Initial Consideration of Tolerance Requirement Related to neighborRateRatio measurement in an IEC/IEEE 60802 Network

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Outline

- Introduction
- Possible tests
- Possible requirements
- Next steps

Introduction - 1

- References [1] and [2], and references cited there, present simulation results for accumulated maximum absolute value of relative dynamic time error (max|dTE_R|), relative to the grandmaster (GM), over an IEC/IEEE 60802 network
  - The results in [1] are used in the initial discussion of constant time error accumulation and requirements, given in [3]
- The control of dTE_R accumulation depends, in part, on how accurately neighborRateRatio is measured
- IEEE Std 802.1AS-2020 requires, in B.2.4, that "The error inherent in any scheme used to measure rate ratio shall not exceed ±0.1 ppm."
  - B.2.4 is not clear on whether "rate ratio" means neighborRateRatio or accumulated rateRatio relative to the GM
  - The results in [2] indicate that the limit of 802.1AS-2020, B.2.4, of ±0.1 ppm will give acceptable results because the results obtained in cases 16, 18, and 22 of [2] had maximum neighbor frequency offset error of 0.56 ppm with no GM time error variation (obtained in reference [1] of [2]) and 0.72 ppm with the GM time error variation considered here

Introduction - 2

- The results in [1] indicate that the 1 μs objective for max|TE| can be met over 64 hops, and possibly over 100 hops, even if the error in rateRatio relative to the GM exceeds 0.1 ppm (in both [1] and [2], the error in accumulated rateRatio relative to the GM is often in the range 0.5 ppm – 1 ppm
- In the simulations of [1] and [2], neighborRateRatio was measured using a window of size 11 and computation of the median (see those presentations for details)
- However, 802.1AS does not specify how neighborRateRatio is measured; the particular method used is implementation specific
- The IEC/IEEE 60802 profile should allow any measurement scheme, as long as respective requirements are met
- Since the Follow_Up Information TLV carries accumulated measured rateRatio, it would seem that it should be possible to test a single PTP Instance with a test set both serving as the GM and measuring the result
  - However, while measured rateRatio is known, actual rateRatio is not known
  - It will be seen that it is more straightforward to directly test the time error due to a single PTP Instance
    - This is an acceptable alternative because the accuracy of the rateRatio measurement influences the time error

Introduction - 3

- Limits on timestamp granularity and dynamic timestamp error also are relevant
  - These are tolerance requirements when the accuracy of the neighborRateRatio measurement or time error is tested
  - In such a test, the test set would need to impose both the specified timestamp granularity and dynamic timestamp error on the PTP event messages sent to the equipment under test (EUT), because the scheme used in the neighborRateRatio measurement would need to tolerate these errors
  - But, there would be no explicit requirement on timestamp granularity or dynamic timestamp error for the timestamping of incoming PTP event messages by the EUT itself
    - Rather, any timestamp granularity, dynamic timestamp error, and method for measuring neighborRateRatio would be allowed at the ingress to the EUT as long as the error in measured neighborRateRatio did not exceed the specified limit
  - However, it would be necessary to constrain the timestamp granularity and dynamic timestamp error for the timestamping of PTP event messages on egress, because there would be limits on the tolerance of the downstream PTP Instance

