

The ITU-T has recently approved Recommendation G.8273.4, which describes the performance of clocks designed to work in the Partial Timing Support synchronisation architecture. This document provides an overview of what PTS is and how it is used in the network. It also describes the clocks themselves and how they work.

Calnex document number CX6007 is a companion document and describes the approach required to test these clocks in the lab.

What is Partial Timing Support (PTS)?



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Level of PTP support provided by the network

Precision Time Protocol (PTP) is a method of distributing time over a packet network that is widely used in telecoms networks to meet the synchronisation needs of mobile basestations. While it can be operated over various types of packet networks, for best accuracy, it is desirable if the switches or routers in the network are “PTP-aware” and provide support for the PTP protocol such as boundary or transparent clocks. These types of clocks not only participate in the protocol, they also provide additional correction to reduce the effect of variable delay through each network element, such as might be caused by queuing and congestion in the network.

The ITU-T has defined two different models for time distribution over networks using PTP, depending on the level of PTP support provided within the network itself. If all the nodes in a network provide PTP support, this is known as “Full Timing Support” or FTS. In this model, time is derived initially from one of the global navigation satellite systems (GNSS) via a Primary Reference Time Clock (PRTC), and transmitted using PTP across a “fully PTP-aware” network to the T-TSC (Telecom – Time Slave Clock), as shown in Figure 1.

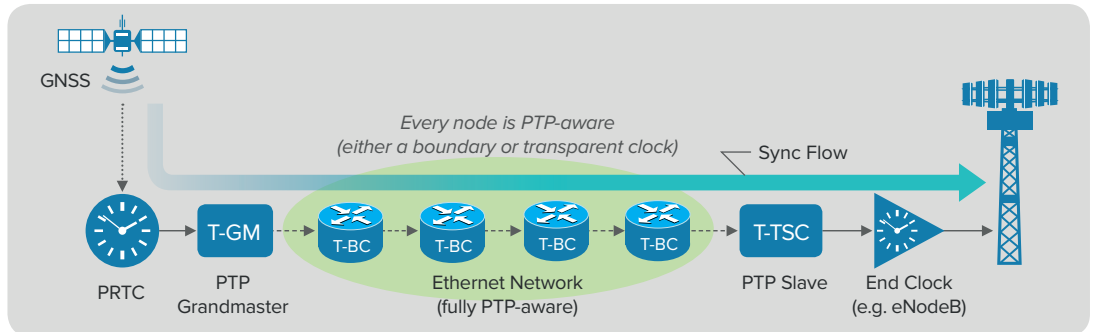


Figure 1: Delivering time over a fully PTP-aware network

In an FTS network, the PTP is carried from node-to-node at the Ethernet layer. The protocol aspects of the method are described in a “PTP Profile” (a set of operating parameters for PTP), defined in ITU-T Recommendation G.8275.1.

However, it is also possible to operate PTP over networks that don’t provide such support, or only provide PTP support at a limited number of nodes. This is known as “Partial Timing Support”, or PTS. An example is shown in Figure 2, where time is derived initially from GNSS, and transmitted using PTP across a “partially PTP-aware” network to the T-TSC-P (Telecom – Time Slave Clock – Partial). In the example shown, only one of the nodes has any PTP support. For PTS networks, PTP is distributed at the IP layer using the PTP profile described in ITU-T Recommendation G.8275.2.

