Constraints about Sync

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Abstract

This document describes as an example the constraints for synchronization used today for products.

Log

V0.1	Initial version
V0.2	Added local clock
V1.0	Include feedback from contributors

Content

Figures

Tables

1 References

60802-industrial-use-cases-0918-v13.pdf

60802-Steindl-ExampleSelections-0119-v02.pdf

60802-Steindl-QuantityFigures-0519-v01.pdf

60802-Steindl-TimelinessUseCases-0718-v01.pdf

P802.1AS-Rev/D8.1 (available at http://www.ieee802.org/1/files/private/as-rev-drafts/d8/802-1AS-rev-d8-1.pdf)

ITU-T Rec. G.810-1996, Defnitions and terminology for synchronization networks (available at https://www.itu.int/ITU-T/recommendations/rec.aspx?rec=3713)

ITU-T Rec. G.8260-2015, Defnitions and terminology for synchronization in packet networks (available at h https://www.itu.int/ITU-T/recommendations/rec.aspx?rec=12545)

[Editor’s note: PDFs of ITU-T Recommendations are freely available 6 months after approval.]

2 Terms and Definitions

2.1 Definitions

[Editor's note: definitions (a) – (d) are consistent with analogous definitions in ITU-T Recommendations G.8260 and G.810.]

a) Time error (TE): the difference between the time of a clock and the time of a specified reference clock.
NOTE 1 – the specified reference clock is often a recognized timing standard, e.g., TAI.
NOTE 2 – In general, TE is a function of time.

b) Maximum absolute time error (max|TE|): the maximum of the absolute value of the time error.
NOTE – max|TE| is often computed over a specified time (measurement) interval.

c) Relative time error ($TE_{R(A,B)}$): the difference between the time of clock A (T_A) and the time of clock B (T_B), i.e., $TE_{R(A,B)} = T_A – T_B$.

d) Maximum absolute relative time error (max|TE_R|): the maximum of the absolute value of the relative time error
NOTE – max|TE_R| is often computed over a specified time (measurement) interval.

e) Constant time error (cTE): time error or relative time error that is constant in time (i.e., static)

f) Dynamic time error (dTE): the zero-mean, random component of time error.
NOTE – For a random time error process whose mean is constant in time, the cTE is equal to the mean and the remainder of the random process is the dTE. If the mean is time-varying, it is possible to consider the cTE as being the time average of the mean over a specified time interval, though in practice this might be difficult to measure or compute. The remaining portion of the time-varying mean after subtracting its time average is, in general, not considered to be part of dTE; rather, it is considered a separate component. An example of such a time varying component is the time error due to periodic temperature variation over 24 hours (diurnal variation) of a long fiber link.

g) Jitter: Time error or relative time error, filtered by a specified high-pass measurement filter.
NOTE 1 – The roll-off of the measurement filter below the high-pass corner frequency is usually 20 dB/decade, and the filter has no gain peaking. The high-pass corner frequency is generally 10 Hz or larger.
NOTE 2 – In some cases, a much higher low-pass corner frequency is specified, with corresponding roll-off; in any case, for discrete-time signals the filter has an implied low-pass cutoff at the Nyquist frequency (i.e., one-half the sampling rate).
NOTE 3 – In the synchronization and metrology literature, the term ''jitter' is as defined here. In other literature (e.g., data networking), 'jitter' is often used to mean 'delay variation' (i.e., the time-varying component of delay), but without any high-pass measurement filter. To avoid confusion, the present document uses the term 'jitter' to denote time error filtered by a high-pass measurement filter and dTE to denote unfiltered dynamic time error. Any cTE that is present is removed by a high-pass measurement filter.

application clock
Any step change in the time of an end application clock whose absolute value exceeds 1 µs leads to action being taken by the application or by a person.

If the change is in Global Time, it is reported (i.e., the jumped from time A to time B is reported), and the “new” time is used.

