60802 Time Sync – Should 60802 Apply Correction So TSGE Averages to Zero?

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Version 2

References

[1] David McCall, "60802 Time Synchronisation – Monte Carlo Analysis: 100-hop Model, "Linear" Clock Drift, NRR Accumulation Overview & Details, Including Equations – v2", 60802 contribution, Sept 2022

[2] David McCall "IEC/IEEE 60802 Contribution – Time Sync Informative Annex – v6", 60802 Contribution, Sept 2023

Content

- Source of TGSE & Probability Distribution
- Timestamp for preciseOriginTimestamp + correctionField at Grandmaster
- Mixing Nodes with Different TGSE
- Normative Requirements for TGSE

Source of TGSE
& Probability Distribution

Source of Timestamp Granularity Error (TSGE)

- Timestamp Granularity Error is related to Local Clock frequency
- Minimum interval between timestamps = $\frac{1}{f_{localClock}}$

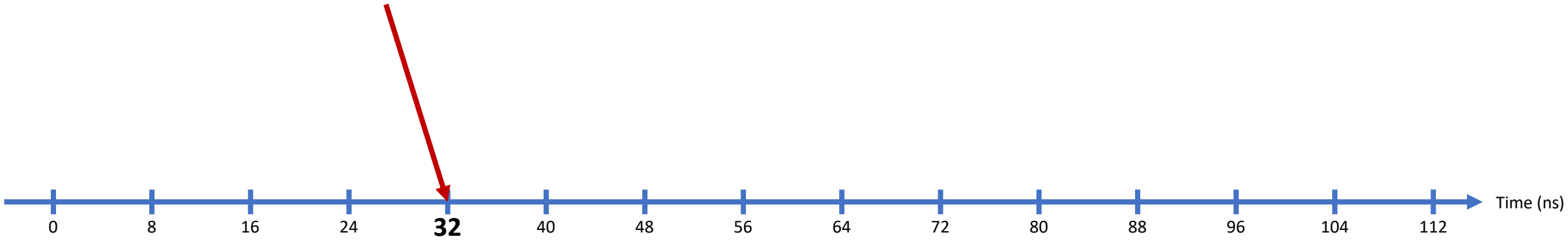
Assumed min f for 60802 (model for simulations)

$f_{localClock}$	Minimum Interval
125 MHz	8 ns
250 MHz	4 ns
500 MHz	2 ns

Timeline for 125 MHz Clock

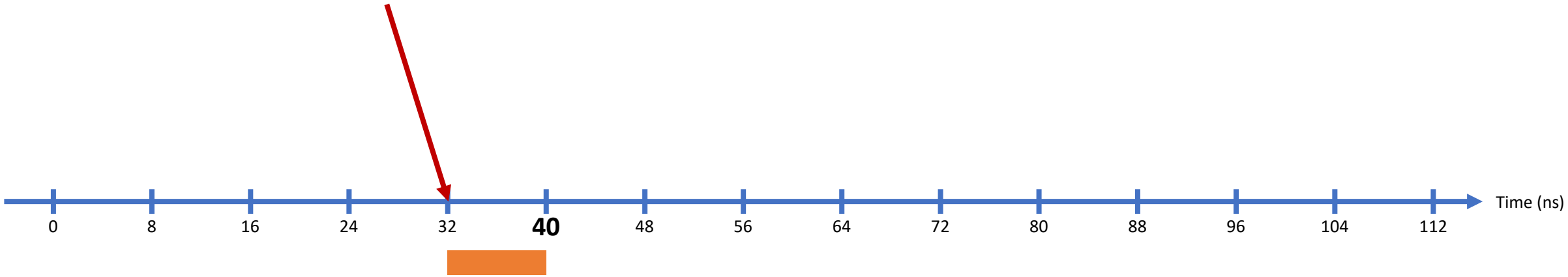
Clock tick every 8ns.

