Overcoming Obstacles to Deploying Precision Time Protocol (PTP) in Networks

Real-World Lessons from the Field

Daniel B. Burch - Senior Manager Business Development
Norway Fjord Transmission Line Span
3152m (10,341ft)

USA Average Transmission Line Span
152m – 366m (500ft – 1,200ft)
PTP LESSONS TO LIVE BY

1. Proper use of PTP Profiles to achieve budgeted accuracies
2. Understanding, measuring & adjusting for network asymmetry
3. Classes of boundary/transparent clocks
4. When to:
   • Supplement site with GNSS (GPS)
   • Add more boundary clocks
   • Implement APTS
## Smart grid time sync requirements

<table>
<thead>
<tr>
<th>Application</th>
<th>Measurement</th>
<th>Accuracy</th>
<th>Time Interface</th>
<th>Sync Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TW Fault Locator</strong></td>
<td>300 m (line span)</td>
<td>1 μs</td>
<td>PTP, IRIG-B, PPO</td>
<td>GPS, 1588 GMC</td>
</tr>
<tr>
<td><strong>Phasor Measurements</strong></td>
<td>± 0.1 degree</td>
<td>1 μs</td>
<td>PTP, IRIG-B (1344)</td>
<td>GPS, 1588 GMC</td>
</tr>
<tr>
<td>Lightning Strike Correlation</td>
<td>Grid-wide events</td>
<td>1 ms</td>
<td>IRIG-B</td>
<td>GPS</td>
</tr>
<tr>
<td>Protection Relaying events</td>
<td>&lt; 1 cycle</td>
<td>1 ms</td>
<td>PTP, IRIG-B, IEC 61850</td>
<td>GPS, IRIG-B, 1588 GMC</td>
</tr>
<tr>
<td>Event/Disturbance Recorders</td>
<td>&lt; 1 cycle</td>
<td>1 ms</td>
<td>PTP, IRIG-B, PPO</td>
<td>GPS, 1588 GM</td>
</tr>
<tr>
<td>Network, Distribution &amp; Substation Control</td>
<td>Grid-wide events</td>
<td>1 ms</td>
<td>PTP, IRIG-B</td>
<td>GPS, Control Centre, 1588 GMC</td>
</tr>
<tr>
<td>Quality of Supply Metering</td>
<td>Freq, time error</td>
<td>0.5 sec</td>
<td>PTP, IRIG-B, PPO</td>
<td>GPS, 1588 GMC</td>
</tr>
<tr>
<td>Bulk Metering</td>
<td>Energy registers</td>
<td>0.5 sec</td>
<td>Proprietary, PPO</td>
<td>Proprietary</td>
</tr>
<tr>
<td>Customer Premises Metering</td>
<td>Energy registers</td>
<td>1 sec</td>
<td>NTP, Proprietary</td>
<td>Proprietary, NTP</td>
</tr>
<tr>
<td>SCADA/EMS/PAS</td>
<td>Grid-wide status</td>
<td>1 ms</td>
<td>NTP, ASCII</td>
<td>GPS</td>
</tr>
<tr>
<td>Frequency Measurement</td>
<td>Frequency</td>
<td>1 ms</td>
<td>N/A</td>
<td>GPS</td>
</tr>
<tr>
<td><strong>Sampled Values</strong></td>
<td>Volt/Current</td>
<td>1 μs</td>
<td>PTP</td>
<td>1588 GM</td>
</tr>
<tr>
<td>Telecommunication</td>
<td>SDH/PDH</td>
<td>G.812/813</td>
<td>PTP G.8265 2.048 Mbps/MHz</td>
<td>GPS, 1588 GMC</td>
</tr>
</tbody>
</table>
PTP Profiles for Telecom & Power Applications
Which PTP Profile is appropriate?

Telecom Profiles:
• G.8265.1  Layer 3 only  Frequency only
• G.8275.1  Layer 2 only  Frequency & Phase  Network Fully Aware
• G.8275.2  Layer 3 only  Frequency & Phase  Network Partially Aware

Power Profiles:
• C37.238:2011  Layer 2 only
• C37.238:2017  Layer 2 only
• 61850-9-3  Layer 2 only
Typical freq/time sync delivery over optical network

Core Network:
- DWDM / IP MPLS
- SONET/SDH

Access Network to SubStations & other Facilities:
- Eth or Copper
- Fiber
- PowerLine
- Mobile
- MW