In the case of Working Clock time, a time change of this magnitude or greater is avoided to protect assets and prevent damage. Thus, the end application clock is decoupled (see Figure 1) from the PTP-maintained clock.

The two end application clocks are traceable to a reliable source of time, which should be synchronized to Global Time and Working Clock. The end application clock contains at any time the status of this source of time.

The status is given by the state of the application clock, i.e., “arbitrary”, “free running”, and “in synch”).

2.2 IEEE802 terms

The following terms are defined in the indicated subclauses of IEEE Std 802.1AS-20xx:

a) fractional frequency offset (3.8)
b) Grandmaster Clock (3.13)
c) local clock (3.16)
d) synchronized time (3.29)
e) PTP Instance (3.22)
f) PTP Relay Instance (3.24)
g) PTP End Instance (3.21)
h) PTP Link (3.23)
i) gPTP Communication Path (3.11)

3 TSN in Industrial Automation

3.1 Synchronization

3.1.1 General

A device may be Grandmaster PTP Instance and PTP End Instance

- for the same Clock concurrently to support hot-standby use cases.
- for different Clocks concurrently to support Working Clock and Global Time.

The external error – the error introduced in the system by e.g. receiving time from GPS to synchronize the Clock of the Global Time Grandmaster PTP Instance needs to be stated.

3.1.2 Grandmaster PTP Instance requirements

A Grandmaster Clock shall meet the following requirements under all of its allowed working conditions and for its lifetime

- the fractional frequency offset is in the range of -100ppm / +100ppm
- the absolute value of the maximum rate of change of fractional frequency offset is 3ppm/s
- the counter value increases monotonically

3.1.3 PTP End Instance requirements

A PTP End Instance shall meet the following requirements under all of its allowed working conditions and for its lifetime

- the fractional frequency offset of its local clock is in the range of -100ppm / +100ppm
- the absolute value of the maximum rate of change of fractional frequency offset of its local clock is 3ppm/s
- the counter value increases monotonically
- the PTP End Instance implements an algorithm to control its synchronized time, when the Grandmaster operates under its specified working conditions

3.1.4 Working Clock Domain

For a dedicated network, where the longest path between the Grandmaster PTP Instance and any PTP End Instance as determined by the Best Master Clock Algorithm is 64 hops, $\max|TE_R|$ of the synchronized time, relative to the Grandmaster Clock, shall not exceed |1 µs|.

For a dedicated network, where the longest path between the Grandmaster PTP Instance and any PTP End Instance as determined by the Best Master Clock Algorithm is 100 hops, $\max|TE_R|$ of the synchronized time, relative to the Grandmaster Clock, shall not exceed |1 µs|.

In the above requirements, max$|TE_R|$ is measured between the application clock outputs of the Grandmaster Clock and the PTP End Instance, i.e., clock A is the PTP End Instance application clock and clock B is the Grandmaster Clock.

3.1.5 Global Time Domain

In a network where the longest path between the Grandmaster PTP Instance and any PTP End Instance as determined by the Best Master Clock Algorithm is 100 hops, max$|TE_R|$ of the synchronized time, relative to the Grandmaster Clock, shall not exceed |100 µs|. max$|TE_R|$ is measured between the application clock outputs of the Grandmaster Clock and the PTP End Instance, i.e., clock A is the PTP End Instance application clock and clock B is the Grandmaster Clock.

3.1.6 Device model for clocks

Figure 1 shows the device internal model for clocks with the two instances needed to ensure the availability of a traceable time in a device independent from the availability of the network or a Grandmaster.