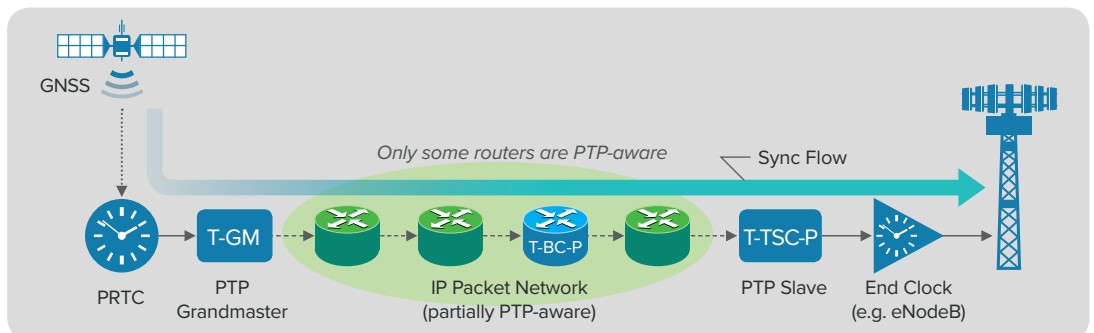


Figure 2: Delivering time over a partially PTP-aware network

It is also possible that none of the switches and routers provide any PTP support, as shown in Figure 3:

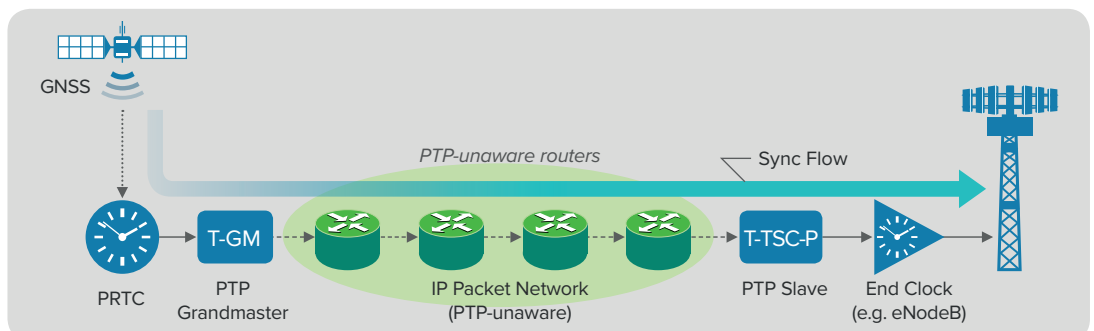


Figure 3: Delivering time over a PTP-unaware network

2 Use Cases for PTS

There are three main use cases for PTS in mobile telecoms:

- Operation over a network that has no (or limited) timing support
- Bridging between areas of full timing support
- As a backup to a GNSS receiver

2.1 Operation over a network that has no (or limited) timing support

A typical use case is where the mobile operator wants to provide service across a campus or large building (such as an airport, a shopping mall, or an office complex). One solution is to put a GNSS antenna on the roof to get the correct time, and distribute timing using PTP over the campus network to the various small cells or Radio Units (RUs) around the campus, as shown in Figure 4.

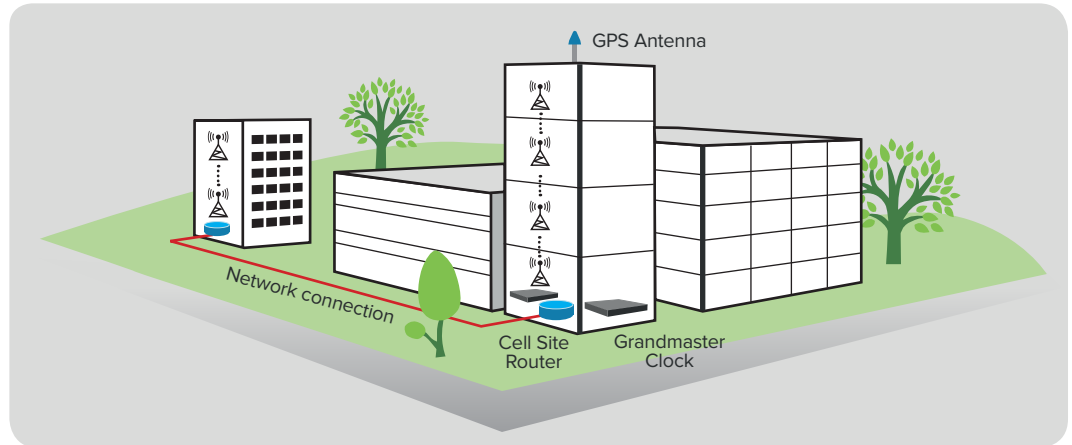


Figure 4: Delivering time over a PTP-unaware campus or building network

However, the campus network is generally owned and operated by the building owner rather than the mobile operator, and they may be unlikely to provision PTP-aware devices in their network. Therefore, this is normally equivalent to the PTP-unaware case shown in Figure 3.

