PTP PRIMER

The Precision Time Protocol (PTP) allows precise timing over Ethernet, and as such is an integral element of IEC 61850 development and deployment. This paper examines the applications and benefits of PTP, and provides a summary of the Utility and Power PTP profiles.

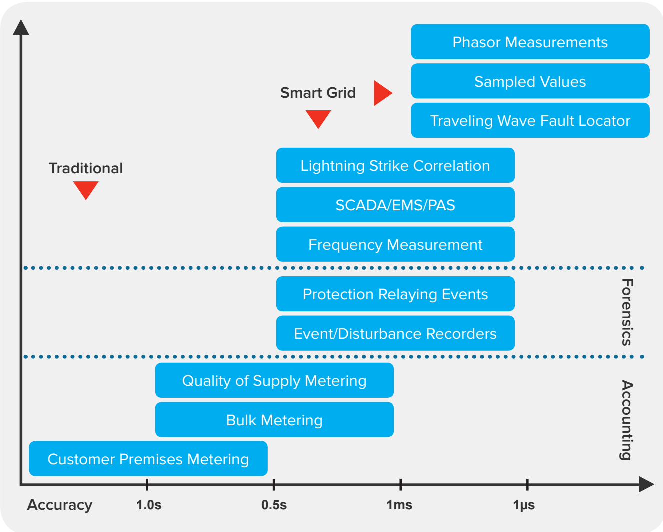
Calnex
Insight and Innovation

Precision Time Protocol (PTP): Synchronization in IEC 61850 environments

PTP – Synchronization through Ethernet networks

Globally, there is a growing trend in widely varying applications to move from existing single-purpose (and often proprietary) systems to multi-functional Ethernet networks. In Power/Utilities systems, IEC 61850 provides the framework for migrating all communications to Ethernet-based protocols.

In addition to existing system synchronisation requirements, such as differential line protection, there are range of emerging applications, many falling under 'Smart Grid' that require or benefit from synchronisation, for example Intelligent Electronic Devices (IEDs) exchanging real-time information.



Precision Time Protocol (PTP) as defined in IEEE 1588 is a widely adopted technique for synchronizing devices across Ethernet networks, for example as a fundamental part of International Telecommunication Union Standards for packet transport networks. PTP satisfies the need for packet timing in IEC 61850, and is also capable of the very tight (sub-microsecond) network timing levels that are essential for some applications and advantageous in many others.

What is PTP?

PTP is a message-based time transfer protocol that is used for transferring time (phase) across a packet-based network. It ensures various points in the network are precisely synchronized to the reference (master) clock so that the network meets specific performance limits according to the network's application.

PTP timing messages are carried within the packet payload. The precise time a packet passes an ingress or egress point of a PTP-aware device is recorded using a timestamp. Because packets take different lengths of time to travel through the network – caused by queuing in switches and routers on the path – this results in Packet Delay Variation (PDV). To reduce the impact of PDV, Boundary Clocks (BCs) or Transparent Clocks (TCs) can be used to meet the target accuracy of the network.

- BCs calibrate themselves by recovering and regenerating the PTP timing from the previous clock in the chain, thereby minimizing the PDV accumulation at the slave.
- If TCs are used, the measured link delay and residence time is written by each TC into a correction field within the packet. The end slave then has a record of the delay for each TC on the path.

Assessing the Time Error introduced by these devices is critical to determining network topology and suitability of equipment, and demonstrating network timing compliance.

How does PTP work?

PTP uses the exchange of timed messages to communicate time from a master clock to a number of slave clocks.

