Quantization in the Modeling of the Message Propagation and Estimation of Required variables (i.e. pDelay, nRR, RR, etc.) in Time-Series Simulation

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Motivation

The specification of the planned time-series simulation includes specification of different “independent” random error sources:

- TSGEtx <- 4 # +/- ns - Error due to Timestamp Granularity on TX
- TSGErx <- 4 # +/- ns - Error due to Timestamp Granularity on RX

→ This is for 125MHz oscillators, where the quantization can be anywhere between [0, 8]ns. If this is considered to be a distribution with a mean of 4ns, this mean has to be subtracted whenever this distribution is used in order to get the above state error distributions of [-4, +4]ns.

Time-Series Simulation

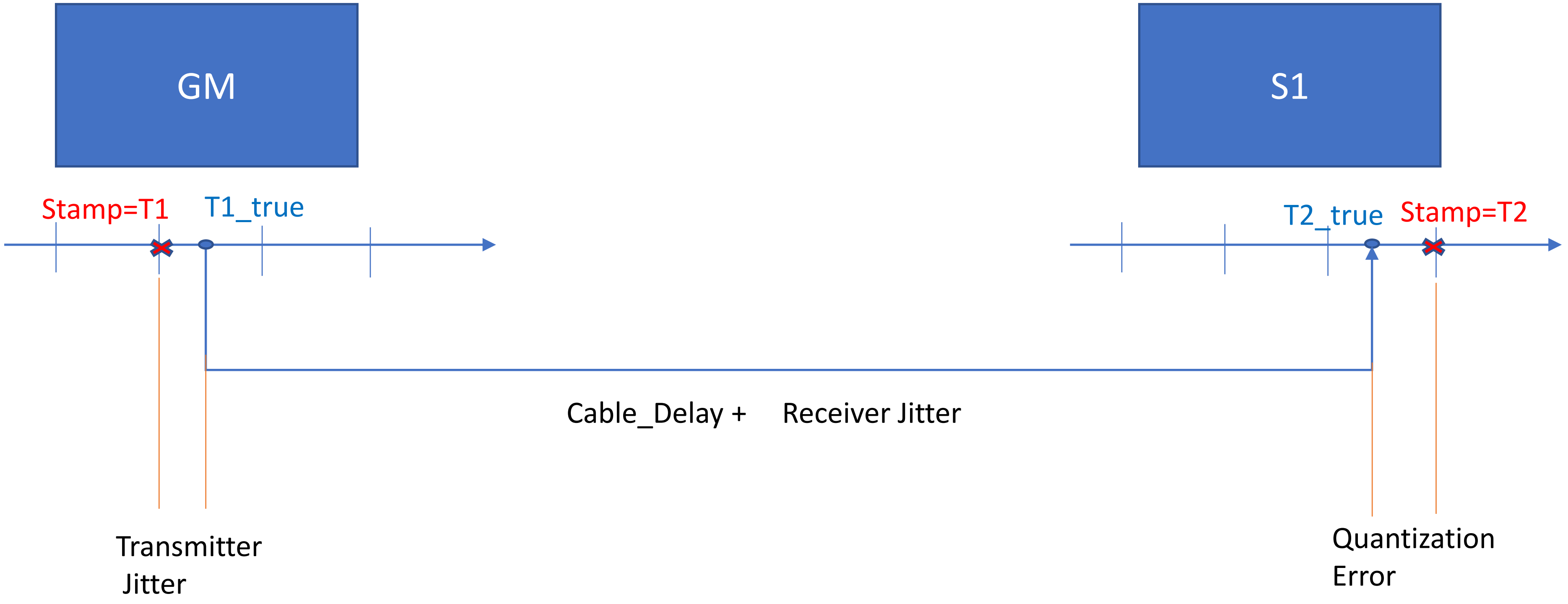
Two Main Tasks:

- Provide a realistic model of Message propagation and stamping (sources of delays such as transmitter / receiver jitter, cable delays, residence times, quantization, …)
  - It is important so specify which variables are random and provide their probability distribution functions (TX / RX jitter, …)
  - → Quantization is a deterministic process, it is not per se an independent source of randomness and it should not be described as such (no probability distribution of its "contribution" should be provided)

- Implement Estimation process of necessary variables such as nRR, RR, pDelays, etc.
  - Quantization is a deterministic process, its does has neither a "mean" nor a "standard deviation" which can be used in the estimation process explicitly
  - But it will influence the estimation of the variables of interest such as pDelays, nRR, and RR, but this is "not a problem"

