IEC/IEEE 60802
Synchronization requirements and solution examples

Update after July 2020 plenary

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Scope

Industrial automation systems used in the areas of

- Public transportation
- Factory automation
- Process automation
- Power generation
- Building automation
- …

do have different environmental requirements.

The environmental conditions from this areas together with the device lifetime and the basic Ethernet PHY frequency quality are defining the requirements for the oscillators.

Many industrial automation products are build based on just one oscillator, which is the only source to drive a local time.

This applies to grandmaster, PTP relay and PTP end instance in this area.

1) http://www.ieee802.org/1/files/public/docs2019/60802-industrial-use-cases-0918-v13.pd

Basic Requirements

Data rate	Upper bound[2)]
10/100Mbit/s	100ppm
1Gbit/s	50ppm
>1Gbit/s	???

Lifetime[1)] > 10years

df/dt <= “Area specific”

Upper bound to f/fN <= “Link speed”

Requirements:

1) For the whole lifetime of the device under all supported environmental conditions, the frequency shall stay in the “upper bounds” and shall not change faster as stated by df/dt.

2) The sync deviation shall stay under all above stated conditions below |1µs|

	Public Transportation	Factory Automation	Process Automation	Other
df/dt	< 3ppm	< 0,3ppm	< 0,3ppm	???

1) Typical value for industrial automation. The real value depends on the product.
2) Given by IEEE802.3 MAU type requirements.

Constraints

There are a lot of sources for frequency deviation effecting error contribution of Grandmasters, PTP relays and PTP end instances. They are all just looked at summed up for the purpose of this contribution.

Production deviation, temperature deviation, aging, voltage ripple, shock and vibration all together shall not create a frequency deviation greater than the “upper bounds” from the previous slides.

Same is valid for the speed of frequency change which shall not be greater than “df/dt” from the previous slides.

The values are not derived from measuring one oscillator – they need to be guaranteed by the oscillator vendor.

Assumption:

Worst case happens if both, the grandmaster and the end-instances are moving from the opposite endpoints of the frequency with the maximum allowed df/dt to the other endpoints, undetected due the transmission delay of the sync message, while still staying inside the stated f/fN limit.

Working Clock and Global Time:

The stated constraints are valid for both.

The IEC/IEEE 60802 requirements for Working Clock seems only achievable with optimizations of the IEEE802.1AS model.

Parameter assumptions for simulation

- Grandmaster
- PTP end instance
- PTP relay
- Link delay

Constraints:
No oscillator ever shows a df/dt of more than the stated limits.
Thus, sinusoidal behavior shall be used for the simulation.
Maximum values derived from the usage of Gigabit data rate applies.

Assumption for simulation Grandmaster

- Oscillator
  - f/fN +/- 50 ppm
- Behavior of the local oscillator
  (a) random movement with max df/dt
  (b) use complete range with max df/dt
  - (I) df/dt = 3 ppm/s [start value]
  - (II) df/dt = 0,3 ppms/s [fallback]
- Sync interval
  - 31,25 ms
- Timestamp precision (500 MHz clock)
  - 2 ns
- Origin Time precision (500 MHz clock)
  - 2 ns

Additional error sources are ignored for this simulation

Assumption for simulation PTP end instance / PTP relay

- Oscillator
  - f/fN +/- 50 ppm

- Behavior of the local oscillator
  (a) random starting point
  (b) worst case shift between GM and PTP end instance)
  - (I) df/dt = 3 ppm/s [start value]
  - (II) df/dt = 0,3 ppms/s [fallback]

- Sync interval
  - 31,25 ms

- Timestamp precision (500 MHz clock)
  - 2 ns

- Origin Time precision (500 MHz clock)
  - 2 ns

- Sync residence time
  - 4 ms
  - syncLocked mode

- Rate calculation/compensation
  - Sliding window, window size seven sync messages
  - Filter median
  - Calculated rate values greater than |250ppm| are assumed to be invalid

- Offset calculation/compensation
  - KiKo (65) and KpKo (11) filter

- Number of hops
  - 100

Assumption for simulation
Link delay

- Pdelay residence time
  - 10 ms
- Timestamp precision (500 MHz clock)
  - 2 ns
- Link asymmetry
  - 0 ns
- Additional error (PHY rx/tx delay variation)
  - +/- 8 ns

Errors in link delay compensation are as critical as errors in residence delay due to the required number of 98/100 hops

Contributors feedback
(Measured Sync deviation value in real world with real products)

An in available products implemented IEEE 802.1AS model based solution using

- 31,25 ms sync interval, 1 s pdelay interval
- syncLocked mode
- Sync residence time (minimum 1ms, majority 4ms and maximum 10ms)
- 2,5 ns Timestamp granularity
- 100 hops, linear topology with GM as first device
- Sinusoidal 3 ppm df/dt for the GM
  Production, temperature, age, voltage variation, … noise df/dt for the PTP end instances
- Upper bound f/fN 100 ppm

Additionally, a sliding window using the sync messages for GM rate calculation in the PTP relays/instances is implemented.