TSGE RX



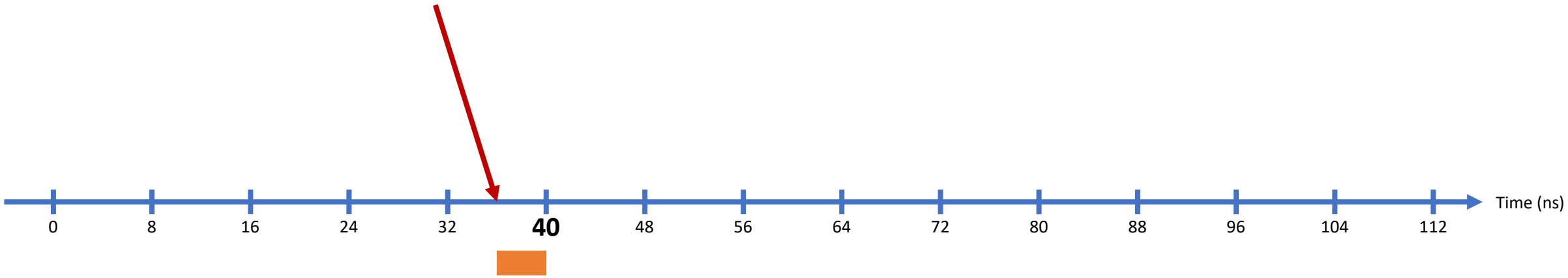
TSGE = 0 ns

TSGE RX



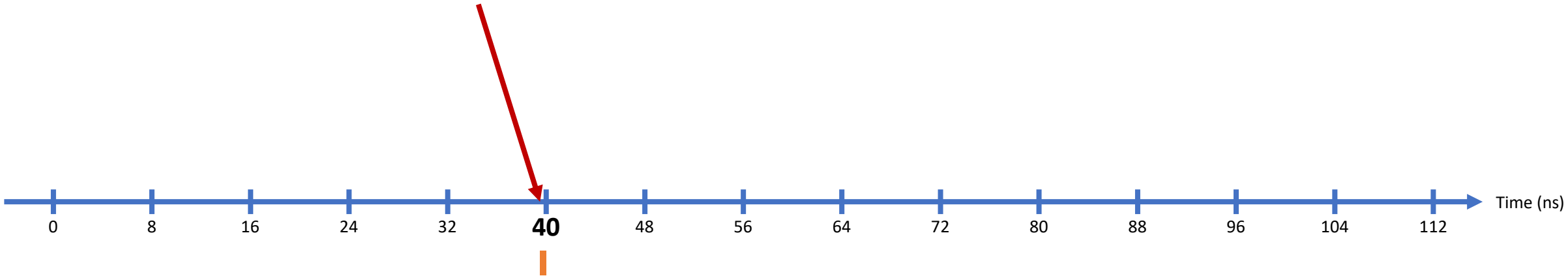
TSGE = +8 ns

TSGE RX



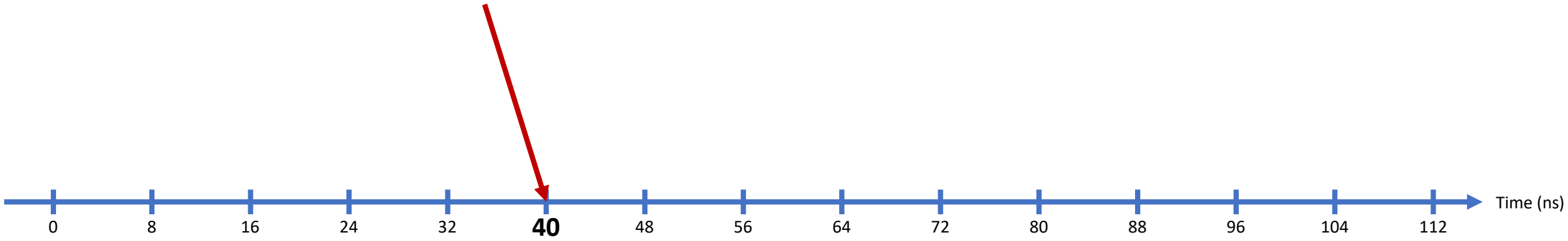
TSGE = +4 ns

TSGE RX



TSGE = +0.5 ns

TSGE RX

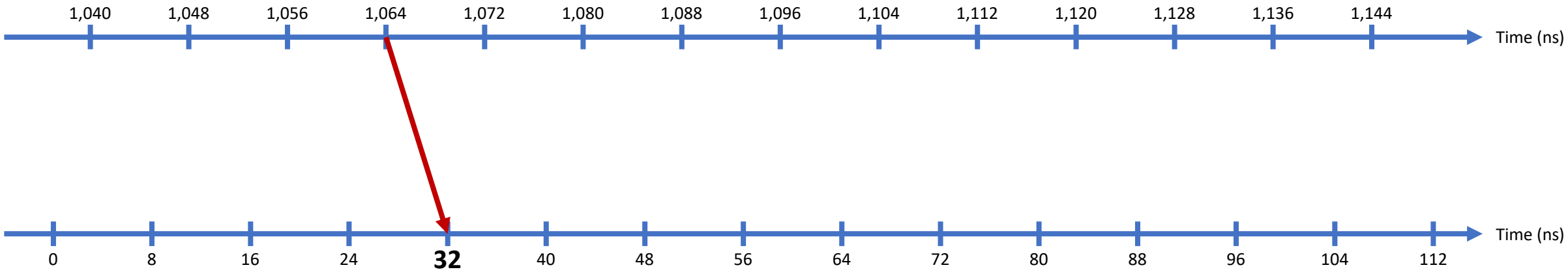


TSGE = 0 ns

TSGE RX Distribution?

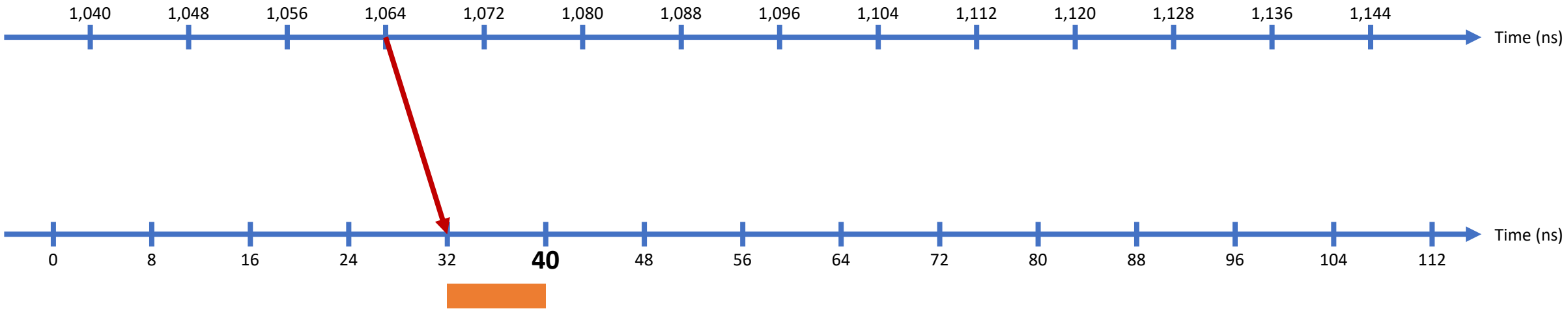
- 0 to +8 ns
- Is the distribution random and uniform across this range? (Uniform probability distribution.)
  - For a single measurement?
  - For a two or more measurements? (Is the amount of error independent from one measurement to the next?)
- Look at two cases…
  - The first message that arrives after startup
  - The 2nd message that arrives after startup