Telecom Profiles

Large Substation
- GNSS
- OSA5412 with PTP/SyncE backup

Small Substation
- GNSS
- OSA 5405/01 with PTP/SyncE backup
Best Practice Timing Delivery For Substations

• … Today and Tomorrow

PTP Telcom Profiles work on LAN or WAN
PTP Power Profile works on LAN only (looking for TC)
PTP Profiles for Telecom Applications
### G.8265.1 Annex A ITU-T Telecom Profile for Frequency

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permitted Nodes</td>
<td>Grandmasters and Slave-Only Clocks</td>
</tr>
<tr>
<td>Operation</td>
<td>Unicast Only</td>
</tr>
<tr>
<td>Addressing</td>
<td>IP Addressing – Layer 3 Only</td>
</tr>
<tr>
<td>Clock Recovery</td>
<td>Masters must support both one-way and two-way. Slaves may support one-way,</td>
</tr>
<tr>
<td></td>
<td>two-way or both (Note two-way supports phase)</td>
</tr>
<tr>
<td>Domain</td>
<td>Configurable 4-23 (No default)</td>
</tr>
<tr>
<td>Timescale</td>
<td>PTP or Arbitrary</td>
</tr>
<tr>
<td>Announce</td>
<td>1 per 16 seconds up to 8 per second (default is 1 per 2 seconds)</td>
</tr>
<tr>
<td>Sync &amp; Follow-up</td>
<td>1 per 16 seconds to 128 per second</td>
</tr>
<tr>
<td>Peer Delay request/response</td>
<td>1 per 16 seconds to 128 per second</td>
</tr>
<tr>
<td>Protection Switching</td>
<td>Priority or Quality Messaging or LOS</td>
</tr>
</tbody>
</table>
# G.8275.1 Annex A

## 8275.1 Annex A – ITU-T Telecom Profile for Phase/Time

<table>
<thead>
<tr>
<th>Permitted Nodes</th>
<th>Grandmasters, Boundary Clocks and Slave Only Clocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multicast/Unicast</td>
<td>Multicast Only</td>
</tr>
<tr>
<td>Addressing</td>
<td>Mac addressing – Layer 2 only</td>
</tr>
<tr>
<td>Clock Recovery</td>
<td>Two-way Only (Phase)</td>
</tr>
<tr>
<td>Domain</td>
<td>24 default (configurable 24-43)</td>
</tr>
<tr>
<td>Timescale</td>
<td>PTP Timescale</td>
</tr>
<tr>
<td>Announce</td>
<td>8 per second</td>
</tr>
<tr>
<td>Sync &amp; Follow-up</td>
<td>16 per second</td>
</tr>
<tr>
<td>Delay request/response</td>
<td>16 per second</td>
</tr>
<tr>
<td>Protection Switching</td>
<td>Alternate-BMCA</td>
</tr>
</tbody>
</table>
## G.8275.2 Telecom Profile

### G.8275.2 ITU-T Telecom Profile for Frequency and Phase

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permitted Nodes</strong></td>
<td>Grandmasters, Boundary Clocks and Slave Only Clocks</td>
</tr>
<tr>
<td><strong>Operation</strong></td>
<td>Unicast Only</td>
</tr>
<tr>
<td><strong>Addressing</strong></td>
<td>IP Addressing – Layer 3 Only</td>
</tr>
<tr>
<td><strong>Clock Recovery</strong></td>
<td>Both One-way and Two-way modes are supported (Two-way required for Phase)</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td>Default is 44 – Configurable 44-63</td>
</tr>
<tr>
<td><strong>Timescale</strong></td>
<td>PTP or Arbitrary</td>
</tr>
<tr>
<td><strong>Announce</strong></td>
<td>1 per 16 seconds up to 8 per second (default is 1 per 2 seconds)</td>
</tr>
<tr>
<td><strong>Sync &amp; Follow-up</strong></td>
<td>1 per 16 seconds to 128 per second</td>
</tr>
<tr>
<td><strong>Peer Delay request/response</strong></td>
<td>1 per 16 seconds to 128 per second</td>
</tr>
<tr>
<td><strong>Protection Switching</strong></td>
<td>Priority or Quality Messaging or LOS (ABMCA)</td>
</tr>
<tr>
<td><strong>PTP Backup with ACDC</strong></td>
<td>Standards include requirement that PTP backup with Automatic Asymmetry delay Compensation to be supported by Grandmasters</td>
</tr>
</tbody>
</table>
PTP Profiles for Power Utilities Applications
# IEEE PTP Profiles for Power Systems Applications