<u>Measured values </u>based on this setup

Sync deviation measured (at the sync out signal pins) between GM and any of the PTP instances
is below |300 ns|

Model assumption for simulation

Basic timer model

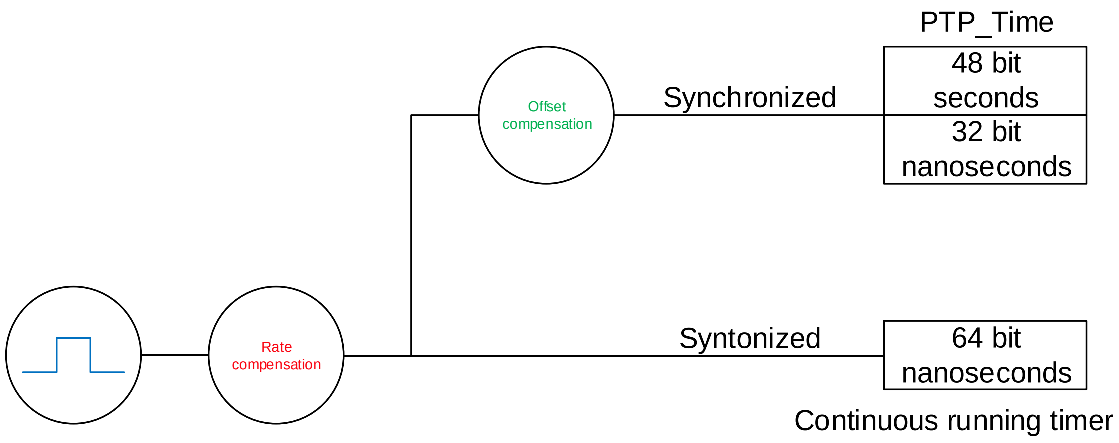
The used timer model of this contribution is build as shown in the figure on this slide.

The rate compensated frequency (rate to the GM) is used for the 64 bit continuous running timer and as basis for the PTP time of the PTP end instance.

-> 64 bit continuous running timer
used to rate compensate residence time

The offset correction is done by an additional rate compensation for the PTP end instance time.

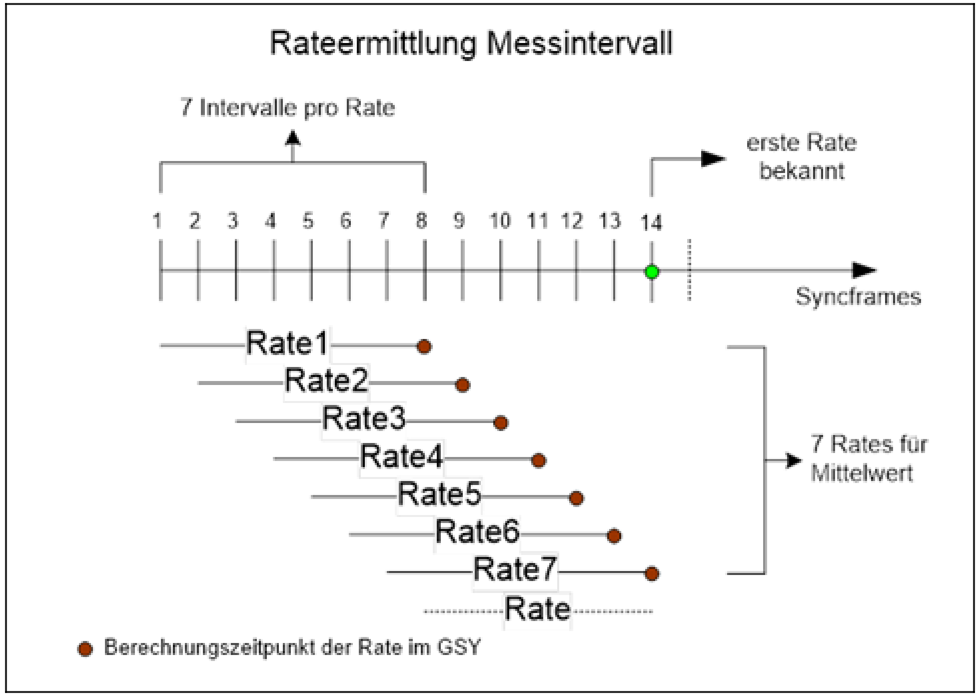
-> used for PTP time



PTP relay model

The PTP relay uses the sliding window (window size seven sync messages (210ms)) calculated and filtered (median over the last seven calculated values) rate to the GM for the residence time of the sync message.