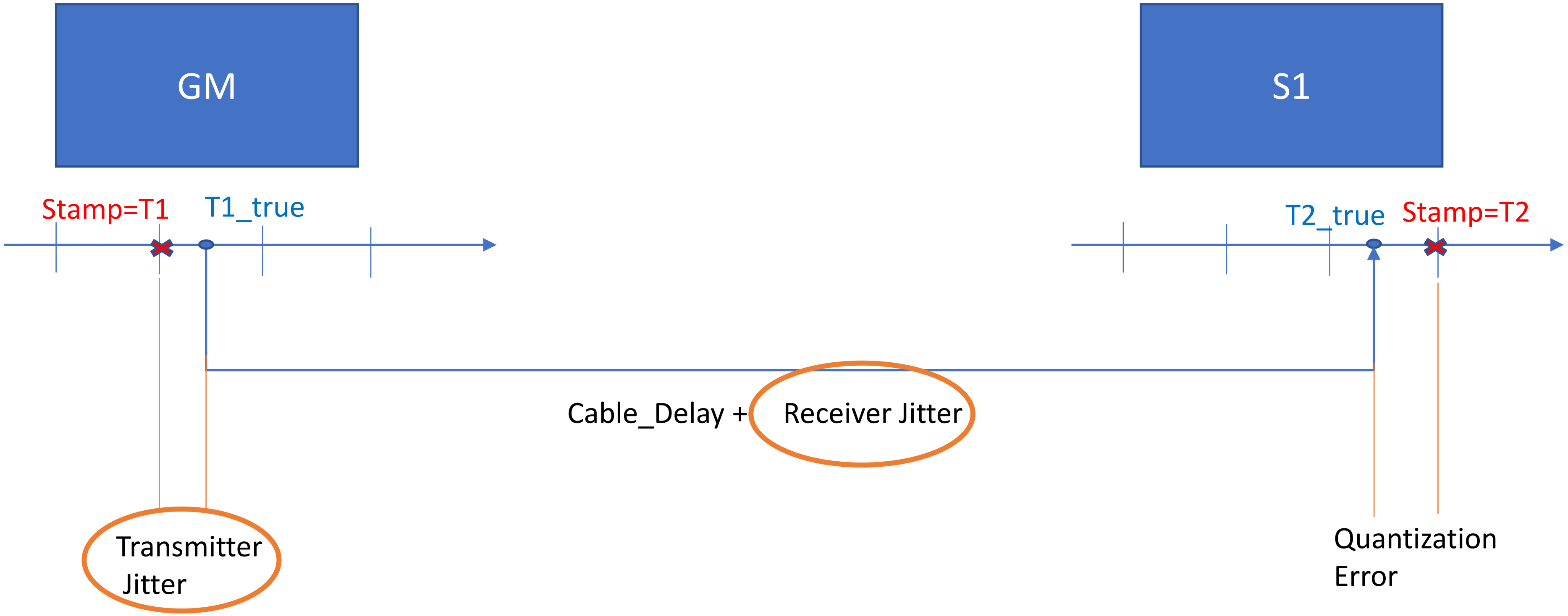
Randomness of the Message Arrival Time

- Shown are the stamped (blue dots) and “true” sending / receiving times (red crosses) in the Sync Message forwarding.