TSGE RX



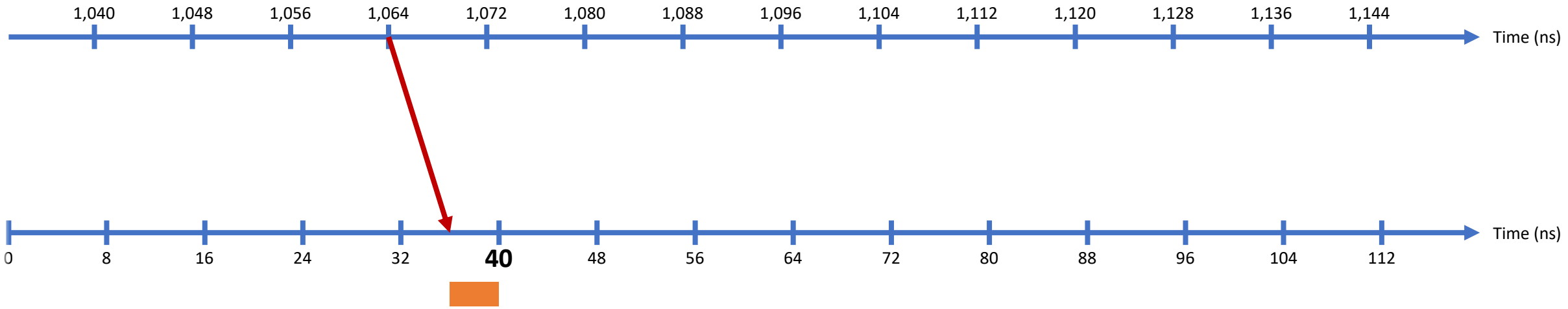
TSGE = 0 ns

TSGE RX



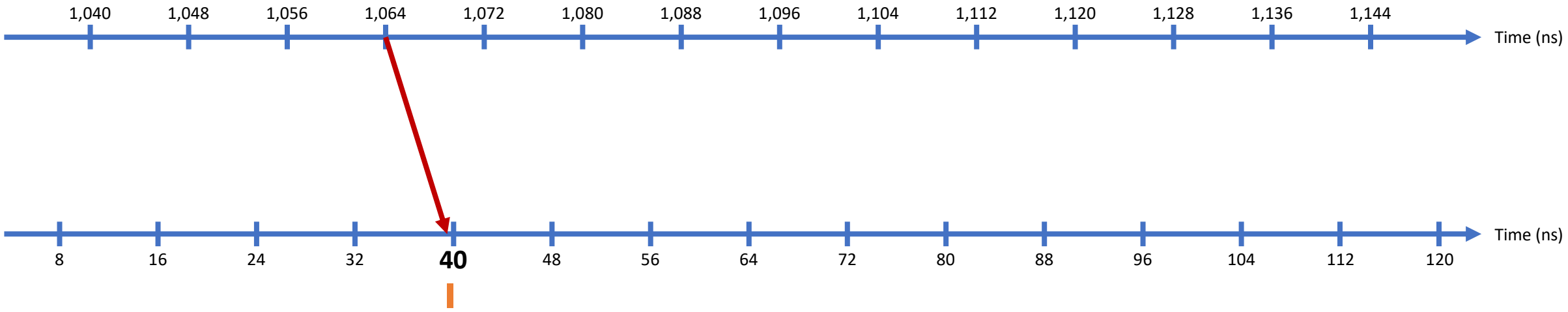
TSGE = +8 ns

TSGE RX



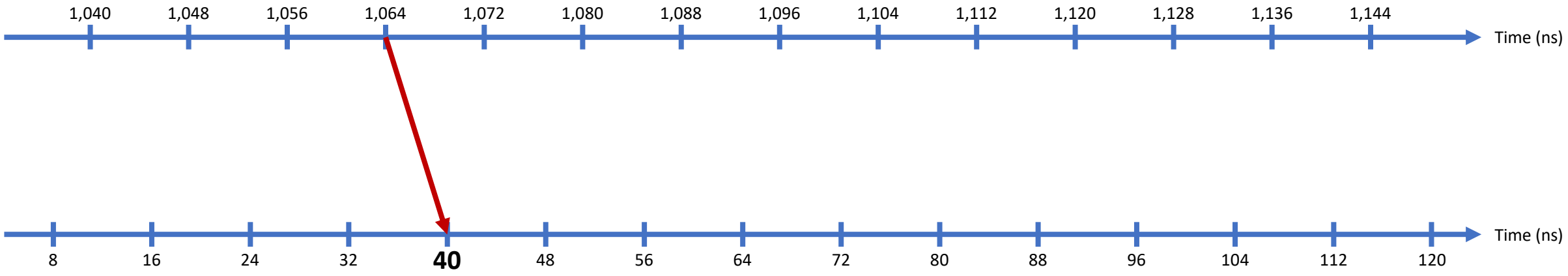
TSGE = +4 ns

TSGE RX



TSGE = +0.5 ns

TSGE RX



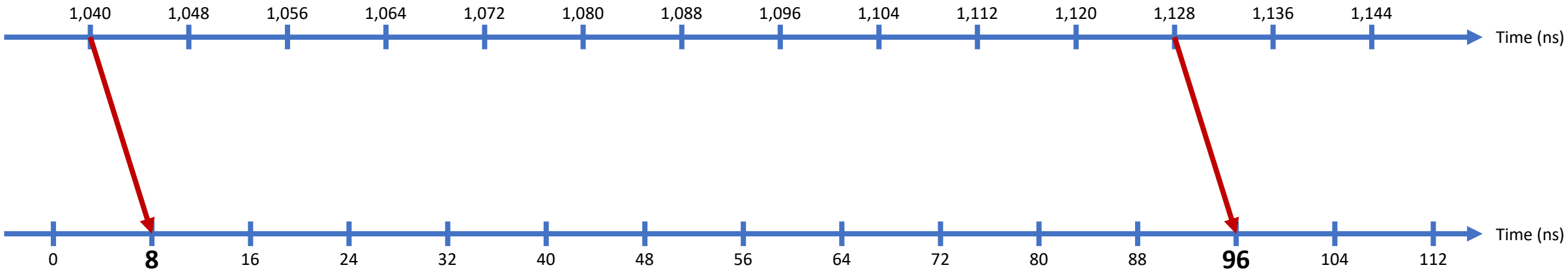
TSGE = 0 ns

TSGE RX Distribution

- Local Clock (i.e. source of timestamp) at each node is independent and free-running, therefore…
- TGSE distribution for first message that arrives after startup is uniform between minimum and maximum.
  - For 125 MHz crystal, uniform distribution between 0 to +8 ns

- For 2nd message, independence of RX TSGE from first message depends on two factors…
  - Whether TX timing (of 2nd message) is independent at this scale
    - For example, if message TX time is scheduled at the µs resolution but actual TX is essentially random at an 8 ns scale, RX TSGE will also exhibit uniform distribution
  - Whether deviations from nominal frequencies result in sufficiently large changes to timestamp offsets between 1st and 2nd message
    - If small deviations from nominal frequencies result in essentially random alignment, RX TSGE will exhibit uniform distribution **even if TX timing isn't independent**