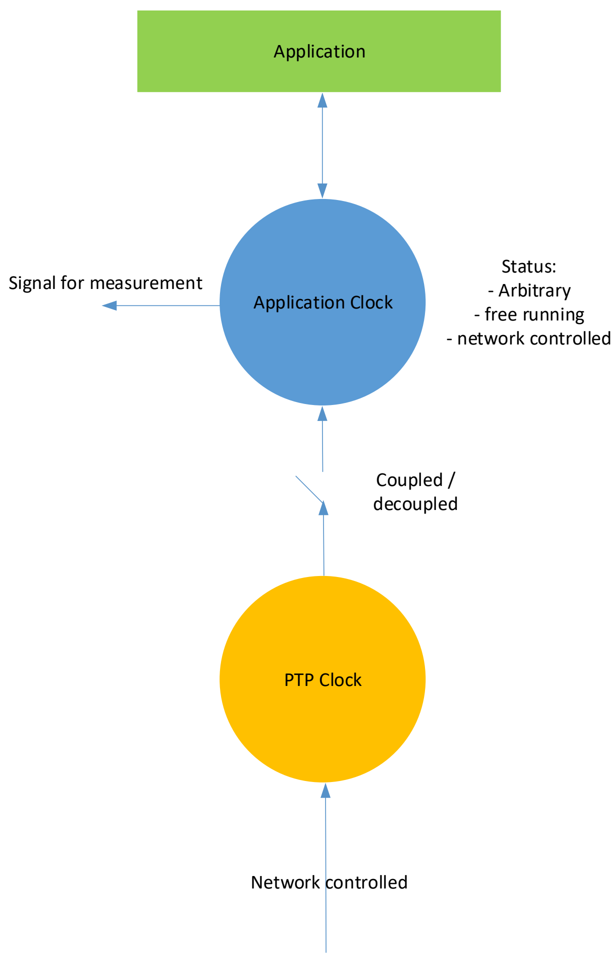

Figure 1: Clock usage principles

3.1.7 Error model

3.1.7.1 General

Synchronization needs to handle the whole path, from Grandmaster PTP Instance to PTP End Instance, through the intermediate PTP Relay Instances. thru the forwarding nodes to the SyncSlave time.

All time errors, cTE and dTE, are accumulated during this process.

Time error can arise in the following two processes:

a) the transporting of time in a PTP Instance and via PTP Links that connect PTP Instances,
b) the providing of time to the Grandmaster PTP Instance, from the ClockSource entity via he ClockMaster entity, and
c) the providing of time to a ClockTarget entity (end application) via the ClockSlave entity.

NOTE – (a) includes time error introduced in a PTP End Instance between the slave port and the ClockSlave entity, and between the ClockSource entity and a master port.

3.1.7.2 Time error components due to relaying of time

Both, the PTP Instances and the PTP Links (in IEEE Std 802.1AS-20xx, a PTP Link is a gPTP Communication Path) contribute to time error. The error components are either cTE (e.g. static link delay error due to asymmetry, PHY delay error due to structure) or dTE (e.g., local clock phase noise, timestamp error due to timestamp granularity). The sources of time error due to relaying time are illustrated in Figure 1.

cTE is either positive or negative; while cTE components at different PTP Instances or PTP Links might compensate each other, in the worst case the cTE components would have the same sign and add linearly. cTE needs to be limited to avoid max|TE| exceeding the respective limit (see 3.1.3 and 3.1.4). dTE is random with zero mean. The distribution of dTE is generally assumed to be either Gaussian (for clock phase noise) or uniform (for timestamp granularity). dTE also must be limited to avoid max|TE| exceeding the respective limit (see 3.1.3 and 3.1.4).

The requirements for cTE are:

- for a PTP Link, cTE shall be in the range of -10ns / +10ns
- for a PTP Instance cTE shall be in the range of -5ns / +5ns

The requirements for dTE are:

- For a PTP Link, dTE is assumed to be zero
- For a PTP Instance, dTE shall be in the range of -50ns / +50ns
  NOTE – for most implementations, dTE is in the range of -20ns / +20ns)