2.2 Bridging between areas of full timing support

One common use case in mobile networks is to bridge across a packet network that is owned by a third party, e.g. the incumbent “wired” network provider, or a building or campus network. Many mobile operators use this to extend the reach of their network, enabling provision of basestations without expensive network build-out, or where network provision is not permitted or practical.

In this case, special “synchronisation inter-working functions” (IWF) are required to interface between the different PTP profiles in use. An IWF is similar to a boundary clock from a synchronisation perspective and has similar performance characteristics, but from a protocol perspective, each PTP profile is a distinct and separate PTP domain. These are shown in Figure 5.

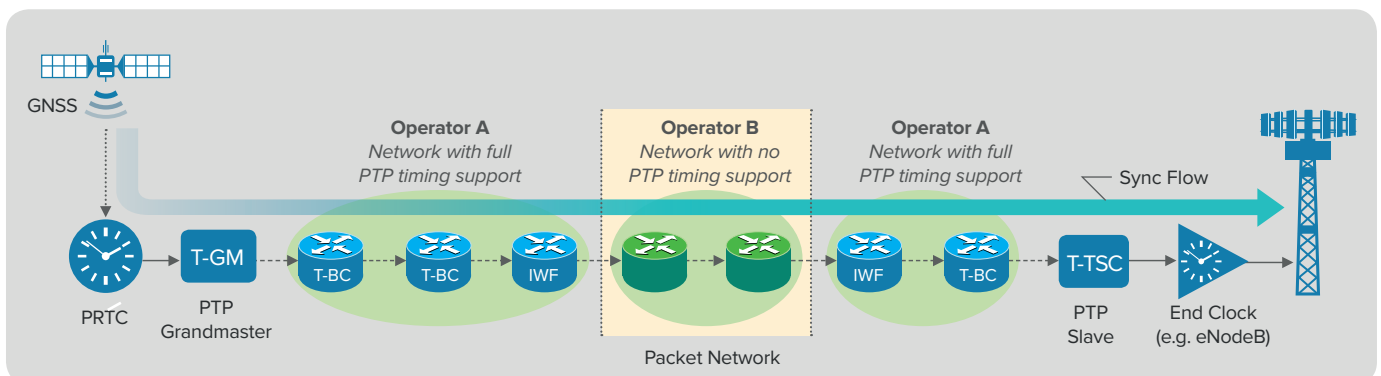


Figure 5: Bridging over a PTP-unaware network

2.3 Assisted Partial Timing Support (APTS)

A special case of a PTS network is called “Assisted Partial Timing Support”, or APTS. In this case, the primary sync flow is provided by a GNSS receiver at or very close to the end clock or basestation. In order to provide a backup option, PTP is used over a third-party network provider. This is very common in North America, where the mobile operators may have originally deployed cdmaOne or cdma2000 mobile networks. These required a GPS receiver at every basestation, therefore there is already a GPS receiver at most cell sites.

Over the years there has been a growing realisation in these mobile operators that GNSS systems are vulnerable either to interference from jammers or spoofers, or more commonly due to weather damage to antennas. Therefore, the use of PTP is a good backup for when the GNSS receiver may fail, allowing enough time for the operator to send someone out to fix the antenna.