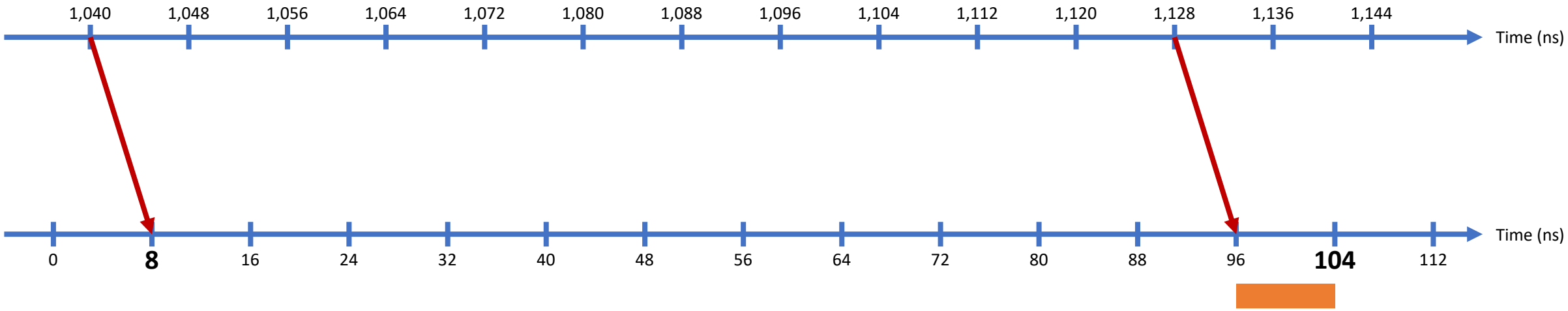
TSGE RX



TSGE = 0 ns

TSGE = 0 ns

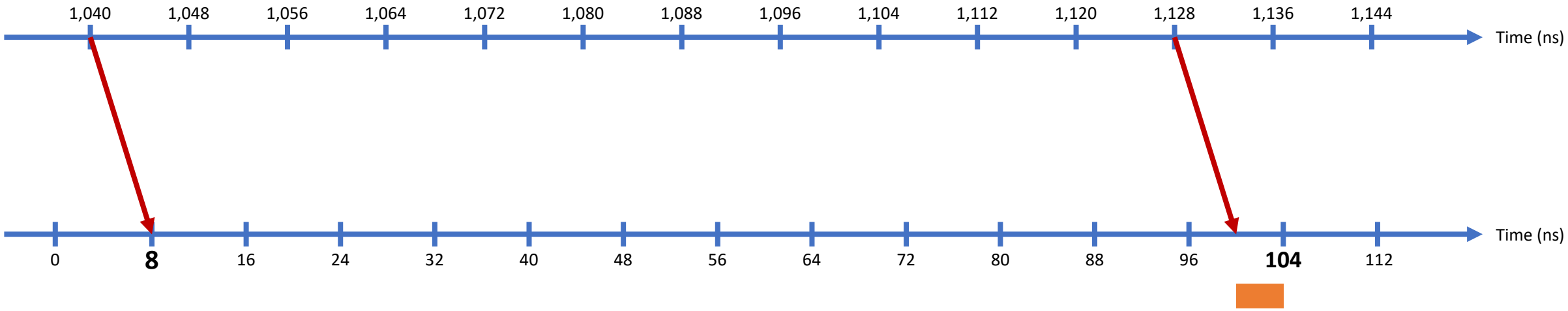
TSGE RX



TSGE = 0 ns

TSGE = +8 ns

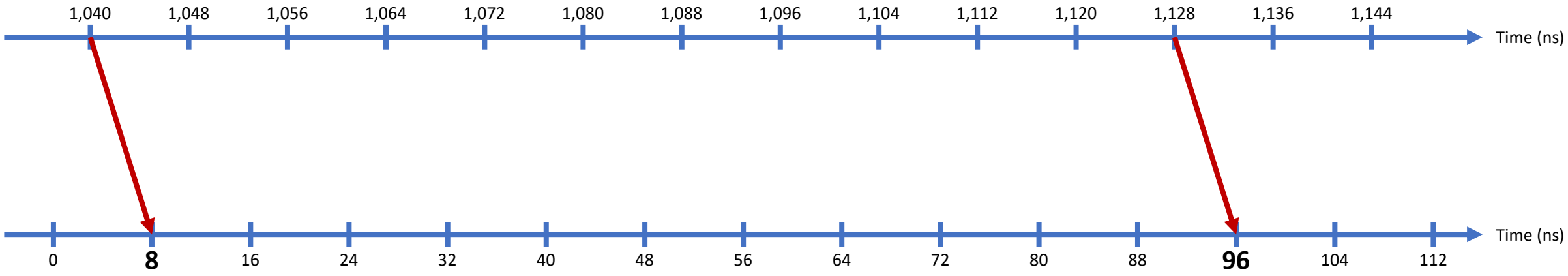
TSGE RX



TSGE = 0 ns

TSGE = +4 ns

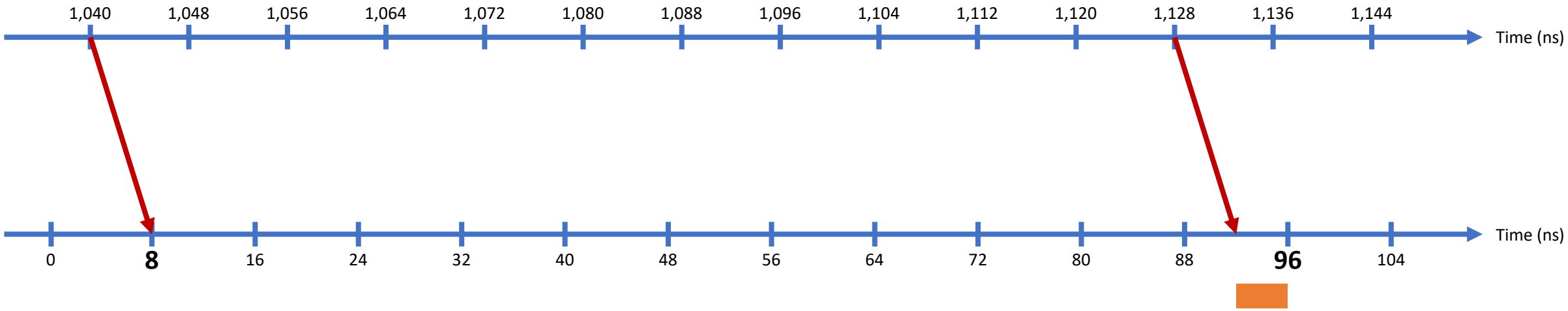
TSGE RX



TSGE = 0 ns

TSGE = 0 ns

TSGE RX



TSGE = 0 ns

TSGE = +4 ns

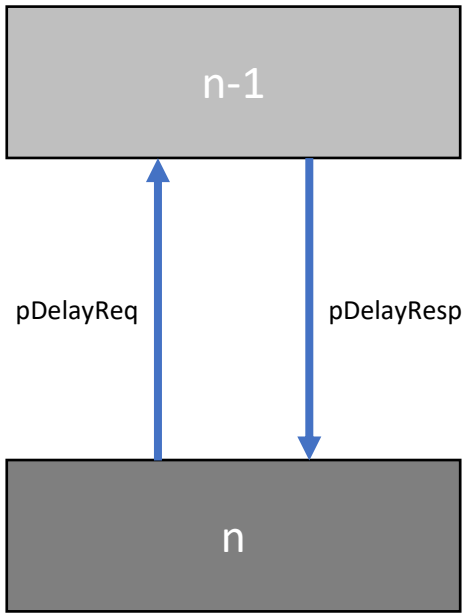
TSGE RX Distribution

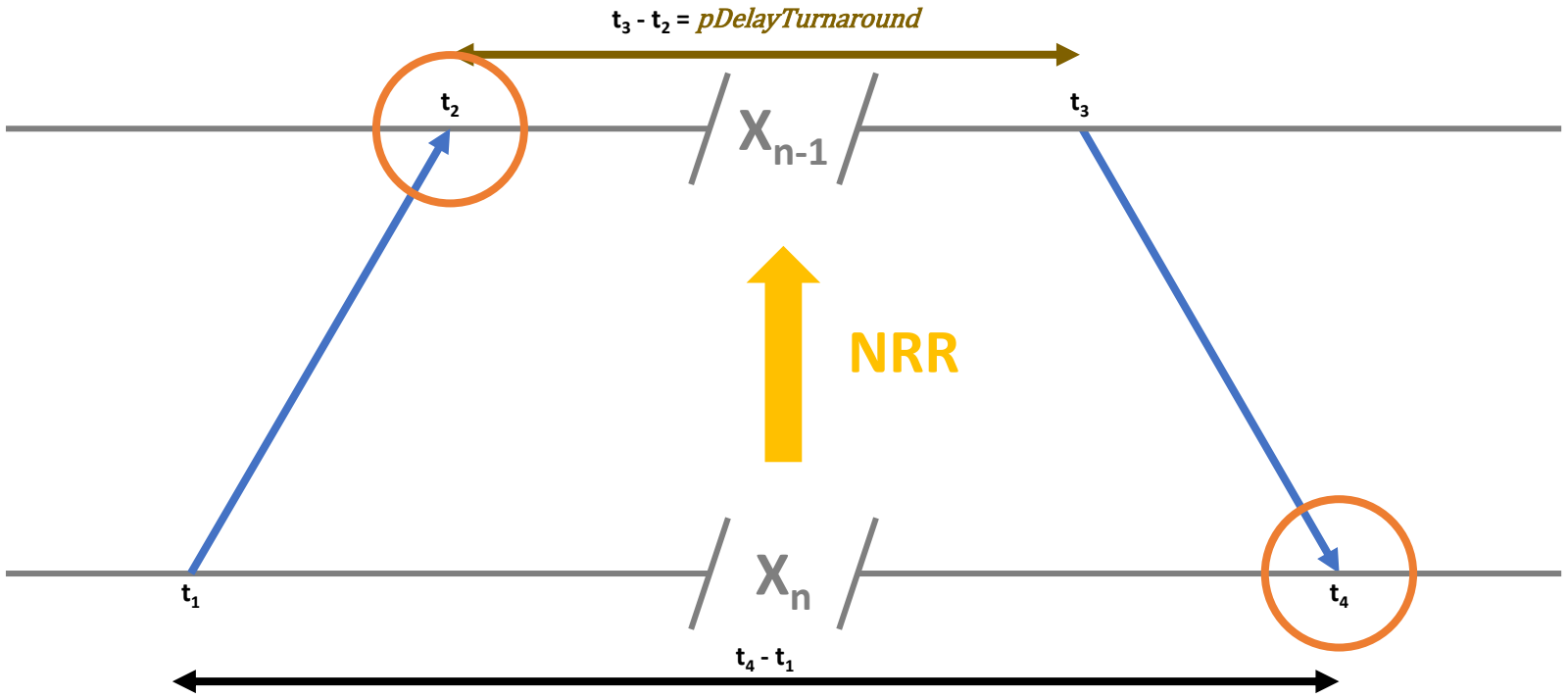
- Relevant timestamp offsets change according to Neighbor Rate Ratio
- If NRR is essentially random over the differences of interest, then timestamp offsets will be essentially random between one message and the next and TSGE on message RX will be a uniform distribution between minimum and maximum

TSGE RX Distribution

- What is the “difference of interest”?
  - High enough to produce a ± change in offset equivalent to the TSGE range over the interval of interest
    - For a 125 MHz Local Clock: ±4 ns (same range as 0 to +8 ns)
  - The “interval of interest” varies according to the type of measurement
    - Sync Interval: 119 - 131 ms
    - Pdelay Interval: 119 – 131 ms
    - Pdelay Turnaround: Mean 10 ms; Standard Deviation 1.8 ms; Truncated at 1 ms and 15 ms
    - Residence Time: Mean 10 ms; Standard Deviation 1.8 ms; Truncated at 1 ms and 15 ms
- +1 ppm NRR generates a +4 ns offset between neighboring clocks every 4 ms.

