PTP PRIMER

The Precision Time Protocol (PTP) allows precise timing over Ethernet, but interoperability challenges can be a major barrier to deployment. This document explains the benefits – and challenges – of multiple PTP profiles, and possible test solutions.

PTP Profile Compliance

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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. Whether the benefit is weight reduction in automotive systems due to elimination of point-to-point and ring topologies, or deployment and maintenance cost reduction in mobile backhaul – achieved by delivering customers high-bandwidth data alongside essential network signals – the reach of Ethernet is continuously increasing.

The rising number of applications using Ethernet brings with it many benefits, including an ever-expanding set of 'add-on' features that often have value outside of their initial scope. A prime example is the expansion of the IEEE 802.1 Time-Sensitive Networking (TSN) task group to add to and develop the 802.1 group of standards originally designed for Audio-Video applications to provide a 'toolbox' for Ethernet networks. This allowed application-specific deployments leveraging new features for accurate synchronization, deterministic latency and controlled bandwidth.

Precision Time Protocol (PTP) is a widely adopted technique for synchronizing devices across Ethernet networks, for example as a fundamental part of the Time Sensitive Networking standards mentioned above, as well as an integral part of International Telecommunication Union Standards for packet transport networks.

What is PTP?

PTP is a message-based time transfer protocol that is used for transferring time (phase) and/or frequency 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.

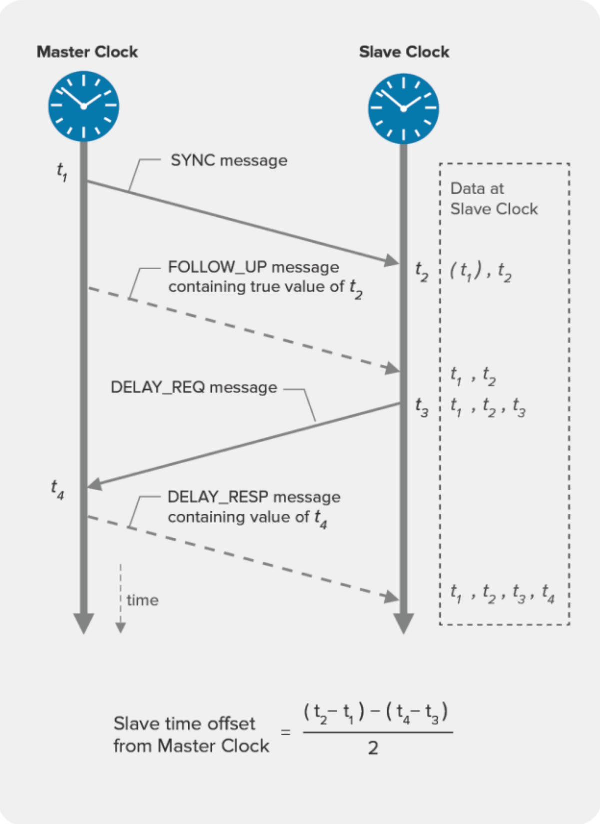
PTP timing messages are carried within the packet payload. The precise time a packet passes an ingress or egress point of a PTP-aware device is recorded using a timestamp. Because packets take different lengths of time to travel through the network – caused by queuing in switches and routers on the path – 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 PDV 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, 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. The timed messages are SYNC, FOLLOW_UP, DELAY_REQ and DELAY_RESP as shown below.



These messages yield four timestamps (t1, t2, t3 and t4), from which it is possible to calculate the round trip time for messages from the master to the slave, and back to the master (assuming that the slave clock is advancing at a similar rate to the master).

The time offset is then estimated using the assumption that the one-way network delay is half the round trip delay, and is used to correct the slave time base to align to the master.

