PTP PRIMER

This document outlines how IEEE 802.1AS (gPTP) provides the high-accuracy synchronization which is the foundation of Time Sensitive Networking (TSN), what the challenges are for testing and developing Automotive gPTP, and recommended best practice for proving synchronization performance of devices and networks.

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gPTP: Proving time accuracy for Automotive Systems

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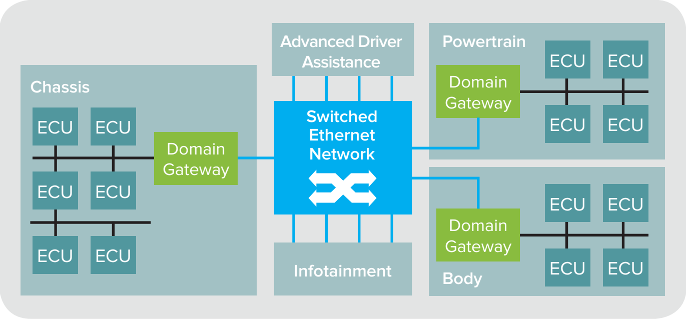
IEEE 802.1 – TSN and Synchronization

Automotive systems encompass a wide range of applications such as audio-video, motion sensing, parking assistance and in some cases automated driving that, while varying in specific networking requirements, all share a common need for distributed real-time data transfer. To allow potential new capabilities, as well as provide a solution ready to handle current and future data requirements, plus benefit from reduced weight and simplified connections provided by switched multiplexed network topologies, the clear trend is a move from the point-to-point and ring topologies of CAN and MOST respectively, to a full in-car Ethernet network.



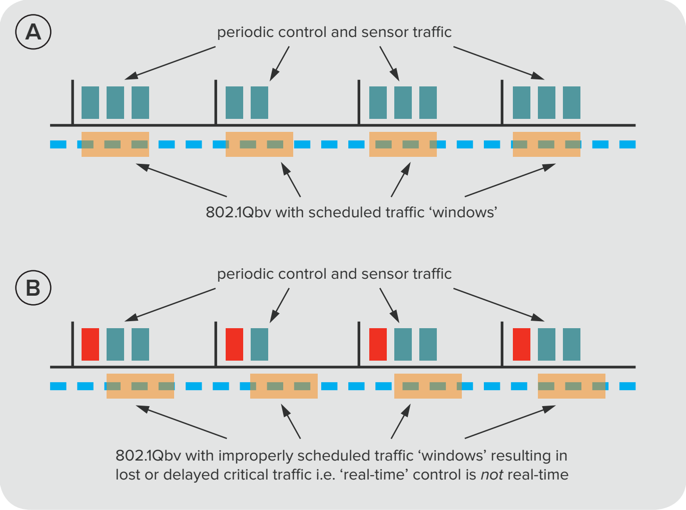
To allow Ethernet to serve the particular requirements of distributed real-time systems which are increasingly important in automotive applications (among many others), the IEEE 802.1 Time-Sensitive Networking (TSN) task group aims to add to and develop the 802.1 group of standards to provide a 'toolbox' for Ethernet networks, allowing application-specific deployments to leverage available capabilities to meet specific needs.

Although details can vary greatly based on the end application, it is generally agreed that network implementations must provide:

- Accurate Synchronization
- Deterministic Latency
- Controlled Bandwidth

Synchronization is inherently required for many in-car applications, ranging from infotainment to automated driver assist and ultimately autonomous driving. Equipment participating in these applications should be time aligned to better than 1µs across the system.

Beyond this, many of the defined 802.1 standards which provide other required networking features, such as 802.1Qbv for Quality of Service guarantees through time-aware traffic scheduling, rely on accurate time provided through the Ethernet network to enable performance. The impact on time-aware scheduling of timing errors is illustrated below. Errors in the transfer of time will therefore manifest in degraded or failed performance of other TSN features.



Introduction to gPTP (IEEE 802.1AS)

Shared time throughout an Automotive Ethernet network is essential for synchronizing end applications, as well as to enable Time-Sensitive Networking functions such as scheduling that improve determinism of network latency (note also that the higher the level of synchronization that can be guaranteed through networks and devices, the better potential end performance – especially important for safety-critical applications).

For communication systems built using Ethernet, PTP (Precision Time Protocol, defined in IEEE1588-2008) provides a highly accurate method of transferring time. Furthermore, 1588 allows application-specific 'profiles' to be developed for particular needs, resulting in the IEEE 802.1AS general PTP (gPTP) profile being developed (originally for Audio-Video Bridging applications) and being further developed by the TSN task group as 802.1AS-REV.

What is PTP?