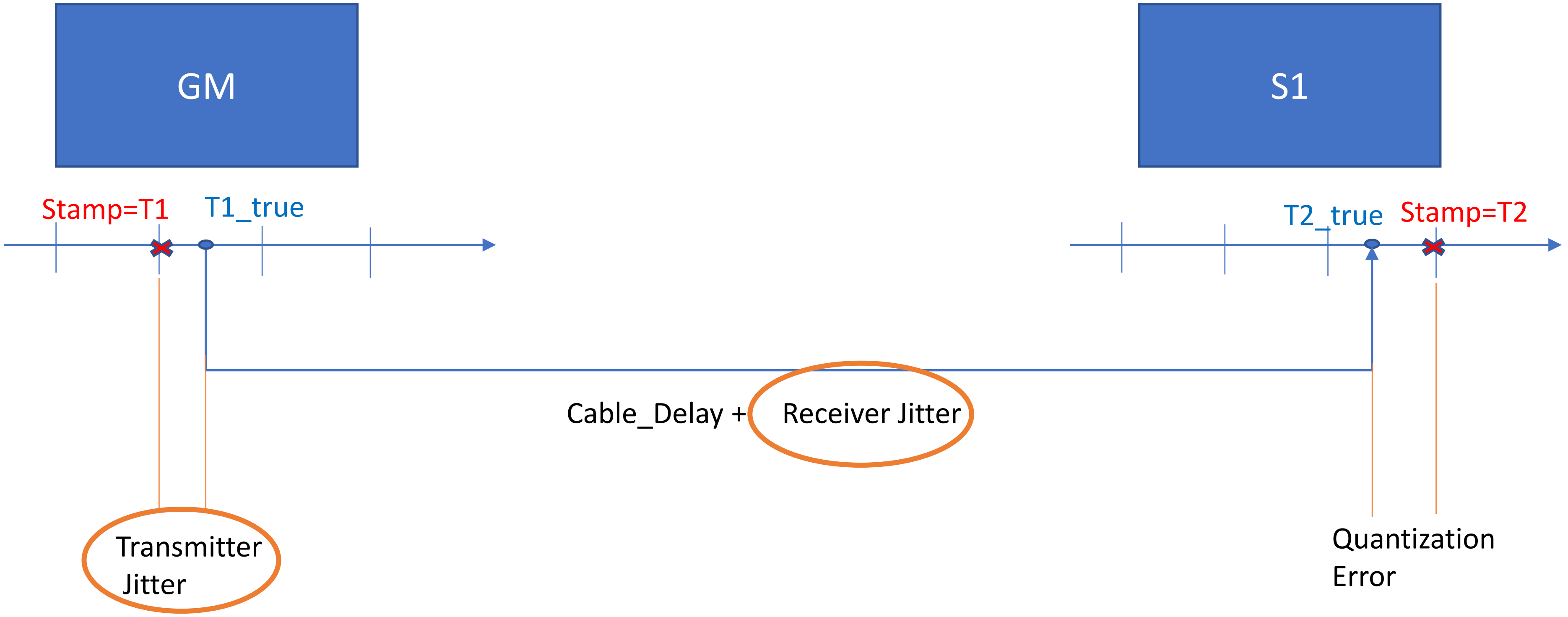
Randomness of the Message Arrival Time

What are the sources of the randomness of T2_true?



Randomness of the Message Arrival Time

T2_true (the true arrival time) is random as the consequence of the sum of the Transmitter and Receiver jitter → there is no reason why (**T2** - **T2_true**) will have a distribution with the mean equal to the half of the quantization interval (e.g. 4ns)!



Randomness of the Message Arrival Time: Example 1

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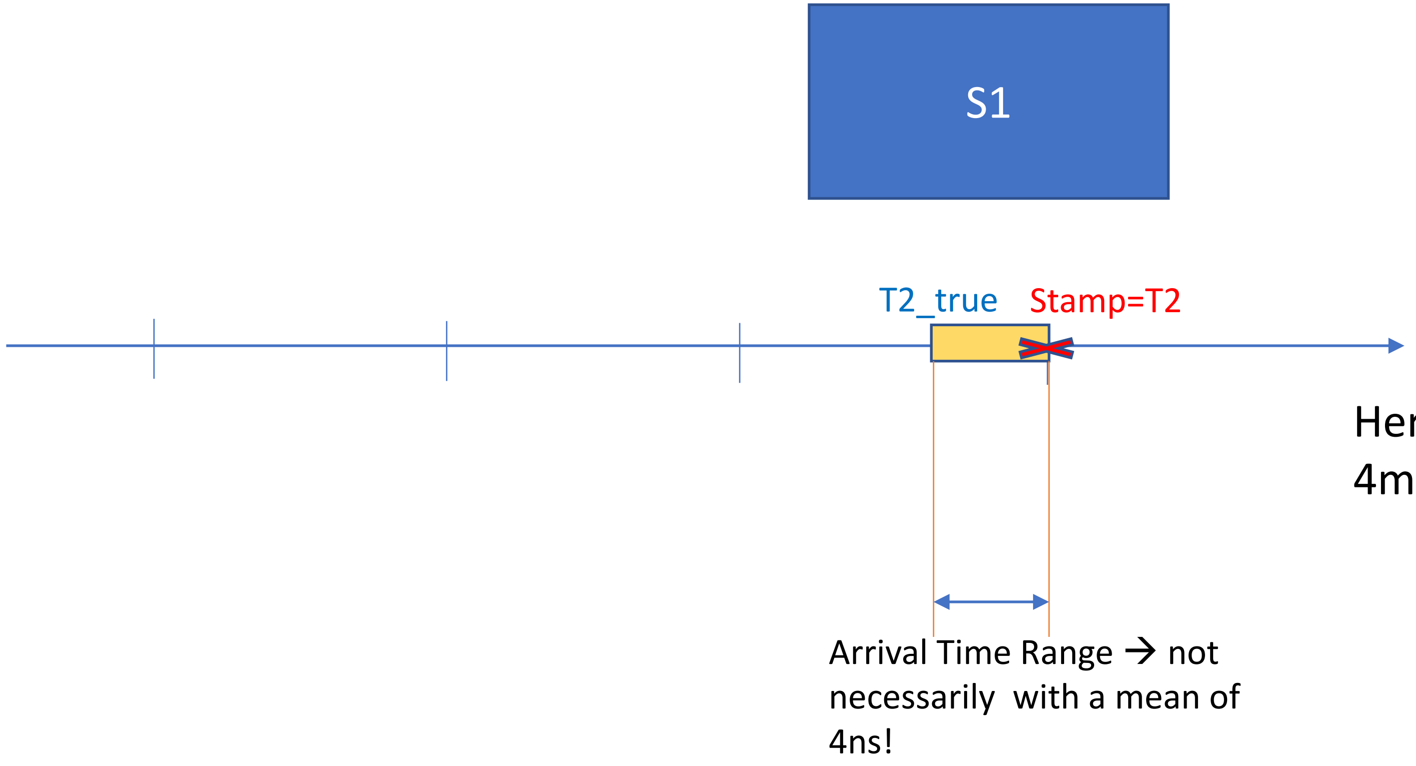

