Discussion of Assumptions Needed for 60802 Network Simulations

Geoffrey M. Garner
Huawei (Consultant)
gmgarner@alum.mit.edu

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Outline

- Introduction
- Discussion of assumptions needed
- Proposal

Introduction - 1

- At the November 2019 IEC/IEEE 60802 meeting, the author of this presentation indicated during the comment resolution discussion that it would be possible to perform simulations of end-to-end dynamic time error (dTE) performance for an Industrial (i.e., 60802) network
- The author has begun this work; however, assumptions are needed for various parameters and other aspects of the simulation model
  - While the latest draft 60802 profile document (D1.1) [1] contains information that can be used for some of the assumptions, that information is incomplete in terms of what is needed for simulations
- The purpose of this presentation is to describe the types of assumptions needed and stimulate discussion of them in the IEC/IEEE 60802 joint project meeting
  - It is hoped that at agreement can be reached on an initial starting point for the assumptions
  - This would only be a starting point, mainly to use for the initial set of simulations; the assumptions can be changed after initial simulation results are available
  - It is intended that the author will document the assumptions in a subsequent presentation, and bring initial simulation results to the next meeting

Introduction - 2

- Previous simulations for 802.1AS performance were presented in 802.1 presentations during the 2006 – 2011 period
- Reference [3] (from July 2010) is one of the later presentations, and contains references to many of the earlier presentations
- Reference [3] describes the simulation model, and also lists the assumptions (parameter values) used at that time
- In the following slides, the assumptions needed for the 60802 network simulations are listed
  - Parameter values are taken from 60802/D1.1 if available
    - It is realized that comment resolution of the D1.1 TB ballot comments is underway; however, since the comment resolution is not yet finished, the most that could be used is D1.1 along with the latest published comment resolution document [2]
  - If not available, parameter values are either taken from [3], or else default values given in 802.1AS-2020 are used (in most cases these are the same)
  - Otherwise, various possibilities are discussed

Discussion of Assumptions Needed for Simulations - 1

- Hypothetical Reference Model (HRM) for 60802 network
  - Grandmaster (GM) PTP Instance, followed by 99 PTP Relay Instances, followed by a PTP End Instance
  - This means that the total number of PTP Instances is 101, which gives a maximum number of hops (stepsRemoved) of 100
- PTP Instance Noise Generation
  - The GM is assumed to have zero noise generation, i.e., for the simulations we are interested in the performance of the time transfer by the network, and not the GM performance
  - For the PTP Relay Instances and PTP End Instance, simulations will be performed for 2 models
    - Model 1 – Noise Generation meets the TDEV mask of 802.1AS Annex B
      - The model for generating noise that matches the TDEV mask is described in [3]
    - Model 2 – Noise Generation is such that the phase error of the free-running local clock is sinusoidal, with maximum frequency offset of $\pm$100ppm and maximum frequency drift rate of 3 ppm/s (these values are from [1])
    - Model 3 – Triangular wave that meets the same frequency offset and drift requirements as Model 2; this is slightly more conservative than a sinusoid, as it has the maximum frequency rate of change over its full cycle, and has a shorter period
    - See the companion presentation [4] for more details

Discussion of Assumptions Needed for Simulations - 2

- ❑Timestamp granularity: 8 ns (taken from [1])
- ❑Mean Sync message rate: 8 messages/s (from 802.1AS-2020 and [3])
- ❑Mean Pdelay message rate: 1 message/s (from 802.1AS-2020 and [3])
- ❑Use of syncLocked mode: simulations will be performed both with syncLocked mode used everywhere (which requires that the mean Sync rate is uniform throughout the network), and syncLocked mode not used
- ❑Residence time (only relevant when syncLocked mode is used): 10 ms (from 802.1AS-2020, and used in some of the cases of [3])
- ❑Pdelay turnaround time: 10 ms ((from 802.1AS-2020, and used in some of the cases of [3])
- ❑There will be no PLL filtering (or any kind of filtering) in the PTP Relay Instances
- ❑There will be filtering in the PTP End Instance (details are given in subsequent slides)

Discussion of Assumptions Needed for Simulations - 3

❑Computation of neighborRateRatio

- No assumptions or requirements are given in [1]
- The assumption of the NOTE in 11.2.19.3.3 of 802.1AS-2020 will be used, i.e., the ratio, of the difference between 2 correctedResponderEventTimestamps to the difference between 2 pdelayRespEventIngressTimestamps will be used
- In general, the successive timestamps can be separated by $N-1$ timestamps
- This difference is used in [3] with $N=10$
- In general, using larger N makes causes the computed neighborRateRatio to be less sensitive to noise but less responsive to systematic changes
- It might be suggested to run simulation cases with $N=1$ and $N=10$; however, since the next bullet item indicates we will need to increase the frequency measurement error in accordance with the 802.1AS, Annex B requirements, it is suggested to run simulation cases only with $N=1$.