Editors note: Median and not arithmetic mean is used.



PTP end instance model

	Maximum Offset correction factor	Kp / Ki (KpKo/KiKo)
Working Clock	< 250ppm	11 / 65
Global Time	< 250ppm	11 / 20

The PTP end instance uses the same model as the PTP relay to calculate the rate.

Additionally, the offset between the GM and the end instance time is calculated and a offset correction factor calculated.

Rate = Frequency deviation between GM and PTP end instance
Offset correction factor = Correction (faster/slower) of the frequency used for the PTP end instance time.

The Offset correction factor is calculated by the PI filter of the PTP end instance to minimize the offset between GM and PTP end instance.
The correction speed (maximum Offset correction factor) is limited due to the application timing requirements. Otherwise, local time intervals would get “to small” or “to large”.

New rate(PTP end instance time) = Oscillator + Rate + Offset correction factor
Is used to drive the PTP end instance timescale.

Both, Rate and Offset correction factor are calculated (PI controller with Kp/Ki) and updated with every received sync frame following the stated model.

Architecture questions

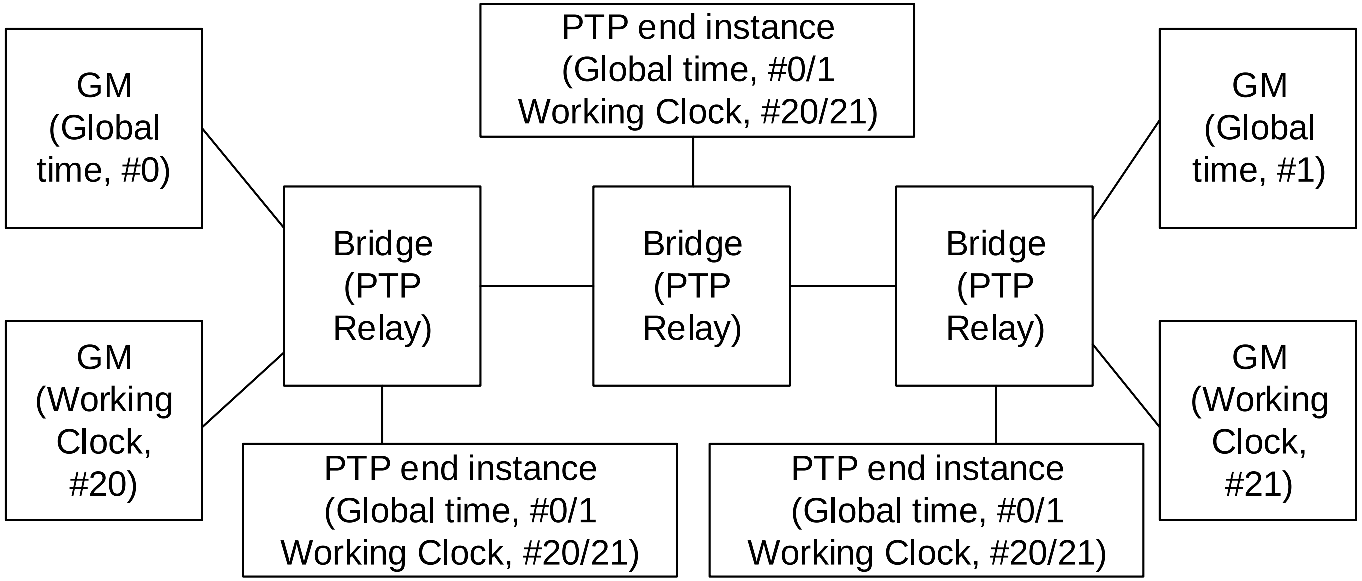
Open issues

Multiple GMs with overlapping sync trees are reality in automation systems.

The stated synchronization requirements need to be fulfilled for the shown setup.

Thus, four rates need to be maintained concurrently.

How is this solved with 802.1AS today, when Pdelay is used for rate calculation?



Questions?