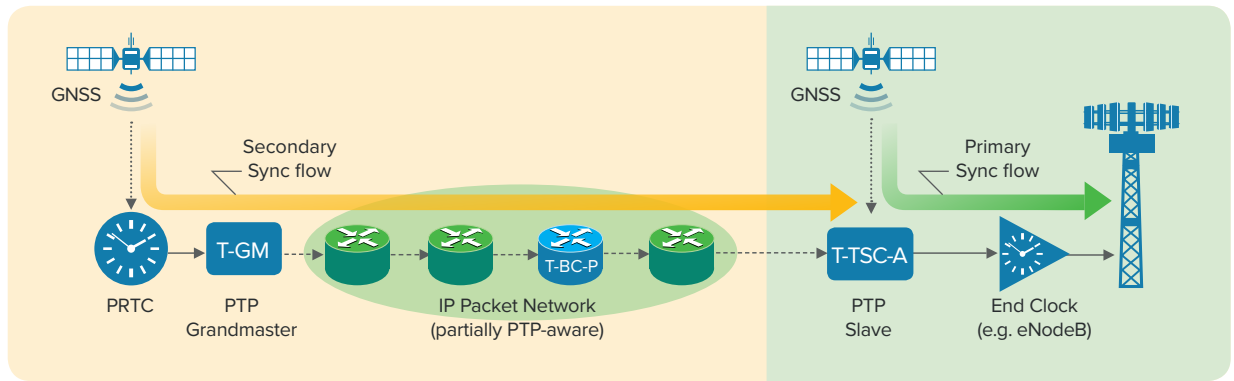


Figure 6: PTP used as backup to GNSS (APTS)

The relevant ITU-T and IEEE standards covering the operation of PTS are the following:

- | | |
|---------------------------------------|------------------------------|
| 1. General aspects and description | G.8275 Appendix I |
| 2. Protocol aspects and PTP profile | G.8275.2, IEEE1588-2008 |
| 3. Network aspects and network limits | G.8271.2 |
| 4. Clock specifications: | |
| • PRTC and T-GM | G.8272 |
| • APTS clocks: T-BC-A and T-TSC-A | G.8273.4 (clause 7, Annex A) |
| • PTS clocks: T-BC-P and T-TSC-P | G.8273.4 (clause 8, Annex B) |

3.1 Protocol Aspects and PTP Profile

The protocol used to transmit time over the network is PTP version 2, as defined in IEEE1588-2008. The specific aspects of PTP used are described in a “PTP Profile” in ITU-T Recommendation G.8275.2.

The key feature of this profile is that it uses PTP over unicast IP allowing it to operate over existing routed networks. The message rates are negotiated between the slave and the grandmaster, with message rates between 1 and 128 messages per second. End-to-end messaging (sync and delay_request/response) is used, as peer-to-peer messaging requires every node to be PTP aware.

The Best Master Clock Algorithm (BMCA) used is the version already defined in G.8275.1, which is slightly modified from the default BMCA in order to allow multiple active grandmasters in a domain. This speeds up the process of swapping between grandmasters in the event of a network failure, or if the grandmaster loses its GNSS connection and goes into holdover. The clockClass definitions are also the same as defined in G.8275.1.

3.2 Network Aspects and Network Limits

ITU-T Recommendation G.8271.2 defines the performance limits that apply at various points across the network. Five reference points are defined, with the time error limit defined for each reference point:

A. Output from the PRTC (normally this is internal to a combined PRTC/T-GM device)	100ns
B. Output from the PTP T-GM (normally the same as reference point A)	100ns
C. Input to the T-TSC-x (the PTP slave clock input)	1100ns
D. Output from the T-TSC-x (often this is internal to the end node)	1350ns
E. Output from the end clock (e.g. the radio signal, defined by 3GPP)	1500ns

The locations of the reference points are shown in Figure 7:

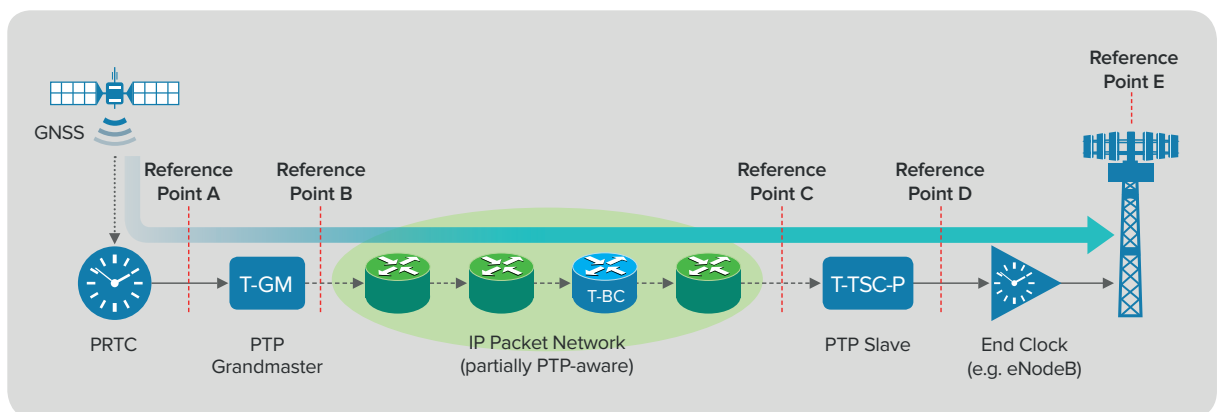


Figure 7: Network Reference Points

Of these, points A and D are not always accessible, as they are commonly internal to the equipment. For example, in the case of a PRTC, the Grandmaster function (T-GM) is normally built into the device. Point B is the specification of the combined PRTC/T-GM, as defined in G.8272. Reference point C is the most important limit, defining the performance of the network itself. Point E is defined on the radio signal at the antenna point, and is covered by the 3GPP specifications for radio synchronisation.

3.3 Dealing with Packet Delay Variation

The time error at reference point C is calculated on the bi-directional flow of PTP messages, comparing the timestamps in the PTP flow to a reference clock. Since most (or all) of the routers in the network may be PTP-unaware, the synchronisation performance will be affected by variations in delay from packet to packet, commonly known as packet delay variation (PDV). Each packet will have a different delay depending on how much queuing it experiences at each node in the network.

In a typical packet network there will be a minimum delay corresponding to packets experiencing no queuing at all at any node. The probability that a given packet experiences significant queuing delays is proportional to the level of traffic in the network. A probability density function of packet delays might look something like Figure 8. As can be seen, the delay is much more likely to be close to the minimum when there is not much network congestion.

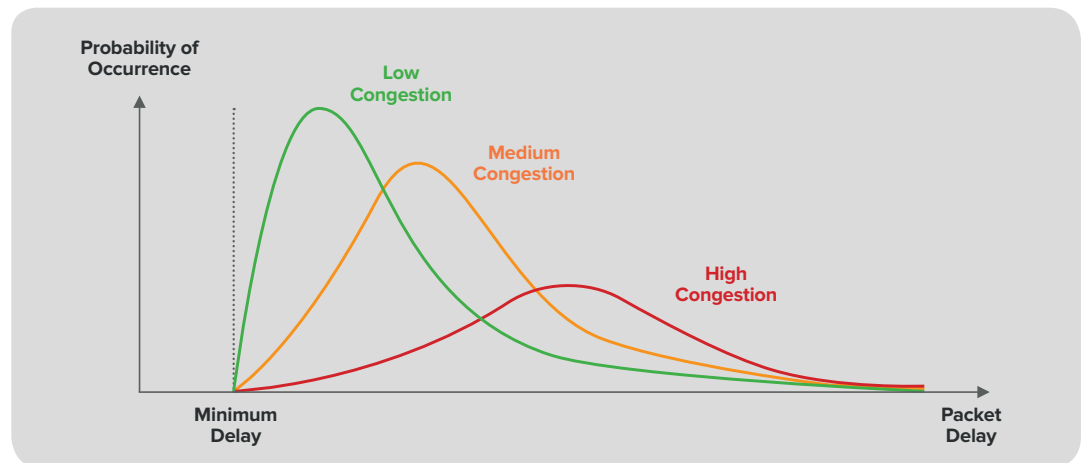


Figure 8: Histogram of packet delays

An intelligent PTP slave clock can take advantage of this distribution of delays. Since the minimum delay is more or less constant (outside of transient events such as re-routing), the clocks use information from those packets with close to the minimum delay to compute the time offset to the master. Packets with much longer delays will introduce more time error into the clock and the information from these packets are therefore discarded.