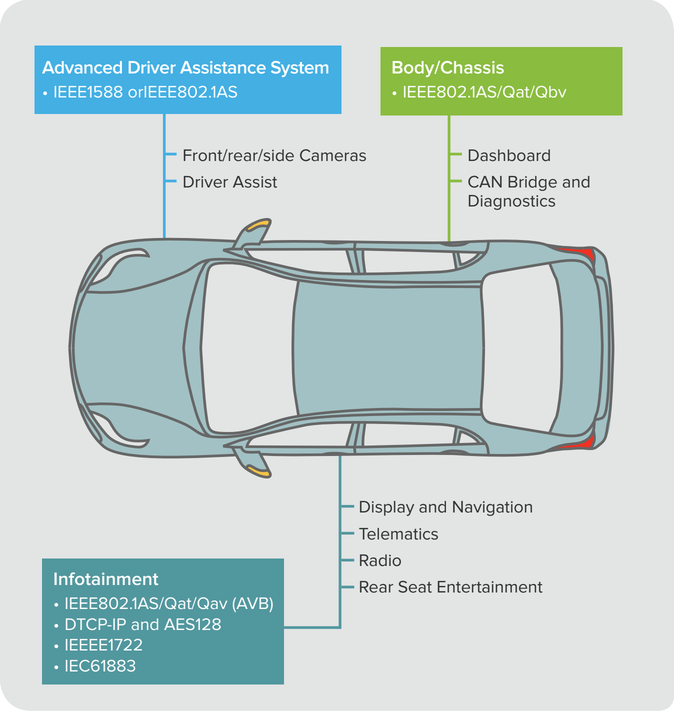
PTP is a message-based time transfer protocol that is used for transferring time (phase) and/or frequency across a packet based network. It ensures various points in the network are precisely synchronized to the reference (master) clock so that the network meets specific performance limits according to the specific 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. Assessing the Time Error introduced by these devices is critical to determining network topology, suitability of equipment, and demonstrating network timing compliance.

Why gPTP?

Specifically advantageous for automotive environments is the ability to have fast 'turn-on' – in the context of synchronization this means having locked and accurate timing within seconds.

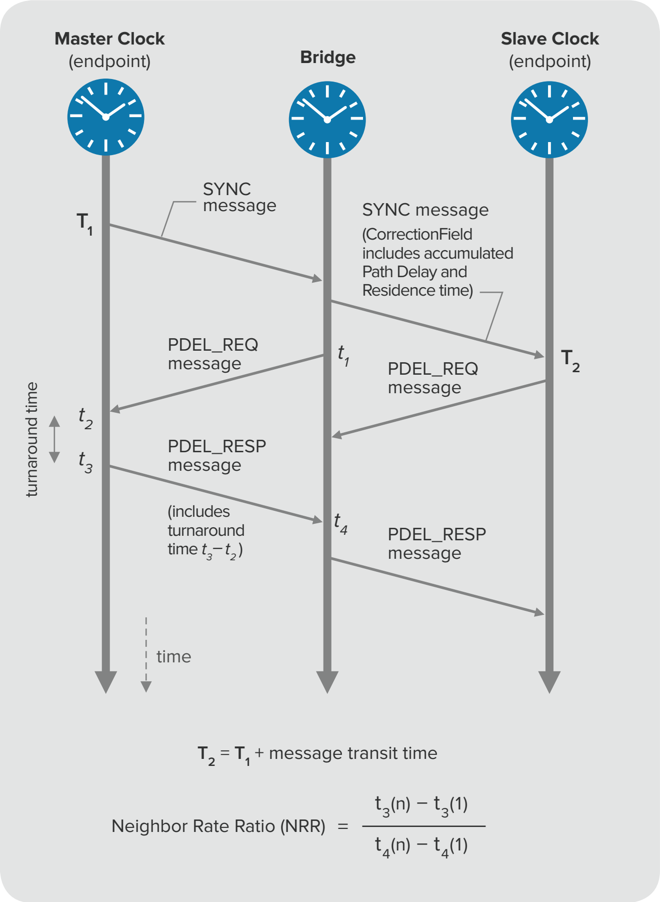
To facilitate this, gPTP systems use a logical syntonization (frequency alignment) technique, in contrast to the physical syntonization technique used in some other PTP systems. This, together with real-time measurement of path and device delays, allows bridge and end-nodes within an automotive system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



How does PTP work?

gPTP uses the exchange of time-stamped messages to communicate time from a master clock to a number of bridge and end-point devices. The time-stamped messages are SYNC, PEER_DELAY_REQ and PEER_DELAY_RESP as shown below.

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.