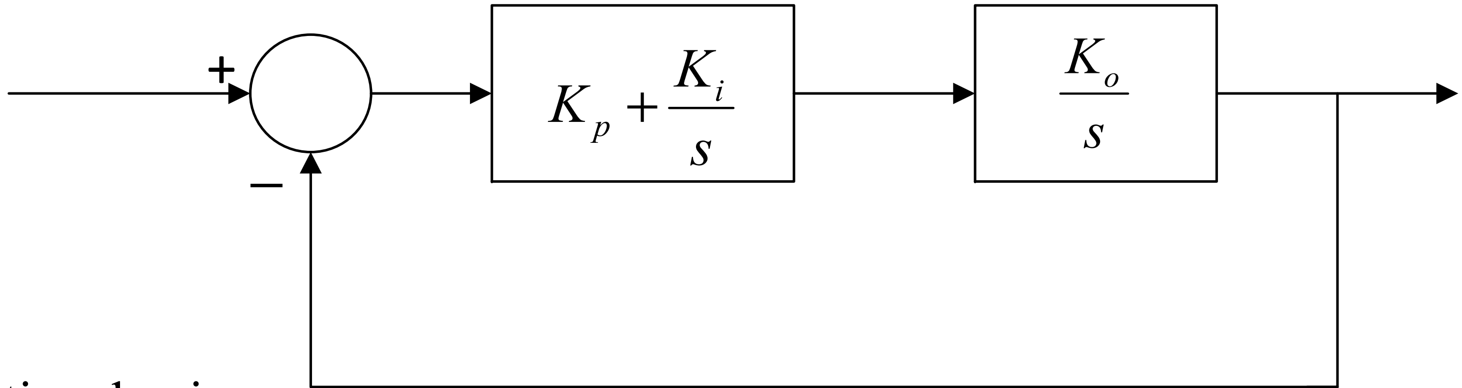
Discussion of Assumptions Needed for Simulations - 4

- Maximum frequency measurement granularity
  - 2.328×10^{-10} was used in [3]; this corresponds to 32-bit fixed point arithmetic in the computation
  - However, the actual requirement in B.2.4 of 802.1AS states that any scheme can be used to compute neighborRateRatio, but that the error inherent in the scheme shall not exceed 0.1 ppm
    - But a note that follows this requirement indicates that this is consistent with 40 ns phase measurement granularity; since 8 ns granularity is used in 60802/D1.1, it seems the error could be decreased, perhaps to (8/40)(0.1 ppm) = 0.02 ppm = 2×10^{-8}
  - It is suggested that simulation cases be run with frequency measurement granularities of 2.328×10^{-10}, 2×10^{-8}, and 10^{-7}

Discussion of Assumptions Needed for Simulations - 4

- In order to see how the transported time error increases with the number of hopes, the transported time and corresponding time error will be computed at the time-aware system of each PTP Relay Instance
  - It will be assumed that this time is available only for use in the ClockSlave entity; it is not used for timestamping incoming or outgoing PTP messages, nor in computing the contents of the correctionField of an outgoing message (timestamps are taken relative to the free-running local clock

Endpoint Filter Model and Assumptions - 1



$K_p =$ proportional gain

$K_i =$ integral gain

$K_o =$ VCO/DCO gain

Transfer function:

$$H(s) = \frac{K_p K_o s + K_i K_o}{s^2 + K_p K_o s + K_i K_o} = \frac{2\varsigma\omega_n s + \omega_n^2}{s^2 + 2\varsigma\omega_n s + \omega_n^2}$$

with

$$\omega_n = \sqrt{K_i K_o} \qquad \varsigma = \frac{K_p}{2}\sqrt{\frac{K_o}{K_i}}$$