Therefore, the metric used to indicate the amount of time error introduced by the network at the input to the slave clock has to take a similar approach to be representative of what real clocks can achieve. The metric used is called “pktSelected2wayTE” (packet-selected two-way time error) and it uses the process shown in Figure 9 to calculate the effective time error at reference point C.

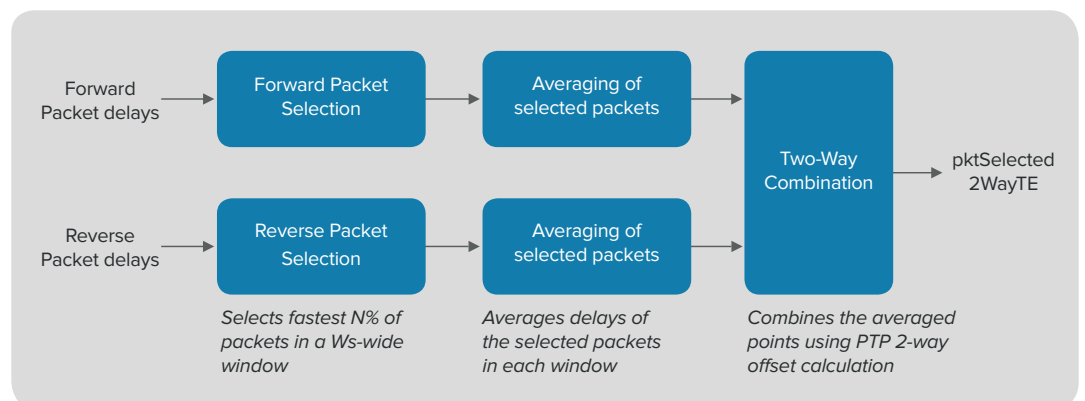


Figure 9: pktSelected2WayTE calculation

This metric involves three stages:

1. The measured delays are divided up into 200s-wide time windows. In each window, and for each direction of flow, the fastest 0.25% of packets are selected.
2. The delays of the selected packets are averaged together helping to reduce noise caused by outlying results. This produces a single value in each direction representing the average minimum delay for each time window.
3. The delay values for each direction are combined using the standard PTP 2-way time offset calculation to produce a single time error value for each time window.

The time window is then slid 20s along the set of measured delays set and the process repeated, yielding a new time error value every 20s.

3.4 Functional Models

3.4.1 APTS Clocks

Annex A of G.8273.4 describes the functional model of the T-BC-A and T-TSC-A. The following diagram is a simplified version of Figure A.1 from that document:

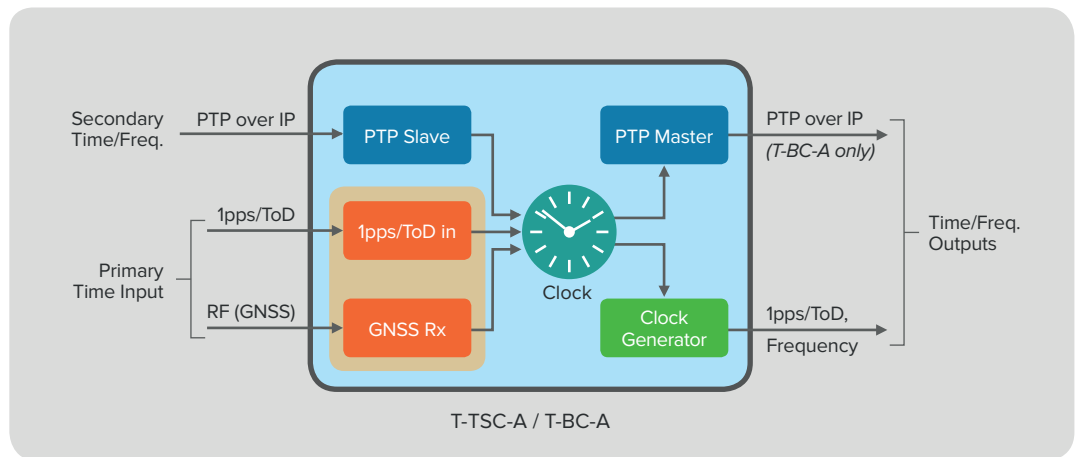


Figure 10: T-TSC-A and T-BC-A Functional model

The primary time input is usually an RF signal from the GNSS antenna. In some situations, the GNSS receiver is a separate device, and the primary time input is a 1pps/ToD signal.