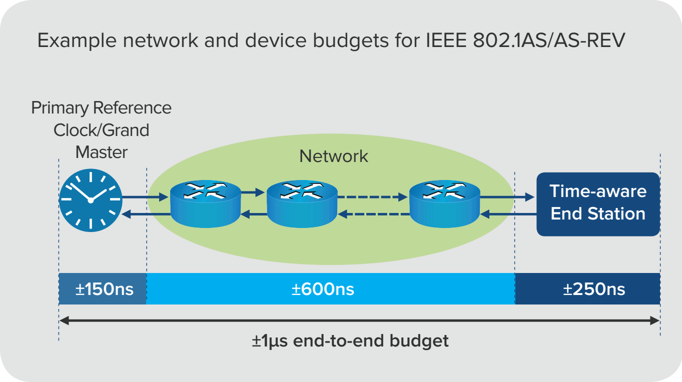
Methods are suggested in 802.1AS that allow Peer Delay messages to also be used real-time to estimate the frequency offset from the Master. Peer nodes calculate the Neighbour Rate Ratio (Frequency Offset from the Peer Node), and use this to adjust the CumulativeScaledRateOffset (CSRO) field in ANNOUNCE 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.

Determining and validating gPTP performance

What is the required network and equipment performance? As described, gPTP is intended to deliver a time signal with a maximum of ±1μs divergence across a time-aware network.

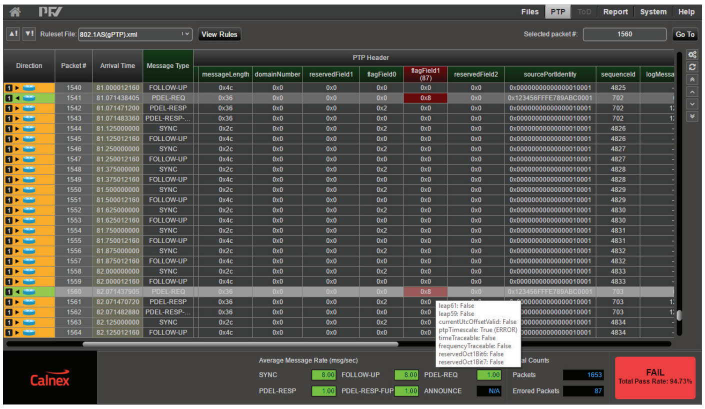
The illustration below gives an example of how this specification can be broken down to provide equipment specifications for Grand Master endpoint devices, time-aware bridges, and slave endpoint devices.

Dependent on the number of network hops between the end points of the network, bridge performance limits can vary by application and deployment. As per the illustration, 5 hops would give a per device limit of +/- 600ns / 5 = 120ns per device. Better timing performance could enable larger networks and/or more efficient operation of TSN techniques.


Example network and device budgets for IEEE 802.1AS/AS-REV

gPTP protocol interoperability

Often overlooked, a key item in deploying robust PTP networks, is ensuring all devices apply the same PTP profile correctly and consistently. This is particularly important in development environments, where 802.1AS-2011 and 802.1AS-REV implementations, or even other PTP profile implementations, could be available on the same pieces of network equipment. Initial ‘on-boarding’ and evaluation should include validation of PTP message fields.



Ruleset File: 802.1AS(gPTP).xml

Selected packet #: 1560

Direction	Packet #	Arrival Time	Message Type	PTP Header								
				messageLength	domainNumber	reservedField1	flagField0	flagField1 (87)	reservedField2	sourcePortIdentity	sequenceId	logMessa
1 ▶	1540	81.000012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	4825	-
1 ◀	1541	81.071438405	PDEL-REQ	0x36	0x0	0x0	0x0	0x8	0x0	0x123456FFFE789ABC0001	702	[illegible]
1 ▶	1542	81.071471200	PDEL-RESP	0x36	0x0	0x0	0x2	0x0	0x0	0x00000000000000010001	702	[illegible]
1 ▶	1543	81.071483360	PDEL-RESP-...	0x36	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	702	[illegible]
1 ▶	1544	81.125000000	SYNC	0x2c	0x0	0x0	0x2	0x0	0x0	0x00000000000000010001	4826	-
1 ▶	1545	81.125012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	4826	-
1 ▶	1546	81.250000000	SYNC	0x2c	0x0	0x0	0x2	0x0	0x0	0x00000000000000010001	4827	-
1 ▶	1547	81.250012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	4827	-
1 ▶	1548	81.375000000	SYNC	0x2c	0x0	0x0	0x2	0x0	0x0	0x00000000000000010001	4828	-
1 ▶	1549	81.375012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	4828	-
1 ▶	1550	81.500000000	SYNC	0x2c	0x0	0x0	0x2	0x0	0x0	0x00000000000000010001	4829	-
1 ▶	1551	81.500012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	4829	-
1 ▶	1552	81.625000000	SYNC	0x2c	0x0	0x0	0x2	0x0	0x0	0x00000000000000010001	4830	-
1 ▶	1553	81.625012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	4830	-
1 ▶	1554	81.750000000	SYNC	0x2c	0x0	0x0	0x2	0x0	0x0	0x00000000000000010001	4831	-
1 ▶	1555	81.750012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	4831	-
1 ▶	1556	81.875000000	SYNC	0x2c	0x0	0x0	0x2	0x0	0x0	0x00000000000000010001	4832	-
1 ▶	1557	81.875012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	4832	-
1 ▶	1558	82.000000000	SYNC	0x2c	0x0	0x0	0x2	0x0	0x0	0x00000000000000010001	4833	-
1 ▶	1559	82.000012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	0x0	0x00000000000000010001	4833	-
1 ◀	1560	82.071437905	PDEL-REQ	0x36	0x0	0x0	0x0	0x8	0x0	0x123456FFFE789ABC0001	703	[illegible]
1 ▶	1561	82.071470720	PDEL-RESP	0x36	0x0	0x0	0x2	0x0	[illegible]	[illegible]	703	[illegible]
1 ▶	1562	82.071482880	PDEL-RESP-...	0x36	0x0	0x0	0x0	0x0	[illegible]	[illegible]	703	[illegible]
1 ▶	1563	82.125000000	SYNC	0x2c	0x0	0x0	0x2	0x0	[illegible]	[illegible]	4834	-
1 ▶	1564	82.125012160	FOLLOW-UP	0x4c	0x0	0x0	0x0	0x0	[illegible]	[illegible]	4834	-