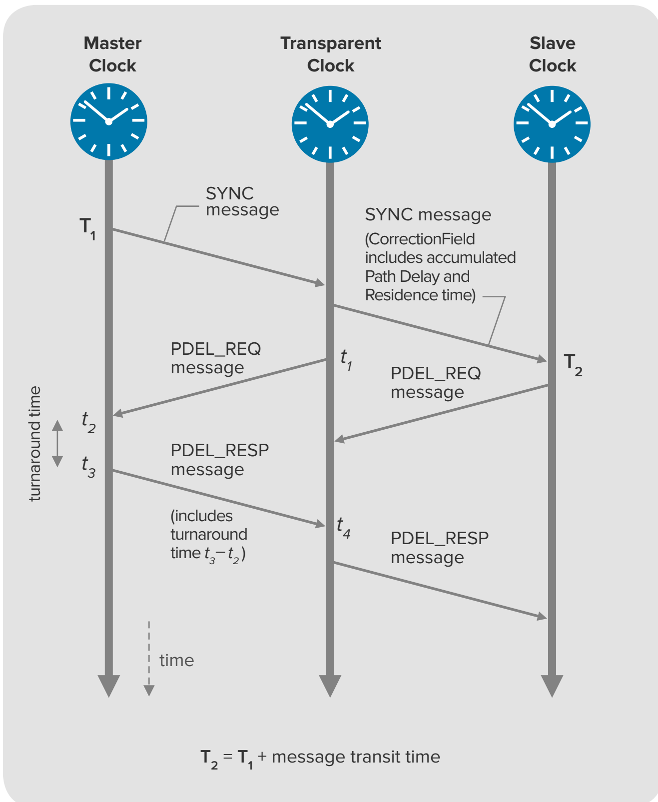
Timestamped messages are generated from the master clock, with time offset through a system then estimated using the assumption that the one-way network delay is half the round trip delay, and used to correct the slave time base to align to the master.

Note that this assumes symmetry, that is, the forward and reverse paths are of equal length. If they are of different lengths, usually caused by queuing in switches and routers, this will introduce an error into the time offset estimate; this is asymmetry.

Two mechanisms can be used for calculating delay: end-to-end, or peer-to-peer (involving delay being calculated on each individual link, rather than the entire system). In Substation networks redundancy is key, and seamless switchover of network paths in the event of failures is therefore critical. To facilitate this, peer-to-peer PTP delay mechanisms are used, as all delay information required for new network paths is already known based on the link delays

For Peer-to-Peer PTP systems, the timed messages are SYNC, PDELAY_REQ and PDELAY_RESP as shown below. (Note: '2-Step' operation removes the requirement for fast hardware timestamping on-the-fly, but is not covered here for simplicity.) Sync messages carry the origin timestamp T1 through the system, and increment the value of the CorrectionField within the packet to account for accumulated delay through network links and devices.

Peer Delay messages yield four timestamps (t1, t2, t3 and t4), from which it is possible to calculate the round-trip time for messages from the initiator to responder and back, and ultimately the link delay.



Requirements of Power/Utilities

In the same way that various Ethernet networking techniques may or may not be used as required for an application, so IEEE-1588 allows for PTP 'profiles', allowing users to use optional elements of PTP differently as suits their needs:

"The purpose of a PTP profile is to allow organizations to specify specific selections of attribute values and optional features of PTP that, when using the same transport protocol, inter-work and achieve a performance that meets the requirements of a particular application."

Many industries have leveraged this to create PTP profiles which give the performance and reliability they need.

Note that the implication is that devices within these systems must apply the 'rules' of the determined PTP profile correctly, otherwise any features of the system which depend on timing (end applications or even other network protocols) will potentially fail to operate.

IEC 61850-9-3 defines the PTP Utility Profile for use in substation applications.

The IEEE 2017 Power Profile: C 37.238-2017 builds on the utility profile and allows some additional options for users as outlined below:

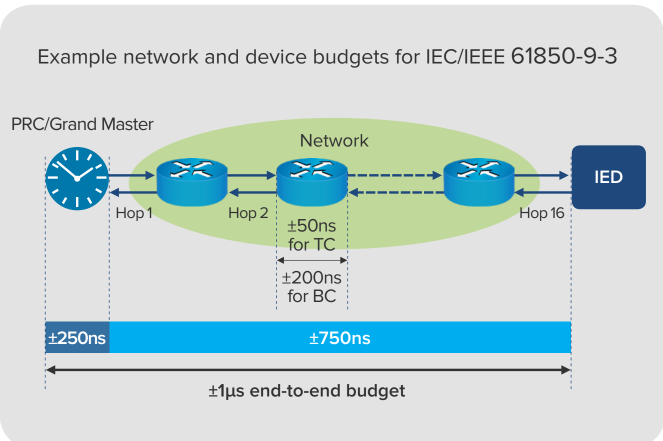
IEC/IEEE 61850-9-3 Utility Profile

- Multicast: 1 pkt/s
- **Grandmaster (GM)** accuracy should be **±250ns**
- **Transparent Clock (TC)** accuracy should be **±50ns** (path delay + Residence time)
- **Boundary Clock (BC)** accuracy should be **±200ns**

IEEE C37.238-2017 Power Profile

- Adds support for TLVs to Utility Profile
- C37.238-2011 (previous revision) also exists as a 'complete' profile

The illustration below gives an example of how this specification can be broken down to provide equipment specifications for Grand Master devices, PTP aware network switches/routers (Boundary or Transparent Clocks), and slave functionality (possibly integrated into IEDs).