The secondary time or frequency input (the backup signal) is provided using PTP carried over an IP network. (For simplification above, the arrow denotes the direction of the synchronisation flow, although PTP packets actually flow in both directions).

The Clock function receives time and frequency from the input sources. In the event of a failure in the GNSS receiver, it will switch to the secondary PTP input. In general, for a wide-area packet network, the asymmetry of the network (the difference between the forward and reverse delays) is unknown and this can lead to a constant time error (cTE) in the PTP time information. However, the clock is able to measure that asymmetry when the GNSS input is present, and use that information to compensate for it afterwards. This is shown in Figure 11.

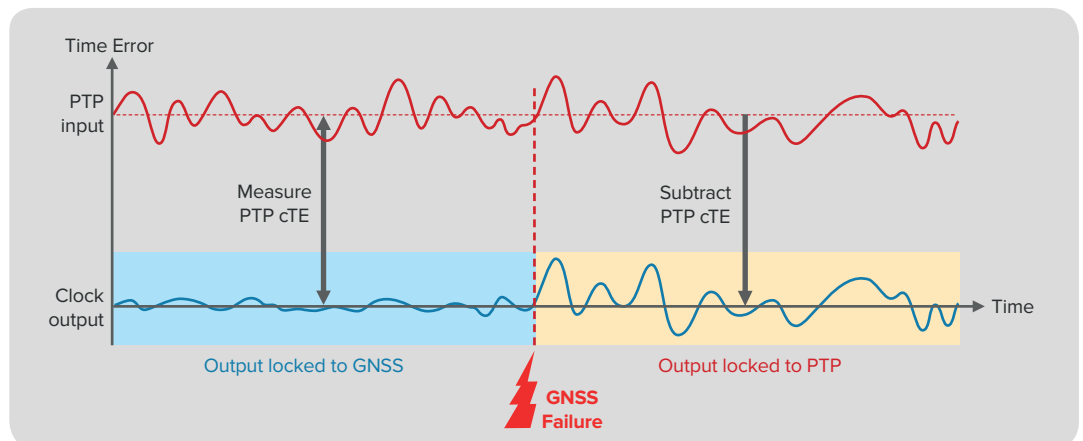


Figure 11: Switching from GNSS to PTP

An alternative but equivalent strategy is to use just the frequency information from PTP, with PTP maintaining the “tick” rate of the clock after the GNSS input is lost.

The clock outputs include PTP (for a boundary clock function, the T-BC-A), 1pps/ToD outputs (for a slave clock function), and sometimes frequency outputs (e.g. telecom frequency signals such as 2.048Mbit/s or 1.544Mbit/s).

As noted in the previous section, this type of clock has to be capable of handling large amounts of PDV caused by the queuing elements within the routers along the network path. Typically this will involve the use of packet selection algorithms and very low-bandwidth filters to reduce the noise. It should not be expected that a T-BC or T-TSC from the FTS method can be used in an APTS architecture as the internal algorithms and performance requirements will be quite different.