leap61: False
leap59: False
currentUtcOffsetValid: False
ptpTimescale: True (ERROR)
timeTraceable: False
frequencyTraceable: False
reservedOct1Bit6: False
reservedOct1Bit7: False

Average Message Rate (msg/sec)

SYNC	8.00	FOLLOW-UP	8.00	PDEL-REQ	1.00
PDEL-RESP	1.00	PDEL-RESP-FUP	1.00	ANNOUNCE	N/A

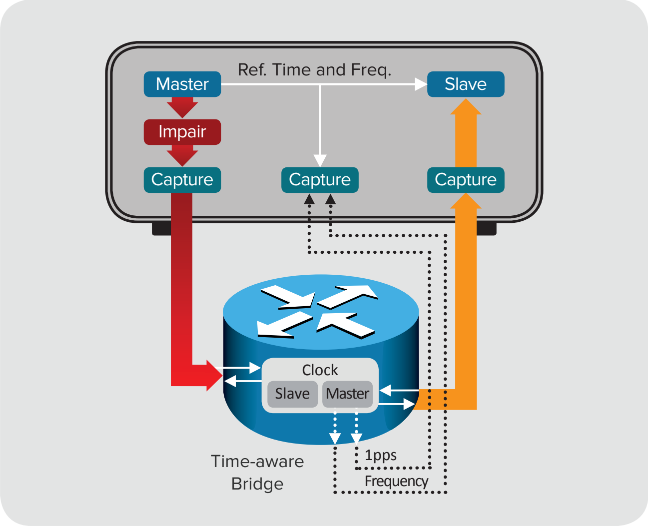
al Counts

Packets: 1653
Errored Packets: 87

FAIL
Total Pass Rate: 94.73%

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 spec (note: 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.



Fully testing contributing error factors

In the event that there is unacceptable time error detected in a device under test, it is critical to be able to further analyze the available data. Taking the example of a time-aware bridge, should the Time Error fail to meet defined performance levels, the contributing error factors are as mentioned previously:

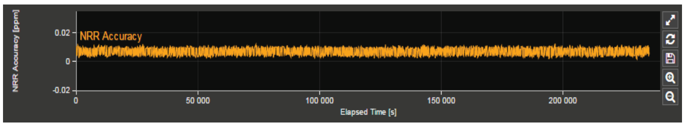
- Device Delay Calculation
- Path Delay Calculation
- Neighbor Rate Ratio (NRR) Calculation

Therefore, it is highly recommended to implement a test environment that provides real-time simultaneous analysis of all of these factors, together with any required stress-testing stimuli.

T1 Time Error

Turnaround Time Accuracy

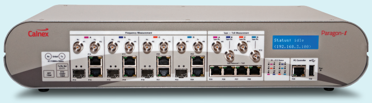
NRR Accuracy



Related Products

Calnex Paragon-One *Automotive*

- Focussed one-box test solution for gPTP
- Master and Slave Emulation for fully controllable protocol and timing test
- Automatic protocol configuration for 802.1AS/AS-REV
- Full timing analysis of all gPTP timing metrics and parameters
- Report Generation capability – prove performance
- Unrivalled test accuracy



Calnex Paragon-t

- Speed up test time and reduce test complexity with multi-clock measurements
- Measure multiple outputs from a chain of time-aware devices
- 4 x Phase (1 pps accuracy) measurements
- 4 x ToD display measurements
- 4 x Frequency measurements

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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