Here the mean is much smaller than 4ms

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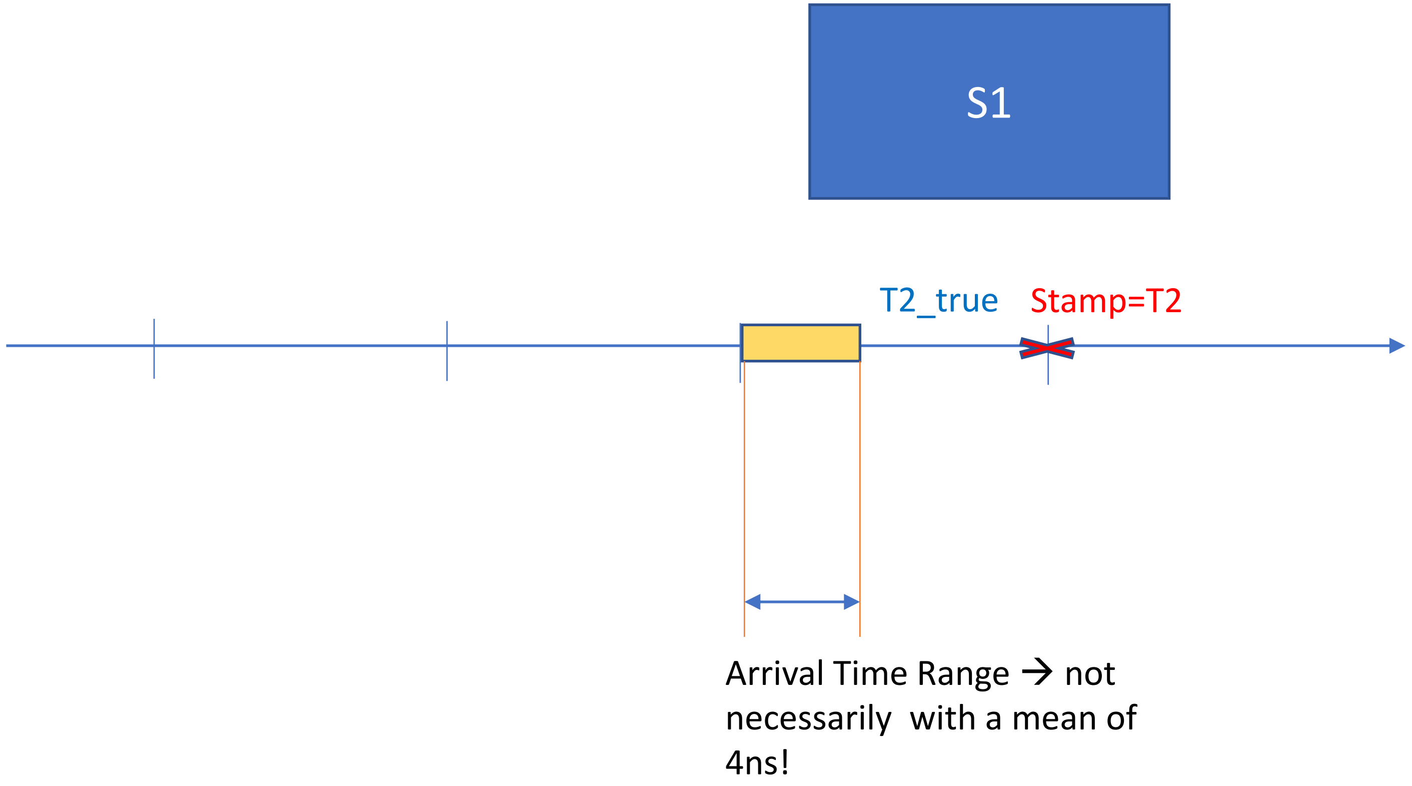