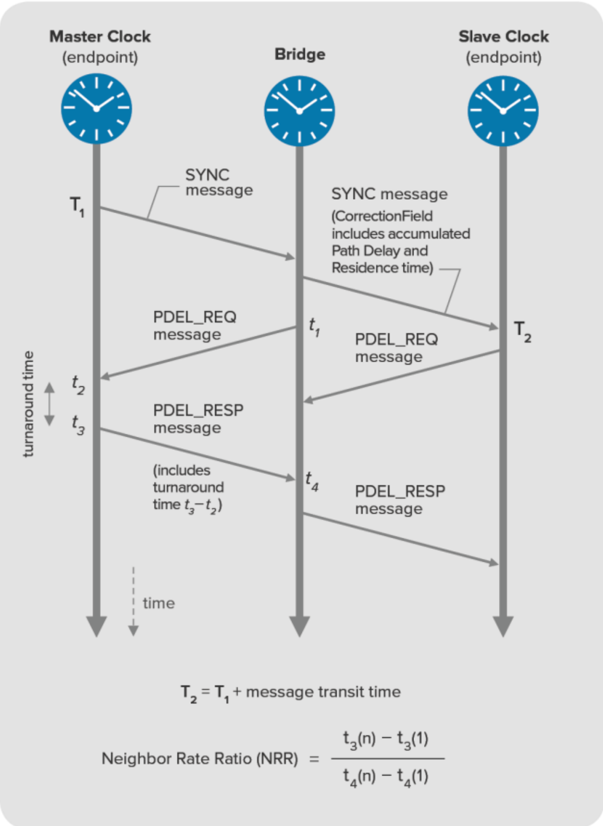
Note that this assumes symmetry, that is, the forward and reverse paths are of equal length. If they are of different lengths, usually caused by queuing in switches and routers, this will introduce an error into the time offset estimate; this is asymmetry.

What is gPTP?

Specifically advantageous for industrial networks is the ability to have fast 'turn-on' – in the context of synchronization this means having locked and accurate timing within seconds. To suit scale and cost requirements, being able to use devices such as 'off-the-shelf' NIC cards that contain lower-cost oscillators is a necessity.

To facilitate this, gPTP systems use a logical syntonization (frequency alignment) technique, in contrast to the physical syntonization technique used in some other PTP systems. This, together with real-time measurement of path and device delays, allows bridge and end-nodes within networks to achieve very fast time alignment.

Distinct from other PTP implementations, gPTP also uses time-stamped messages to calculate frequency offsets and adjust for these during operation. ANNOUNCE messages are also used as described later in this section. (Note: '2-Step' operation allows follow-up messages to carry timestamps of higher accuracy, but is not covered here for simplicity.)



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 path delay.

Bridge devices calculate their own internal delay, and add this to the calculated path delay, incrementing the value in the Sync message CorrectionField to convey this. This allows each node in a chain to calculate time by factoring in the delay which the Master SYNC message has experienced.

Methods are suggested in 802.1AS that allow Peer Delay messages to also be used real-time to estimate the frequency offset from the Master. Peer nodes calculate the Neighbour Rate Ratio (Frequency Offset from the Peer Node), and use this to adjust the CumulativeScaledRateOffset (CSRO) field in ANNOUNCE messages to reflect the accumulated frequency offset. This information is then used to adjust for frequency offsets, and as such is critical for accurate synchronization performance.

Ethernet + PTP = Synchronization for any network?

In principle, the answer to the above is yes. However, 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."

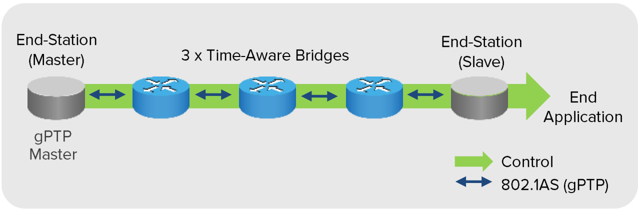
Many industries have leveraged this to create PTP profiles which give the performance and reliability they need, as illustrated in the table below.

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.

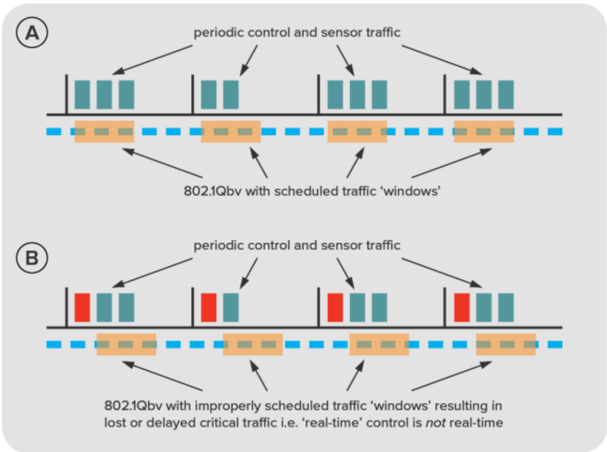
This can become even more complex due to what is generally a benefit of Ethernet equipment – the ability to use 'off-the-shelf' hardware for multiple purposes. As the common core functionalities of networking devices such as switches and routers converge, the likelihood of them being used in discrete applications increases. Ensuring that a 'one-size-fits-all' device applies the correct profile in the correct circumstance is therefore vital.