TSGE RX – meanLinkDelay

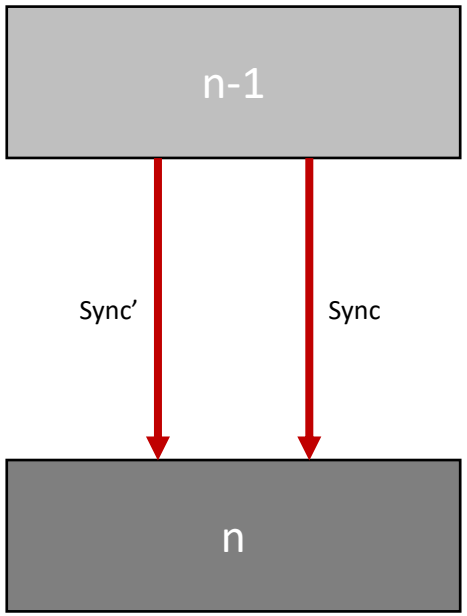


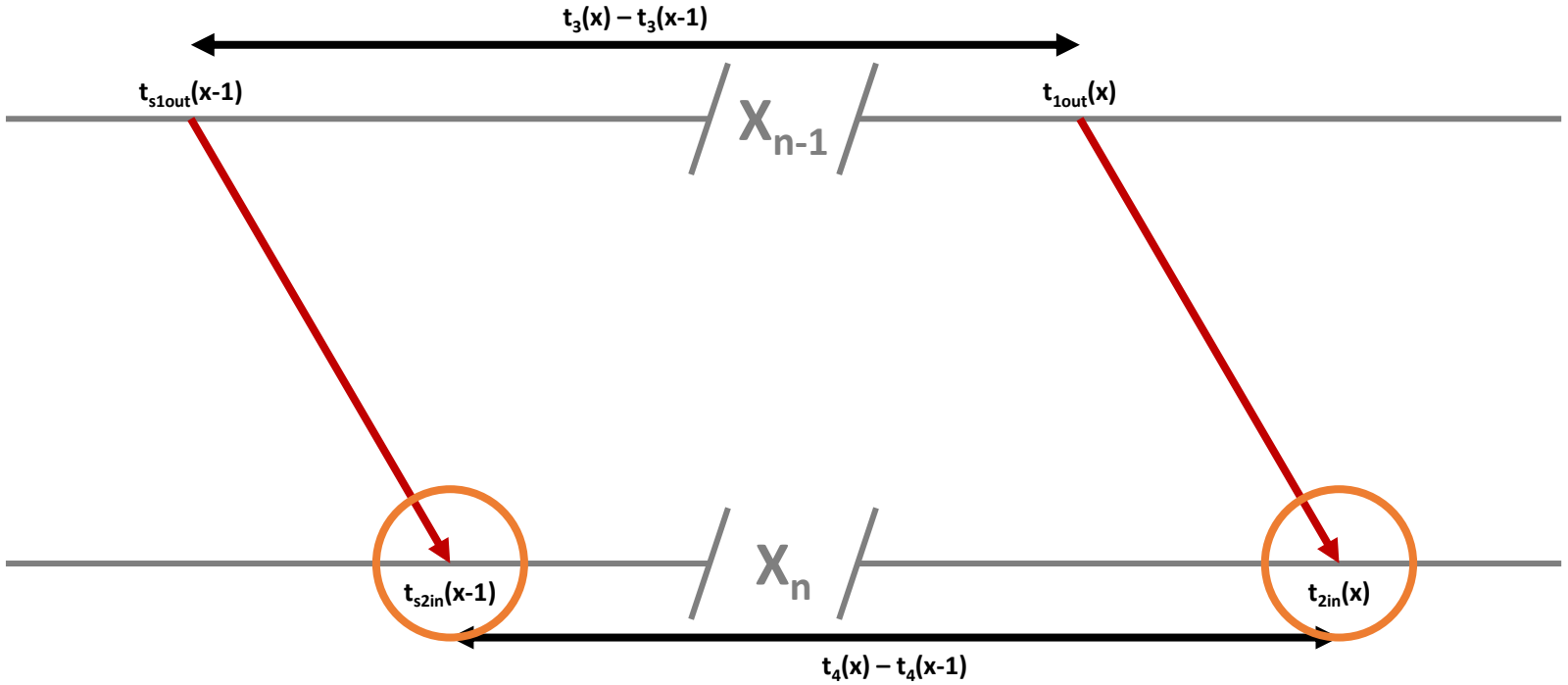


$$meanLinkDelay = \left(\frac{(t_4 - t_1) - \frac{(t_3 - t_2)}{NRR}}{2} \right)$$