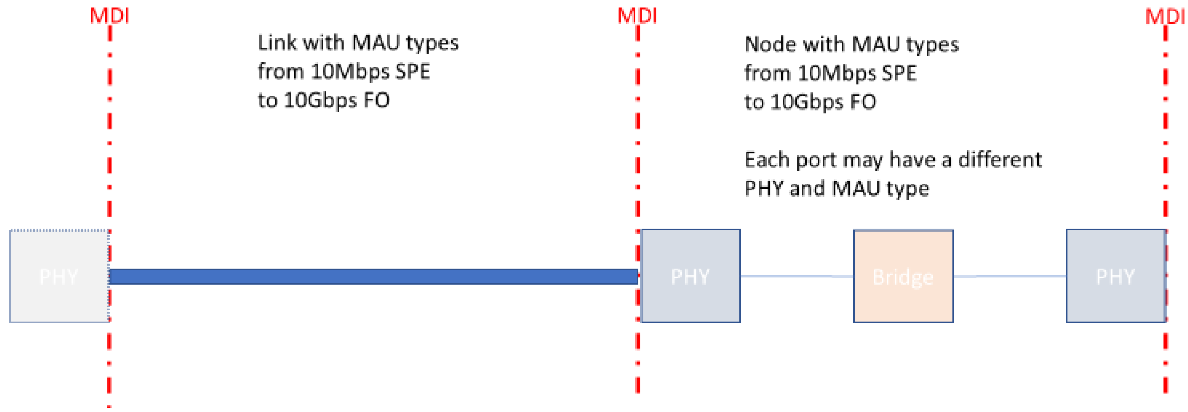

Figure 2: Error scheme – Forwarding

3.1.7.3 Time error components due to providing time to the Grandmaster or to an end application

Both, the Grandmaster PTP Instance and the PTP Instance that provides timing to the end application contribute to time error. The error components are either cTE (e.g., due to reading a value of time for distribution) ordTE.

cTE is either positive or negative; while cTE components at different PTP Instances or PTP Links might compensate each other, in the worst case the cTE components would have the same sign and add linearly. cTE needs to be limited to avoid max|TE| exceeding the respective limit (see 3.1.3 and 3.1.4

dTE is random with zero mean. The distribution of dTE is generally assumed to be either Gaussian (for clock phase noise) or uniform (for timestamp granularity). dTE also must be limited to avoid max|TE| exceeding the respective limit (see 3.1.3 and 3.1.4).

For the transfer of time from the ClockSource to ClockMaster entity at the Grandmaster PTP Instance:

- cTE shall be in the range of -10ns / +10ns.
- dTE is assumed to be in the range -20 ns / +20ns.

For the transfer of time from the ClockSlave to ClockTarget entity at a PTP Instance that is not the Grandmaster PTP Instance:

- cTE shall be in the range of -10ns / +10ns
- dTE shall be in the range -20 ns / +20ns.

For an output synchronization signal (one pulse every ms) at any PTP Instance, used to measure the time error between the Grandmaster Clock and the local clock of a PTP Instance that is not the Grandmaster, total time error (cTE plus dTE) shall be in the range of -10ns / +10ns. The output synchronization signal is illustrated in Figure 2.

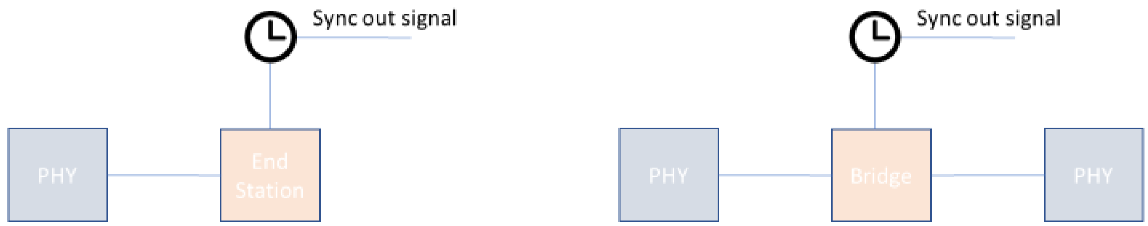

Figure 3: Error scheme – Local clock