Due to the difference in frequencies, the arrival time range can move relative to the S1 time, and the previously small rounding errors now become larger with the mean which is larger than 4ns

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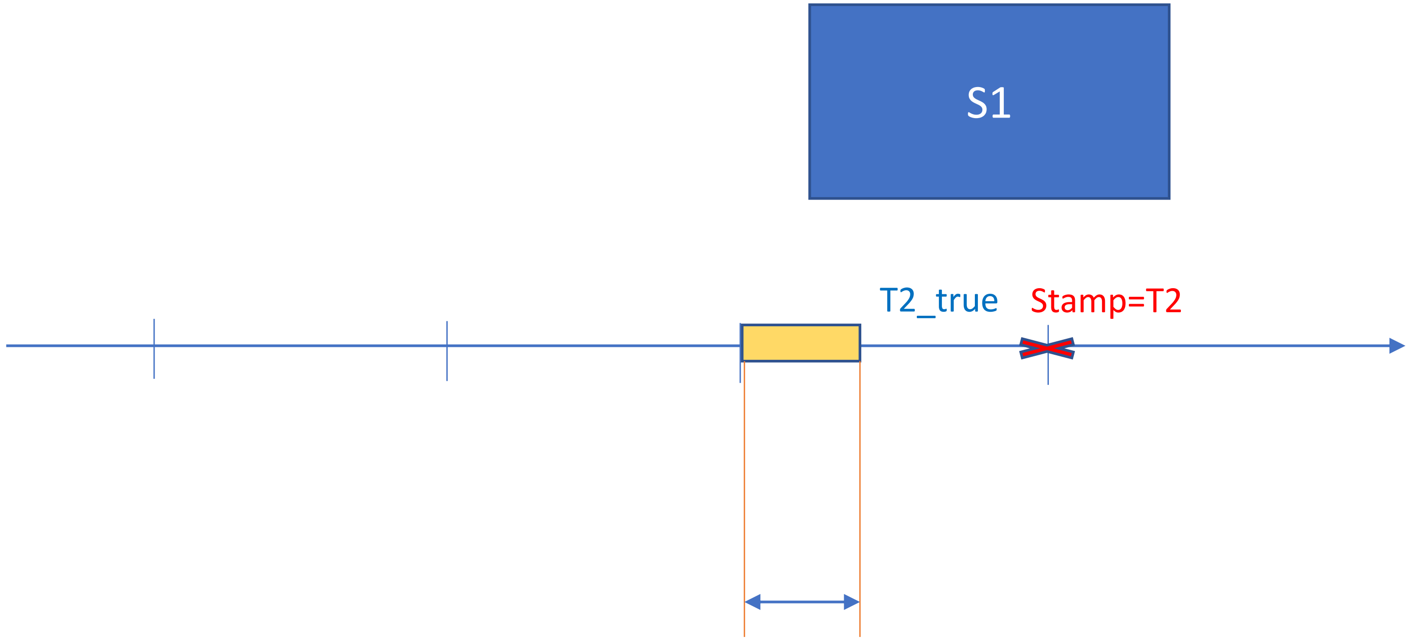