Endpoint Filter Model and Assumptions – 2

- Often the filter parameters (and requirements) are expressed in terms of 3 dB bandwidth ($f_{3\text{dB}}$) and gain peaking (H_p)
  - These are related to damping ration (ζ) and undamped natural frequency (ω_n) by (see [6] and [7]):

$$f_{3\text{dB}} = \frac{\omega_n}{2\pi}\left[1 + 2\varsigma^2 + \sqrt{\left(1 + 2\varsigma^2\right)^2 + 1}\right]^{1/2}$$

$$H_p(\text{dB}) = 20\log_{10}\left\{\left[1 - 2\alpha - 2\alpha^2 + 2\alpha\sqrt{2\alpha + \alpha^2}\right]^{-1/2}\right\}$$

where

$$\alpha = \frac{1}{4\varsigma^2} = \frac{K_i}{K_p^2 K_o}$$

Endpoint Filter Model and Assumptions – 3

- Two sets of assumptions for proportional gain and integral gain were suggested by [5]
  - In these suggestions, the VCO gain was folded into the proportional gain and integral gain (this is equivalent to setting the VCO gain to 1)
- Filter assumption 1
  - $K_p K_o = 20$, $K_i K_o = 80$
  - Using the equations on the previous slides, we obtain
    - $\zeta = 1.12$
    - $\omega_n = 89$ rad/s
    - H_p (gain peaking) = 1.049 dB
    - $f_{3\text{dB}} = 3.78$ Hz

Endpoint Filter Model and Assumptions – 4

- Filter assumption 2
  - $K_p K_o = 9$, $K_i K_o = 95$
  - Using the equations on the previous slides, we obtain
    - $\zeta = 0.4617$
    - $\omega_n = 9.747$ rad/s
    - H_p (gain peaking) = 3.69 dB
    - $f_{3\text{dB}} = 2.77$ Hz
- Note that while the second filter has a narrower bandwidth than the first, it is underdamped, and therefore has a much larger gain peaking (and therefore its response will have much more overshoot)
- In contrast with the above, PLL filters used in telecom (e.g., in ITU-T Recommendations) typically have much smaller gain peaking, i.e., 0.1 dB or 0.2 dB (though this is to prevent jitter and wander accumulation in chains of PLLs, whereas here there is only a single PLL at the endpoint)

Simulation Cases - 1

- The above assumptions include 2 sets of endpoint filter parameters, 3 clock noise generation models, and three values for frequency measurement granularity for use in computing neighborRateRatio
- If all combinations of these assumptions are used, this results in 18 simulation cases
- For each case, 300 independent replications must be run, to obtain 99% confidence intervals for the 0.95 quantile
  - This may be obtained from the distribution of order statistics (see, for example, section 9.2, Eq. (9-25), of [8])
  - The independent runs are made by saving the state of the random number generator at the end of each run and using that to initialize the random number generator for the next run (and using a random number generator with a sufficiently long cycle of pseudo-random samples)
- The above means that 300 independent runs are needed for each of the 18 cases

Simulation Cases - 2

- Simulation time: the goal will be to run each case for 3100 s
  - 100 s for any initial transient to decay, followed by a steady-state period of 3000 s
  - Note that in [3], the run time was 10,010 s, with 10 s for transients to decay
    - However, only 4 cases were run in [3]
  - In any case, the run simulation time might need to be adjusted based on the actual run time, and the initial period might need to be adjusted based on the durations of actual transients
- For each case, the following will be computed at each node:
  - Max|dTE|
  - Is MTIE needed or desired
  - Is TDEV needed or desired
  - Note that if it is decided later that an additional statistic is needed, it likely will be necessary to re-run the simulation cases, because there is insufficient disk storage to save the full phase error histories for all 101 PTP instances, for each of 300 replications, for each case

Proposal

- The IEC/IEEE 60802 Joint Project group should discuss the assumptions described in this presentation, and:
  - Indicate if each assumption can be used as a starting point for initial simulations, or
  - If an assumption cannot be used, indicate what should be used instead

References - 1

[1] IEC/IEEE 60802 - Time-Sensitive Networking Profile for Industrial Automation/D1.1, September 2019

[2] *Proposed Disposition of Second Task Group Ballot Comments on IEEE Draft IEC/IEEE 60802/D1.1*, November 21, 2019.

[3] Geoffrey M. Garner, *Simulation Results for 802.1AS Synchronization Transport with Clock Wander Generation and Updated Residence and Pdelay Turnaround Times*, Samsung presentation to IEEE 802.1, July 12, 2010.

[4] Geoffrey M. Garner, *Comparison of 802.1AS Annex B and 60802 Clock Stability*, IEEE 802.1 Presentation, January 20, 2020.

[5] Email discussions with Guenter Steindl during the period November 2019 – January 2020.

[6] Dan H. Wolaver, *Phase-Locked Loop Circuit Design*, Prentice Hall, 1991.

[7] Floyd M. Gardner, *Phaselock Techniques*, Third Edition, Wiley, 2005.

[8] Athanasios Papoulis, *Probability, Random Variables, and Stochastic Processes*, Third Edition, McGraw-Hill, 1991.

Thank you