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Network Protocol</strong></td>
<td>Ethernet Layer 2</td>
<td>Ethernet Layer 2</td>
<td>Ethernet Layer 2</td>
</tr>
<tr>
<td><strong>Delay Mechanism</strong></td>
<td>Peer-to-Peer (P2P)</td>
<td>Peer-to-Peer (P2P)</td>
<td>Peer-to-Peer (P2P)</td>
</tr>
<tr>
<td><strong>Operation Mode</strong></td>
<td>One Step</td>
<td>One or Two Step(s)</td>
<td>One or Two Step(s)</td>
</tr>
<tr>
<td><strong>Sync / Announce Message Interval</strong></td>
<td>1 per second / 1 per second</td>
<td>1 per second / 1 per second</td>
<td>1 per second / 1 per second</td>
</tr>
<tr>
<td><strong>TLV messages</strong></td>
<td>Required</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td><strong>Grandmaster Priority</strong></td>
<td>#1 and #2 = 128</td>
<td>Selectable, allowing to choose the best grandmaster for holdover conditions</td>
<td>Selectable, allowing to choose the best grandmaster for holdover conditions</td>
</tr>
</tbody>
</table>
IEEE PTP Profiles for Power Systems Applications

The IEEE C37.238:2017 and IEC/IEEE 61850-9-3 are completely compatible and can work together without restrictions on the same network by setting its domain number.

The C37.238:2011 was superseded by the other two standards but may be used in legacy networks and may be compatible depending on the IEEE 1588v2 network configuration.
Network Asymmetry Issues Solved
Assisted Partial Timing Support (APTS)
Operates over (existing) layer 3 networks
Assisted Partial Timing Support (APTS) Automatic Asymmetry Delay Compensation (AADC)

Auto-calibration is used to actively compensate for dynamic network asymmetries

Operates over (existing) layer 3 networks

End-to-End Measurement of Delay Asymmetry

Self-Calibration and Clock Validation

Not all network elements need to be PTP aware (T-BC)
OTC Automatic delay compensation

- Chromatic dispersion TE compensation:
  - Option 1: User enter Delay Asymmetry Value
  - Option 2: Calculated based on user data (wavelengths, fiber length)
  - Option 3: Calculated based on user data (wavelengths)
    Estimate delay with G.8275.1 PTP two-way measurement (t=half round-trip delay),
    Then from delay t calculate distance

• BiDi plugs:
  - One Fiber
  - Two different wavelengths Tx/Rx

PTP over OTC
Syncjack GUI Concept

Several layers of indicators allowing for step by step monitoring and troubleshooting

First layer provides global indication of the Synchronization status

Second layer shows performance indication of each reporting tool

Third layer provides detailed information for fault localization of performance analysis

AADC – Automatic Asymmetry Delay Compensation
PTP Boundary & Transparent Clocks
Original Concept – Grandmaster Clock

Haul PTP across the entire network
Deploy Boundary Clocks to unburden links

Segment the network with Boundary Clocks
(contains oscillator and optional GNSS Receiver)
Introduction of Transparent Clocks

Lower cost and feature of Bridges and Routers
(no oscillator or GNSS Receiver)
What is a Boundary clock

A Boundary Clock extends synchronization across an intermediate network element.

- A boundary clock has an internal oscillator:
  - The oscillator is slaved to the upstream Grandmaster
  - The slaved oscillator is then used as Grandmaster to downstream devices
  - Boundary clocks can be used to extend the reach of the timing or offload capacity from the GM.
A Transparent Clock is neither a master or a slave. It is a switch that adjusts a PTP timestamp to compensate for its own delay.

- A Transparent Clock has no internal oscillator.
- Timestamp on outgoing message is modified to include its own delay.
### G.8273.2 T-BC Classes

Class A and Class B Clock Classes defined

<table>
<thead>
<tr>
<th></th>
<th>T-BC, T-TSC (nsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class A</td>
</tr>
<tr>
<td>maxITEI</td>
<td>unfiltered</td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>maxITEll</td>
<td>Filtered</td>
</tr>
<tr>
<td></td>
<td>-</td>
</tr>
<tr>
<td>cTE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td>dTE_{LP} (MTIE)</td>
<td>constant temp. up to 1.000 sec</td>
</tr>
<tr>
<td></td>
<td>var. temp. up to 10.000 sec</td>
</tr>
<tr>
<td>dTE_{LP} (TDEV)</td>
<td>constant temp. up to 1.000 sec</td>
</tr>
<tr>
<td>dTE_{HP}</td>
<td>up to 1.000 sec</td>
</tr>
</tbody>
</table>