3.4.2 PTS Clocks

Annex B of G.8273.4 describes the functional model of the T-BC-P and T-TSC-P. The following diagram is a simplified version of Figure B.1 from that document:

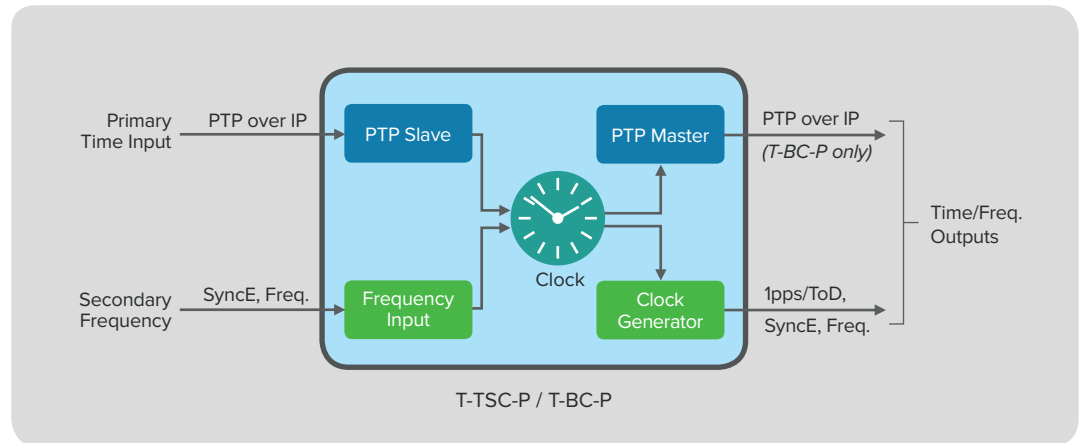


Figure 12: T-TSC-P and T-BC-P Functional model

The primary time input is provided using PTP carried over an IP network. (For simplification above, the arrow denotes the direction of the synchronisation flow, although PTP packets actually flow in both directions.) A secondary frequency input may be used as a backup signal, such as a SyncE signal or a telecom frequency (2.048Mbit/s or 1.544Mbit/s). This input might not be present in all implementations.

The Clock function receives time and frequency from the input sources. In the event of a failure in the PTP signal, it will use the frequency input to maintain an accurate “tick” rate. If there is no valid frequency input, it will rely on its local oscillator.

The clock outputs include PTP (for a boundary clock function, the T-BC-P), 1pps/ToD outputs (for a slave clock function), and sometimes frequency outputs (e.g. SyncE or telecom frequency signals).

Similarly to the APTS clock, this type of clock has to be capable of handling large amounts of PDV caused by the queuing elements within the routers along the network path. It should not be expected that a T-BC or T-TSC from the FTS method can be used in a PTS architecture as the internal algorithms and performance requirements will be quite different.

1pps	1 pulse per second
3GPP	3rd Generation Partnership Project
APTS	Assisted Partial Timing Support
BMCA	Best Master Clock Algorithm
cTE	Constant Time Error
FTS	Full Timing Support
GNSS	Global Navigation Satellite System
IP	Internet Protocol
ITU-T	International Telecommunication Union – Telecommunication Standards
PDV	Packet Delay Variation
PRTC	Primary Reference Time Clock
PTP	Precision Time Protocol
PTS	Partial Timing Support
RU	Radio Unit
SyncE	Synchronous Ethernet
T-BC	Telecom Boundary Clock
T-BC-A	Telecom Boundary Clock – Assisted partial timing support
T-BC-P	Telecom Boundary Clock – Partial timing support
T-GM	Telecom Grandmaster Clock
T-TSC	Telecom Time Slave Clock
T-TSC-A	Telecom Time Slave Clock – Assisted partial timing support
T-TSC-P	Telecom Time Slave Clock – Partial timing support
ToD	Time of Day

Related Products: Calnex Paragon-neo



The Paragon-neo delivers high accuracy sub-nanosecond timing measurements at rates up to 100GbE.

Test hybrid devices simultaneously with PTP Time Error/SyncE wander and measure output packet timing, recovered clocks and SyncE wander with unbeatable test accuracy and repeatability. Plus, test network clocks to the following ITU-T standards:

Application	Standard
Boundary Clock Testing	ITU-T G.8273.2
Transparent Clock Testing	ITU-T G.8273.2
APTS Clock Testing	ITU-T G.8273.4
Master Clock Testing	ITU-T G.8272
Slave Clock Testing	ITU-T G.8273.2



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