ns

TSGE RX – Measured Neighbor Rate Ratio

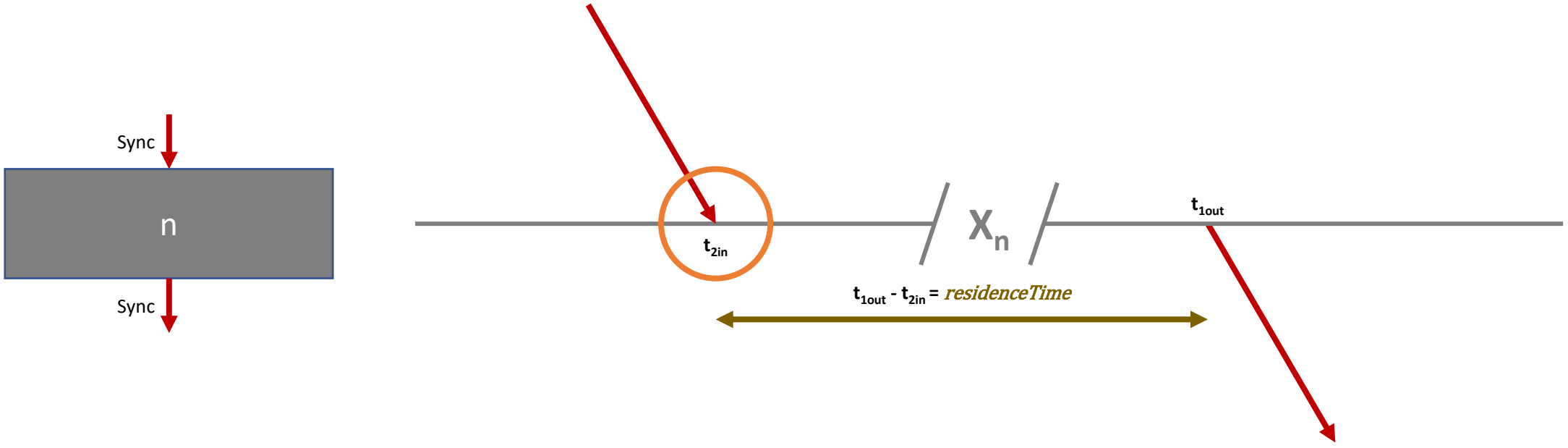




$$mNRR = \left(\frac{t_3 - t_3'}{t_4 - t_4'}\right)$$

ppm

TSGE RX – Residence Time



$$residenceTime = (t_{1out} - t_{2in})$$ **ns**

TSGE RX can be modelled as a uniform distribution between minimum and maximum.

For 125 MHz oscillator & typical implementation: 0 to +8 ns

TSGE TX distbitution can be implementation dependant, but…

For typical implementation message TX is random with respect to message timestamp, i.e. TGSE TX has uniform distribution.

…and distribution should be the same as TGSE RX distribution if meanLinkDelay & residenceTime measurements are to be accurate.

For 125 MHz oscillator & typical implementation: 0 to +8 ns

TGSE TX Distribution

(explanation of statement on previous slide)

- meanLinkDelay is “averaged” using an IIR filter, so the average error of the interval measurement matters.
- Over 100 hops, correctionField accumulates errors from 99 measurements of residenceTime, so the average error of those measurements matters.
- In both cases, the average error for interval measurement is zero if the TGSE TX distribution matches the TGSE RX distribution.

Timestamp for **preciseOriginTimestamp + correctionField** at Grandmaster

Timestamp for preciseOriginTimestamp + correctionField at Grandmaster

- Other examples given so far have related to intervals and Local Clock timestamps.
- preciseOriginTimestamp + correctionfield at Grandmaster is unique
  - Only done once; not measuring an interval; based on ClockSource
  - correctionField is modified at PTP Relay Instances based on meanLinkDelay and residenceTime, both of which are measured using Local Clocks and intervals.
- Offset in average TGSE error in preciseOriginTimestamp + correctionfield at Grandmaster will show up as offset in dTE at PTP End Instance
- Since management of Max|dTE| by 60802 is based on managing probabilities, this offset should be eliminated if possible.

Timestamp for preciseOriginTimestamp + correctionField at Grandmasters should be calibrated to average zero.

(Separate from the group consensus on the next section.)

Mixing Nodes with Different TGSE

Mixing Nodes with Different TGSE

- Affects NRR and meanLinkDelay measurement (from [1])

$$mNRR_{errorTS\_X} = \frac{\overbrace{(t_{1out} - t_{1out}')}^{\text{Node n-1: TX TX}} - \overbrace{(t_{2in} - t_{2in}')}^{\text{Node n: RX RX}}}{T_{pdelay2pdelay}} \quad \textbf{ppm}$$

$$MLD_{errrorTSdirect\_X} = \frac{\overbrace{(t_{4pderror} - t_{1pderror})}^{\text{Node n: RX TX}} - \overbrace{(t_{3pderror} - t_{2pderror})}^{\text{Node n-1: RX TX}}}{2} \quad \textbf{ppm}$$

- In both calculations the average offset at a particular node cancels out and therefore makes no difference to dTE.
  - Provided the average offset for any single node is the same for RX and TX.

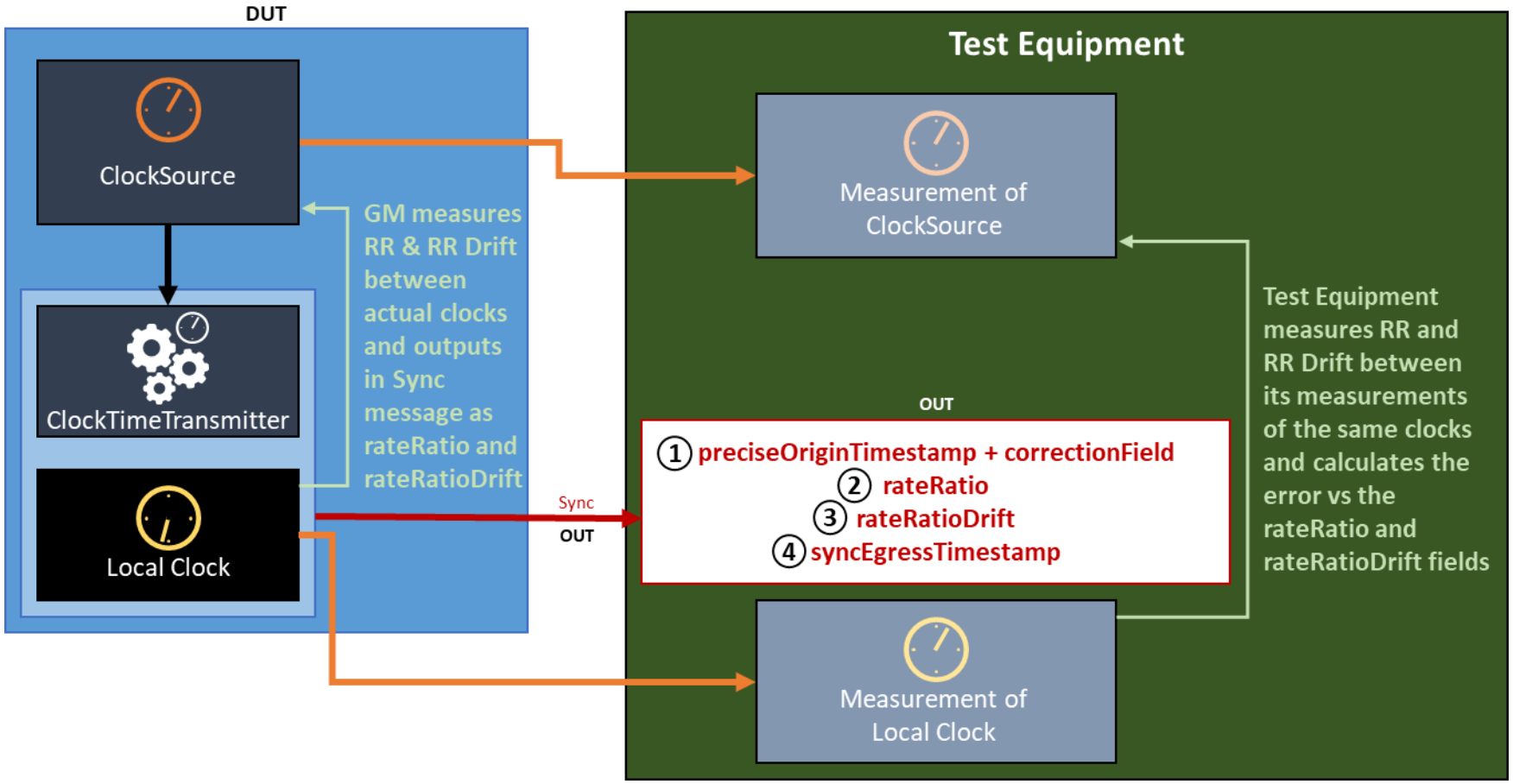
802.1AS does not care about average offset TGSE for Local Clock.
It does not affect dTE.