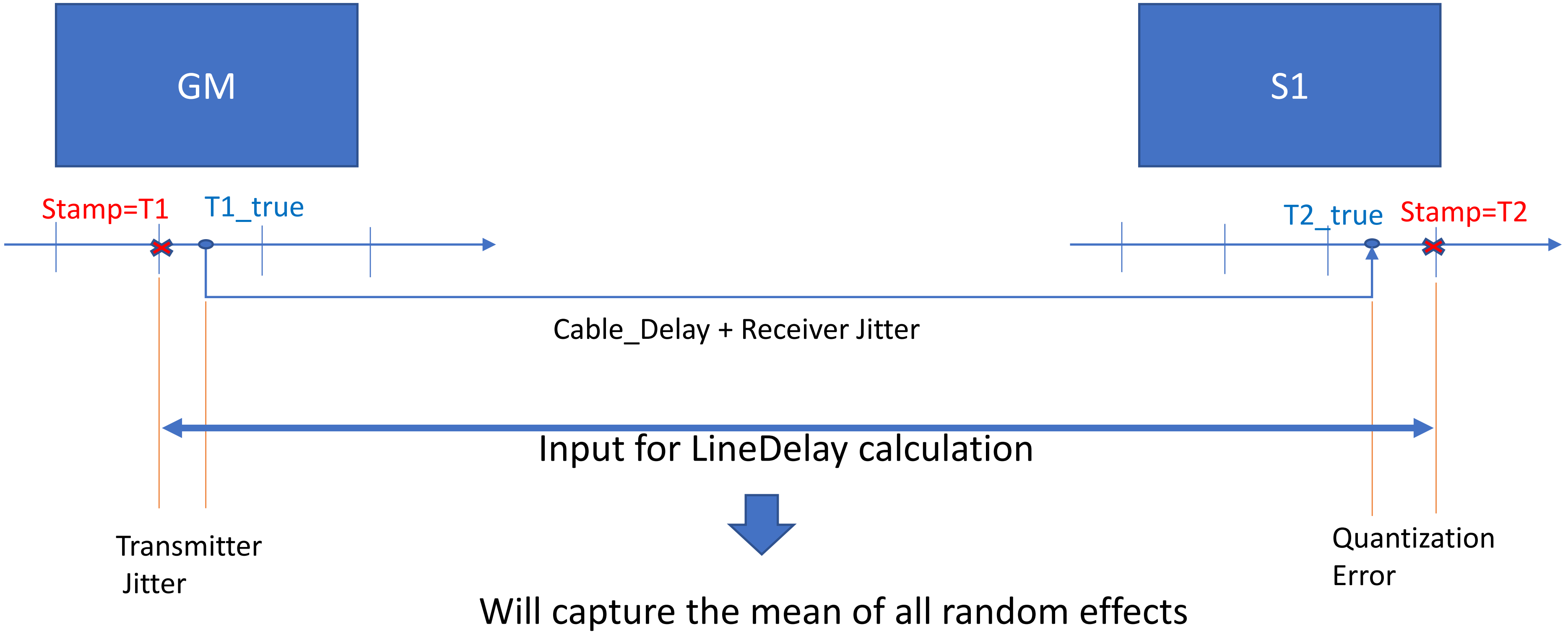
Arrival Time Range → not necessarily with a mean of 4ns!

We do not have enough information to learn this quantization-error distribution and estimate its mean!

- ➔ Do not subtract (add) 4ns, it might make the results worse
- ➔ Question: but can we do something about (the mean of) the quantization error?

Randomness of the Message Arrival Time: LineDelay Estimation will help

- LineDelay estimation is based on the observed intervals between stamped times **T1** and **T2** → it will produce an estimate which reflects the mean values of all underlying jitter sources, which are important for the estimate of the MasterTime at **T2**



Randomness of the Message Arrival Time: Conclusion

- Modelling of the quantization as an independent source of random errors is not justified.
- Hence, removing (adding) 4ns from the observed (stamped) arrival time is justified only if the arrival time quantization error would be distributed with a symmetric distribution with a mean in the middle of the tick-interval
- The above is usually not the case, it depends on the randomness of the transmitter & receiver jitter as well as of the cable delay
- Conclusions:
  - Do not subtract half of the tick-interval (e.g. 4ns) as the mean arrival-time quantization error, because there are no guarantees that this mean estimate is correct
  - A “well-done” LineDelay estimation will compute the mean of all random effect between stamped times at both sides of the LineDelay, i.e. their individual estimates and compensation are not necessary
  - About Simulation: the simulation should generate receiving times of messages by modelling jitters in the transmission/receiving stages

Additional recommendation for the Time-Series Simulation regarding Control-Loops

- Control-loops (in ClockMasters and/ ClockTargets at End Stations) do not influence the underlying time-sync simulation
- Proposal: Run the time-series simulation and save all necessary input signals for the control-loops
- ➔ this will enable us to test different controller implementations without repeating the full simulation!