2.205.209.2)

ASR9000

CarrierE/IP/MPLS

ASR901

SL

This is the Source IP Address of the Slaves PTP Session that the Master will see

Slave will contact Master and negotiate Parameters via TLVs

Default = 0, user-defined up to 127

Default=128, Priority must be higher value than on GrandMaster

2^6=64 Sync Messages per Second to be negotiated with GrandMaster (range: -7..1)

64 Del-req Messages per Second to be negotiated with GrandMaster (range: -7..5)
ASR901 PTP Slave Example

SETS and Frequency Distribution to Base Station

Wait 100 seconds before considering a restored Input for Selection again (default=300sec) “Revertive” → automatically switch back

Enable G.781 compliant Clock Selection

Configure IEEE1588 recovered Frequency as valid Source

Common Global Network-Clock Configuration

- network-clock synchronization automatic
- network-clock synchronization mode QL-enabled
- network-clock input-source 10 interface ToP0/12
- network-clock wait-to-restore 100 global
- network-clock revertive

Frequency provided via External Timing Output (BITS)

network-clock output-source system 10 External 0/0/0

All E1/T1 Interfaces are using System Frequency per default

ASR901#show controllers e1 0/0
E1 0/0 is up.
Applique type is Channelized E1 - balanced
... Framing is crc4, Line Code is HDB3, Clock Source is Internal
IEEE1588 Transport in Access/Aggregation

- Security
  - EoMPLS
  - VPLS
  - L3 MPLS VPN
- Packet Delay Variation
  - Packet Marking
  - Priority Queuing
- Performance/SLA Monitoring
  - IP SLA
  - Y.1731
- Transport Caveats such as Microwave Links
Quality of Service for IEEE1588-2008

Queuing - Guaranteed Transport for PTP

QoS is defined via 1. class-maps (Traffic?) 2. policy-maps (Action?)

QoS is activated by referencing the policy-map under the interface

interface GigabitEthernet2/30
service-policy output ptp

class-map match-all ptp
match dscp ef

policy-map ptp
class ptp
police cir percent 5
priority level 1
class voice
police cir percent 10
priority level 2
class business
bandwidth percent 50
class class-default
random-detect

Strict PQ
CBWFQ
WRED

CarrierE/IP/MPLS

PTP
Realtime Traffic (i.e. Voice, Video)
Guaranteed Bandwidth Traffic (i.e. Business Data, …)
Best Effort
ITU-T Rec for Evaluating Impact of PDV

G.8261 – Timing and Synchronization Aspects in Packet Network

Reference timing signal (PRC)

Packet Timing Flow

CE (TDM traffic generator) → IWF → Traffic generator

- Disturbance load according to traffic models
- Flow of interest

Ethernet switches

Packet delay variation

Test equipment

Test equipment (O.171)

Jitter, wander, frequency accuracy

TDM signal

G.8261-Y.1361_FV1.4

N = 10
GE = 1 Gbit/s Ethernet
FE = 100 Mbit/s Ethernet
Simulated Network Load

ITU-T G.8261 – Timing & Sync Aspects in PSNs

- Appendix VI.5 – Test for Two Way Protocols
- Baseline Test (no Network → Master/Slave back to back)
- Performance Tests (Network & Load)

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Description</th>
<th>Network Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Static Packet Load</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Sudden large and persistent Load Changes</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Slow Load Change over extremely long Time</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Temporary Network Outage</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Temporary Congestion</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Routing Changes caused by failures</td>
<td></td>
</tr>
</tbody>
</table>
G.8261 – Test Case 12 Results
OC Slave, MWR2941, Cisco IOS 15.1(1)MR, 10 hops

Network Load

Master → Slave

80%

Slave → Master

20%

1h

Frequency - TIE

Frequency – MTIE/TDEV

OC ... Ordinary Clock
G.8261 – Test Case 14 Results

OC Slave, MWR2941, Cisco IOS 15.1(1)MR, 10 hops

**Frequency - TIE**

- TIE data from 11.05.18 02:38:00.000 to 11.05.18 02:38:00.000
- Time [s]
- Observations count: 3501992
- Sample rate: 30 / s
- Zoom & analysis range [s]: 0.00 - 86399.70
- Time [s]: 86399.70
- TIE [s]: 951.02
- Drift rate: -0.32, 0.20, 524.42
- Frequency offset: 4.86 ppm/s
- Eliminate