Normative Requirements for TGSE

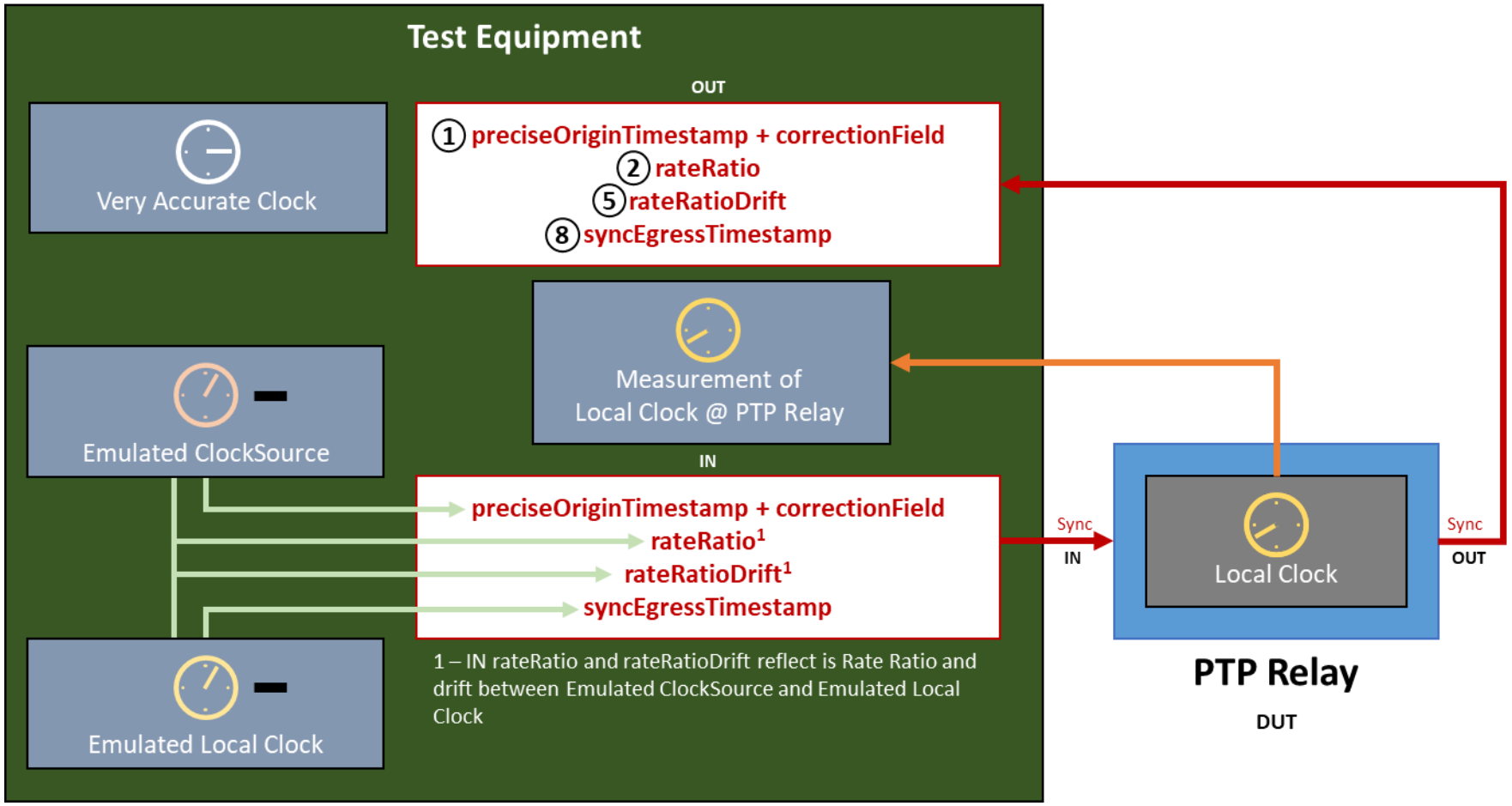
Normative Requirements for TGSE

- From [2], for Grandmaster PTP Relay Instances and PTP Relay Instances there are test for timestamp accuracy.

Normative Requirements for TGSE: Grandmaster PTP Instance



Normative Requirements for TGSE: Grandmaster PTP Instance



Normative Requirements for TGSE

- Test for preciseOriginTimestamp + correctionField at Grandmaster is discussed in previous section.
- Test for preciseOriginTimestamp + correctionField at PTP Relay Instance is based on measurement of residenceTime and meanLinkDelay, both of which are based on interval measurements
  - Not affected by average TGSE offset
- Test for syncEgressTimestamp *is* affected by average TGSE offset.
  - But we don’t actually care, for the purposes of dTE, what the offset is.

Proposal

- Normative requirement for syncEgressTimestamp accuracy is specified in terms of an average TGSE of zero, includes the option for a vendor-defined average offset.
- Average offset may vary according to oscillator frequency.
- Some vendors already apply correction so average offset is zero.

Thank you