LL – LIVING LIST (proposed values)
FFS – For Further Study
PTP Power Profile Network Model
For Substation Timing
PTP Deployment Terms

**Full ON-Path Support**

- Slave Clock
- Boundary Clocks or Transparent Clocks
- Grandmaster Clock

**Partial or No ON-Path Support**

- Slave Clock
- Transport Network with No 1588 Support
- Grandmaster Clock
Precision Time Protocol (PTP) Explained

- Protocol used to synchronize clocks throughout a network.
- The Grandmaster (GM) “reference clock” sends a series of time-stamped messages to slaves.
- Slaves receive the messages, and eliminate the round-trip delay by synchronizing to the Grandmaster.
- Frequency/Time-of-Day/Phase is recovered from the accurate time of day reference from the GM.
- Boundary Clocks (BC) can receive PTP as a reference, while providing GM functionality downstream to other clients.
Synchronous Ethernet

Also referred as **Sync-E**, is an ITU-T standard for computer networking that facilitates the transference of frequency reference signals over the **Ethernet physical layer**. This signal can then be made traceable to an external clock.
Lucky Packet Concept
Lucky Packet Concept

What is a Lucky Packet?

Networks will present a percentage of packets that get across the network with minimal queuing delays. These are referred to as ‘lucky’ packets. Since these lucky packets are never waiting in queues or have minimal wait times, their transit across the network is relatively consistent.

**PTP Slave Clocks run a selection filter on all 1588 packets to find the lucky packets.** Only lucky packets are used in the clock recovery algorithm. The impacts of PDV are thus filtered and greatly mitigated.
Lucky Packet Concept

PTP flow through a network operating at 50% load capacity

PTP flow rate 32pps
Lucky Packet Concept

PTP flow through a network operating at 50% load capacity

All packets are lucky when leaving the GM!

32 Lucky Packets
Lucky Packet Concept

PTP flow through a network operating at 50% load capacity

50% of Packets impacted by queueing delays at 1st Switch

16 Packets remain lucky
Lucky Packet Concept

PTP flow through a network operating at 50% load capacity

50% of Packets impacted by queueing delays at 2nd Switch
8 Packets remain lucky
Lucky Packet Concept

PTP flow through a network operating at 50% load capacity

50% of Packets impacted by queueing delays at 3rd Switch

4 Packets remain lucky
Lucky Packet Concept

PTP flow through a network operating at 50% load capacity

50% of Packets impacted by queueing delays at 4nd Switch
2 Packets remain lucky
Lucky Packet Concept

PTP flow through a network operating at 50% load capacity

50% of Packets impacted by queueing delays at 5th Switch

1 Packets remain lucky
Lucky Packet Concept

PTP flow through a network operating at 50% load capacity

*What happens at the Boundary Clock?*
Lucky Packet Concept

PTP flow through a network operating at 50% load capacity

*Boundary Clock trains its internal oscillator to the recovered clock and generates 32 brand new Lucky Packets!*
Oscilloquartz - 75 years of know-how in network sync

- #1 - Industry’s first supplier of sync solutions
- #1 - The leader in resilient & assured PNT & packet-based timing
- #1 - Leading-edge technologies in defense-in-depth PNT cyberthreat protection, including multilayer detection, zero-trust multisource backup & multilevel fault-tolerant mitigation, aligned with these industry standards:
  - #1 - The leader in field-proven, vendor-agnostic & intelligent sync network management
  - #1 - Industry’s best complete portfolio of trusted sync services, from network design to installation to commissioning

The #1 trusted secure sync solution provider globally
AUTHOR BIO

Daniel Burch, Sr. Business Development Manager NA, Oscilloquartz

Daniel B. Burch has enjoyed a 47-year, award-winning career in Telecommunications, serving roles with national responsibility at GTE/Verizon Communications, Director of Research & Development at Teradyne Broadband Test Division and senior positions in multiple Silicon Valley firms with expertise in Timing & Synchronization, portable and remote automated expert testing solutions, and developing new methods for analyzing complex circuits and services. Burch is now responsible for Oscilloquartz business development in Federal, Smart Grid, Transportation & Public Safety/911 markets.
Thank you!

For Q&A, feel free to contact me at dburch@oscilloquartz.com 214-500-4921