**Network Load**

- 20% Slave → Master
- 55% 12h
- 80% Master → Slave
- 24h

**Frequency – MTIE/TDEV**

- Sample rate: 30 / s
- Analysis range [s]: 0.00 - 86399.70
- Time [s]: 86399.70
- TDEV: N/12 - rec. 0.172

Network Load

OC … Ordinary Clock
IEEE1588 Hop-by-Hop Mode

SP Mobile 4G RAN Transport Evolution (LTE/WCDMA TDD)
2nd Telecom Profile: ITU-T G.8275.1

Time/Phase Transfer

- Full network assistance for IEEE1588/PTP
- Hop-by-hop distribution model: chain of Telecom BCs (T-BCs)
- Physical layer frequency (hybrid mode) recommended
  - T-TSC and T-BC syntonization and holdover
- Mapping: Ethernet (confirmed), IP (to be discussed)
- Transmission: Layer 2 multicast (confirmed), IP (to be discussed)
- Mode: two-way only, one- and two-step
- BMCA: TBD
  - Master and Slave Port State again static on T-TSC and T-GM as in G.8265.1
- Network limit and node characterization: TBD
  - G.827x Specifications (work in progress)

T-TSC … Telecom Time Slave Clock    T-BC … Telecom Boundary Clock
T-GM … Telecom Grand Master
ASR903 Boundary Clock Clock Example

Global IP Configuration

interface Loopback102
ip address 15.88.2.234 255.255.255.255

Global PTP Configuration

ptp clock ordinary domain <0..255>
priority1 <0..255>
priority2 <0..255>
clock-port ASR9000 slave
sync interval -6
delay-req interval -6
transport ipv4 unicast interface Lo101 negotiation
clock source 2.209.234.2

clock-port ASR90x master
sync interval -6
delay-req interval -6
transport ipv4 unicast interface Lo102 negotiation

Boundary Clock Master
Port that will grant
downstream BCs or
Ordinary Slave requests

Slave Port of Boundary
Clock will contact
upstream BC or GM
IEEE1588 End2End Hybrid Mode

SP Mobile 4G RAN Transport Evolution (LTE/WCDMA TDD)

IEEE 1588-2008 (PTP)

IEEE 1588-2008 (PTP)

IEEE 1588-2008 (PTP)

IEEE 1588-2008 (PTP)

IEEE 1588-2008 (PTP)

IEEE 1588-2008 (PTP)

IEEE 1588-2008 (PTP)

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IEEE 1588-2008 (PTP)

IEEE 1588-2008 (PTP)

IEEE 1588-2008 (PTP)

IEEE 1588-2008 (PTP)
Node connected to NodeB or BTS

Cisco IOS Configuration – ME3600/3800X

- SETS Configuration Options similar to Cisco7600

```plaintext
network-clock input-source 10 interface TenGigabitEthernet0/1
network-clock input-source 20 interface TenGigabitEthernet0/2

network-clock synchronization automatic
network-clock synchronization mode QL-enabled

1GE & 10GE Interfaces are per default in “Line” Mode

interface TenGigabitEthernet0/1
  synchronous mode
interface TenGigabitEthernet0/2
  synchronous mode

interface GigabitEthernet0/2
  synchronous mode

If not “selected” Source Interface takes Clock from System (Internal)
```
Node connected to NodeB or BTS

Cisco IOS Configuration – MWR2941

- ESMC supported
- No concurrent support of IEEE1588-2008 and SyncE

- No ESMC support
- Concurrent support of IEEE1588-2008 and SyncE
Node connected to NodeB or BTS
Cisco IOS Verification – ME3600/3800X & MWR2941

Network Clock Configuration

<table>
<thead>
<tr>
<th>Priority</th>
<th>Source</th>
<th>Status</th>
<th>Type</th>
<th>Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Gi0/0</td>
<td>OK</td>
<td>SYNCE</td>
<td>Y</td>
</tr>
</tbody>
</table>