Application	Phase/Time Accuracy Need?	System/ Network	Priority Feature	Solution?	PTP Profile
Mobile Backhaul	TDD, LTE-A, 5G	National	Performance under varying conditions	'Benchmark' test conditions	'Phase Profile' ITU-T G.8275.1
Power/Utilities	Network fault monitoring – 'Synchrophasors' – IEEE C 37.118	Across countries, in Substation	Redundancy	Peer-to-peer, combine with HSR/PRP	'Utility Profile' IEEE/IEC 61850-9-3
Financial	Timestamping for regulation, e.g. MiFID II, RTS-25	Server 'Estate'	No time jumps	Design to 'drift'	'Enterprise Profile' IETF TICTOC
Automotive	In-car entertainment	In-car	Fast start-up	Logical Syntonisation	'General PTP (gPTP)' IEEE 802.1AS

Evidently, incorrect application of a PTP Profile in a Time-Sensitive Network can cause issues. In the diagram below, a device was developed and deployed in a testbed intended to simulate an industrial timing network. Correct performance should allow Time-aware scheduling, as defined in Time Sensitive Networking standard IEEE 802.1Qbv, allowing critical traffic to move deterministically through the system. Correct implementation of the 'gPTP Profile' 802.1AS will allow the timing of prioritised traffic 'gates' to work correctly.



In this example, an unforeseen issue with the PTP protocol implementation has resulted in Sync messages being sent at the wrong rate, causing subsequent issues with the handling of Peer Delay messages.



As a result, timing calculations have run using incorrect timing information, ultimately causing traffic to be incorrectly delayed and dropped. In the case of critical command messages in a deployed system, this could result in mistiming and damage to machinery, incurring costly downtime.

Clearly these situations should be resolved, and continue to be validated during any subsequent development. However, determining PTP profile compliant performance can be complicated and time-consuming for several reasons:

- Issues can be intermittent
- Tools exist to view packet contents, but comparison with expected values is manual, and potentially subject to error
- Platform development can encompass multiple PTP profiles simultaneously, adding further complexity

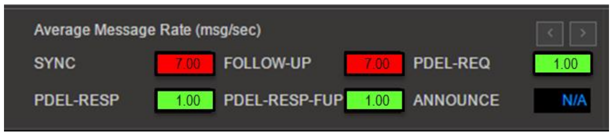
Related Products

PTP Field Verifier (PFV)

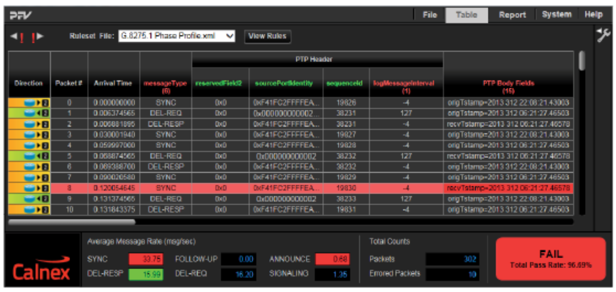
Calnex have developed the PFV to help engineers test and deploy PTP systems.

Users can parse conventional packet capture files, decode and display, and with one click, highlight all areas of non-compliance against a chosen PTP profile.

Here, the issue mentioned in the example above has been immediately highlighted as a failure, saving hours of debug time, and avoiding finding issues at a later (and more costly) date.



Automatic report generation capability also allows users to give third-party validation of their implementations, useful for proposals to customers, and for focussed troubleshooting in multi-vendor environments.



Calnex Solutions Ltd
Oracle Campus
Linlithgow
West Lothian EH49 7LR
United Kingdom

tel: +44 (0) 1506 671 416
email: info@calnexsol.com

calnexsol.com

CX7006 v1.0