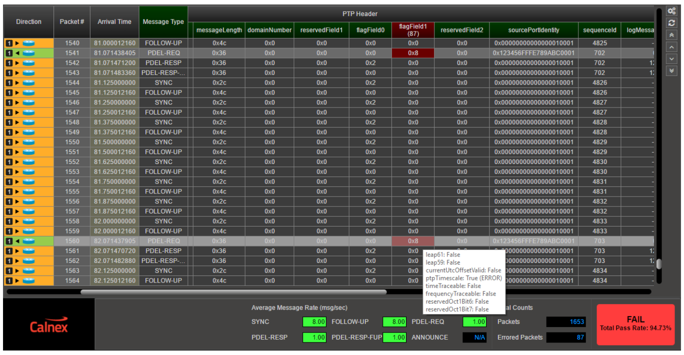


Note that dependent on the number of network hops between the end points of the network, BC and TC performance limits lower than those required for 61850-9-3 compliance may be desirable.

PTP protocol interoperability

Often overlooked, a key item in deploying robust PTP networks is ensuring all devices apply the same PTP profile correctly and consistently. As mentioned previously, there are several related but distinct PTP profiles that could be implemented by equipment vendors, not to mention unforeseen non-compliant implementations.

Initial 'on-boarding' and evaluation should include validation of PTP message fields.

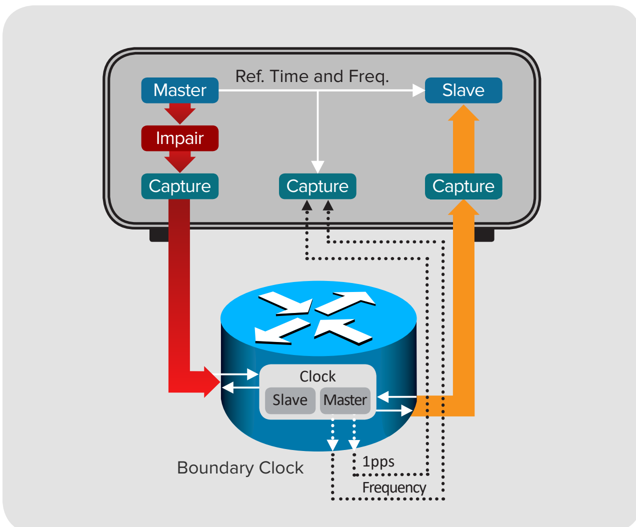


To prove the PTP performance of network equipment:

1. It must be shown that the equipment can connect and engage in a PTP session correctly. It is recommended to use test equipment that can generate and control PTP message exchanges to avoid, for example, masking of interoperability issues (a common problem when using commercial network equipment for test purposes).

2. 'Steady state' timing accuracy should be measured either directly on PTP messages, or on external timing outputs if present. It is essential that test equipment validating performance should have measurement accuracy an order of magnitude better than the device performance specification This should cover the entire stimulus-to-measurement setup, which must be time aligned to confirm, for example, time traceability.

3. Response to likely negative conditions (protocol errors, timing offsets, etc.) should also be tested and measured i.e. 'worst-case performance'. Both long-term gradual timing offsets and short-term jumps in timing should be applied to check robustness of equipment. Again, this should be possible without affecting simultaneous timing accuracy measurements.



Related Products

Calnex Paragon-X

- One box Test Bed for Packet Sync – PTP (1588), SyncE
- PTP (1588) Master and Slave emulation (with optional SyncE support) for fully controllable protocol and timing test
- Unique test methodology for industry-best accuracy
- Complete Standards compliance testing to IEEE 1588-2008, IEC 61850-9-3, IEEE C37.238-2017 (and 2011)

Calnex SNE

- Multi-port, multi-user for maximum flexibility
- 16 ports 1GbE or 12 ports 10GbE/1GbE or 4 ports 25GbE
- Connect "Any Port to Any Port"™
- Over 55 impairments and tools
- Packet fragmentation and reordering
- Network emulation – create complex networks for cloud, data-center and SD-WAN simulation

Calnex PFV

- PTP Field Verifier – decode and view multiple PTP fields in an easy-to-use table format
- Check transmitted PTP messages for compliance with IEEE, IEC, ITU-T and user-defined standards and rules
- Analyze all key fields simultaneously, with individual Pass/Fail indications, plus report generation

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