Current Clock State: LOCK

- clock input Stratum level: 3
- mode: NonRevertive
- hold-timeout: infinite

Priority Based Clock Selection

<table>
<thead>
<tr>
<th>Interface</th>
<th>SigType</th>
<th>Mode/QL</th>
<th>Prio</th>
<th>QL_IN</th>
<th>ESMC Tx</th>
<th>ESMC Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal</td>
<td>NA</td>
<td>NA/Dis</td>
<td>251</td>
<td>QL-SEC</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>*Te0/1</td>
<td>NA</td>
<td>Sync/En</td>
<td>10</td>
<td>QL-PRC</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Te0/2</td>
<td>NA</td>
<td>Sync/En</td>
<td>20</td>
<td>QL-PRC</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

G.781 Compliant Clock Selection

205-13#sh network-clocks

203-15#show network-clocks synchronization

...
IEEE1588-2008 Hybrid Mode
Cisco IOS Configuration – MWR2941

- Configuration

```
interface Vlan213
  ptp sync interval -6
  ptp delay-req interval -6
  ptp slave unicast negotiation hybrid
  ptp clock-source 25.1.0.2
  ptp enable
network-clock-select 1 SYNCE 1
ptp output 10M 1pps
ptp tod ntp
```
IEEE1588-2008 Hybrid Mode
Cisco IOS Verification – MWR2941

• SyncE Line Interface coming up

  *Feb 22 23:58:07.935: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/1, changed state to up
  *Feb 22 23:58:14.944: %NET_CLK_SEL-6-NETCLK_STATE_CHANGE: Network clock state change to LOCK (Gi0/1)

• Bring Interface VLAN up to enable PTP

  *Feb 22 23:59:42.898: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan213, changed state to up

• PTP recovering Time and aligning to SyncE Frequency

  *Feb 23 00:04:27.105: %TOP_MODULE-6-CLK_STATUS_CHANGE: Hybrid clock status changed to WAIT_FOR_DPLL
  *Feb 23 00:04:27.109: %TOP_MODULE-5-APPL_UPDOWN: Timing over packet application is up on Vlan213
  *Feb 23 00:04:29.783: %TOP_MODULE-6-CLK_STATUS_CHANGE: Hybrid clock status changed to WAIT_FOR_CLOCKSTREAM
  *Feb 23 00:04:30.622: %TOP_MODULE-6-CLK_STATUS_CHANGE: Hybrid clock status changed to WAIT_FOR_ALIGN
  *Feb 23 00:04:44.882: %TOP_MODULE-6-CLK_STATUS_CHANGE: Hybrid clock status changed to START_REALIGN
  *Feb 23 00:04:48.238: %TOP_MODULE-6-CLK_STATUS_CHANGE: Hybrid clock status changed to DONE_REALIGN
Summary and Conclusion
What we have discussed

• Motivation for Synchronization in Packet-based Networks
• Frequency and Time Synchronization Overview
• Synchronization Support in Cisco Products
• Deployment Considerations for
  – Industrial Solutions
  – Smart Grid
  – High Speed Trading
  – Service Providers
• Summary and Conclusion
Key Take Aways (1/2)

• Synchronization has two aspects
  – Frequency
  – Time

• Need for Synchronization is growing and growing
  – Service Providers → Mobile Networks
  – Industrial Solutions → more efficient Manufacturing
  – Smart Grid → replacing legacy Time Distribution with Ethernet
  – High Frequency Trading → Regulatory and Market Differentiation
Key Take Aways (2/2)

• Use **Physical Frequency Distribution** where ever possible
  – SyncE, SONET/SDH

• **IEEE1588-2008** provides a “Toolbox” and **Profiles** define Framework for various Use Cases
  – IEEE1588-2008 Default Profile → Industrial Solutions & High Frequency Trading
  – ITU-T G.8265.1 PTP Profile for Frequency Synchronization → Service Providers
  – IEEE C37.238-2011 PTP Profile for Power Systems Applications → Smart Grid

• When using **IEEE1588-2008** evaluate
  – Packet Network **QoS** Configuration
  – Network **Security** (L2/L3 VPN, Access-Lists, …)
  – Packet Delay Variation (**PDV**)
# Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>3GPP</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Generation Partnership Program</td>
</tr>
<tr>
<td>BSC</td>
<td>Base Station Controller</td>
</tr>
<tr>
<td>BTS</td>
<td>Base Transceiver Station</td>
</tr>
<tr>
<td>CDR</td>
<td>Clock Data Recovery</td>
</tr>
<tr>
<td>CES</td>
<td>Circuit Emulation Service</td>
</tr>
<tr>
<td>CSR</td>
<td>Cell Site Router</td>
</tr>
<tr>
<td>DFR</td>
<td>Digital Fault Recorder</td>
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<tr>
<td>E2E</td>
<td>End to End</td>
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<tr>
<td>EEC</td>
<td>Ethernet Equipment Clock</td>
</tr>
<tr>
<td>ESMC</td>
<td>Ethernet Synchronization Messaging Channel</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
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<tr>
<td>MEP</td>
<td>Maintenance Endpoint</td>
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<tr>
<td>NE</td>
<td>Network Element</td>
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<tr>
<td>NTP</td>
<td>Network Time Protocol</td>
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<tr>
<td>P2P</td>
<td>Peer to Peer</td>
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<tr>
<td>PDV</td>
<td>Packet Delay Variation</td>
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<tr>
<td>PLL</td>
<td>Phase Locked Loop</td>
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<tr>
<td>PTP</td>
<td>Precision Time Protocol</td>
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<tr>
<td>PRTC</td>
<td>Primary Reference Time Clock</td>
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<tr>
<td>QL</td>
<td>Quality Level</td>
</tr>
<tr>
<td>QL-DNU</td>
<td>Quality Level – Do Not Use</td>
</tr>
<tr>
<td>QL-DUS</td>
<td>Quality Level – Do not Use for Sync</td>
</tr>
<tr>
<td>QL-EEC</td>
<td>Quality Level – Ethernet Equipment Clock</td>
</tr>
<tr>
<td>QL-PRC</td>
<td>Quality Level – Primary Reference Clock</td>
</tr>
<tr>
<td>QL-PRS</td>
<td>Quality Level – Primary Reference Source</td>
</tr>
<tr>
<td>QL-SEC</td>
<td>Quality Level – Synchronous Equipment Clock</td>
</tr>
<tr>
<td>QL-SMC</td>
<td>Quality Level – SONET Minimum Clock</td>
</tr>
<tr>
<td>QL-SSU</td>
<td>Quality Level – Synchronous Station Unit</td>
</tr>
<tr>
<td>QL-ST3</td>
<td>Quality Level – Stratum 3</td>
</tr>
<tr>
<td>QL-STU</td>
<td>Quality Level – Sync Traceability Unknown</td>
</tr>
<tr>
<td>QL-TNC</td>
<td>Quality Level – Transit Node Clock</td>
</tr>
<tr>
<td>RTU</td>
<td>SCADA Remote Terminal Unit</td>
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<tr>
<td>SEC</td>
<td>Synchronous Equipment Clock</td>
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<tr>
<td>SETG</td>
<td>Synchronous Equipment Timing Generator</td>
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<tr>
<td>SETS</td>
<td>Synchronous Equipment Timing Source</td>
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</table>
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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>SDH</td>
<td>Synchronous Digital Hierarchy</td>
</tr>
<tr>
<td>SONET</td>
<td>Synchronous Optical Network</td>
</tr>
<tr>
<td>SOOC</td>
<td>Slave Only Ordinary Clock</td>
</tr>
<tr>
<td>SSM</td>
<td>Synchronous Status Message</td>
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<tr>
<td>TDD</td>
<td>Time Division Duplex</td>
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<tr>
<td>TDM</td>
<td>Time Division Multiplexing</td>
</tr>
<tr>
<td>ToD</td>
<td>Time of Day</td>
</tr>
<tr>
<td>UTC</td>
<td>Coordinated Universal Time</td>
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<tr>
<td>WAN</td>
<td>Wide Area Network</td>
</tr>
<tr>
<td>WCDM</td>
<td>Wideband Code Division Multiplexing</td>
</tr>
<tr>
<td>XO</td>
<td>Oscillator</td>
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References

• Cisco CGS2500 PTP Configuration Guide

• Cisco IE3000 PTP Configuration Guide

• Nexus 7000 PTP Configuration Guide

• ASR901 PTP Configuration Guide

• ASR903 PTP Configuration Guide
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