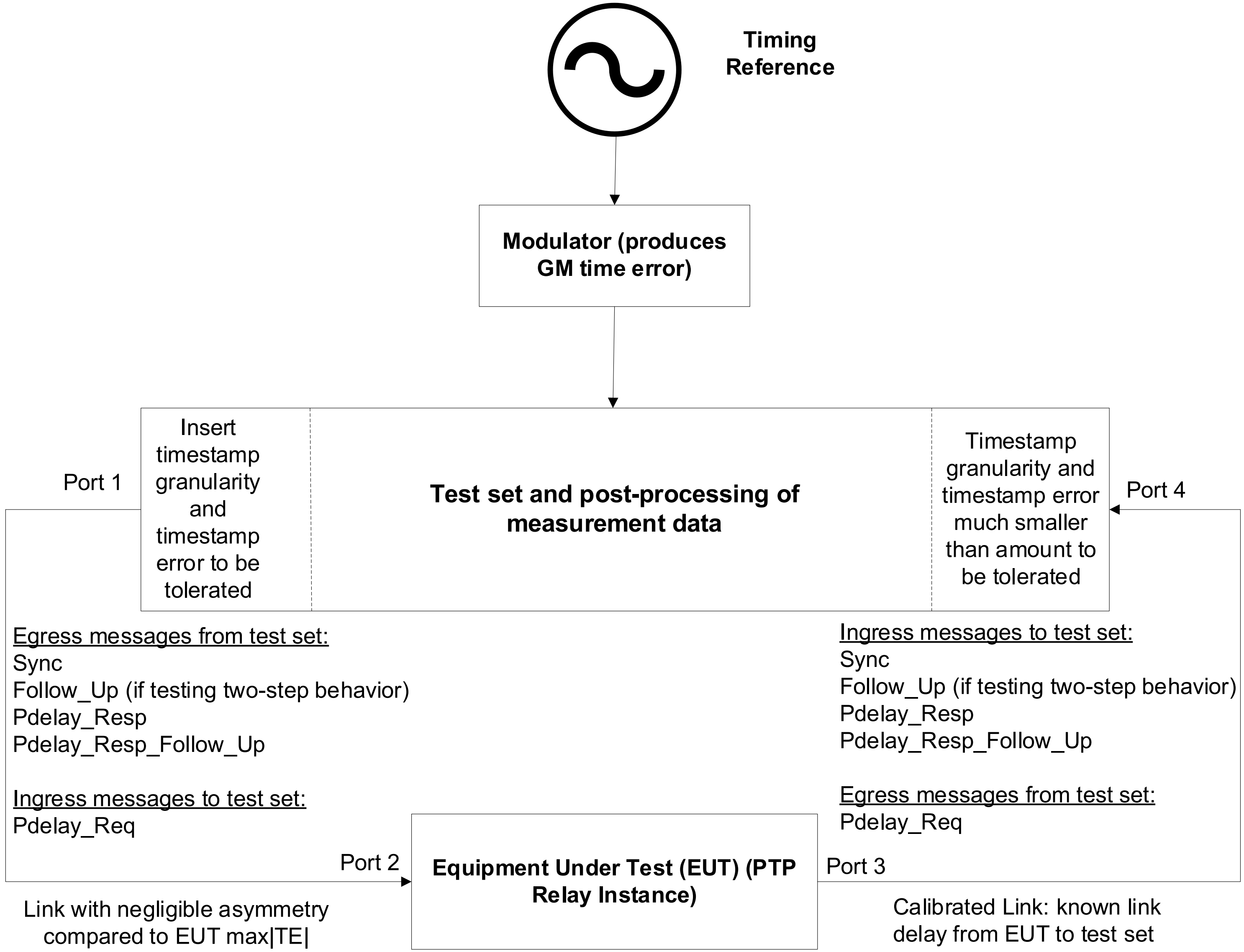
Introduction - 3

- The current presentation discusses, in general, input tolerance and output requirements for a single PTP Instance, for the purpose of testing compliance
- For now, the discussion is general, and is limited to the types of measurements and tests that might be done
- Specific numerical values for requirements are not given
  - That is a subject for future work, and might require simulations of the test scenarios to obtain specific values

Possible Tests – PTP Relay Instance – 1

- ❑A general test setup for a PTP Relay Instance is shown on the following slide
- ❑A test set acts as a GM and sends Sync (and Follow_Up if the EUT is two-step) messages to a PTP Relay Instance, on Port 1
- ❑The PTP Relay Instance sends Pdelay_Req messages to the test set on Port 2; the test set responds on Port 1 with Pdelay_Resp and Pdelay_Resp_Follow_Up. The PTP Relay Instance measures neighborRateRatio and meanLinkDelay
- ❑The test set is timed by the output of a modulator
  - The modulator input is a timing reference
  - The modulator output is the worst-case GM time error, which is based on the GM frequency stability versus temperature and the specified temperature profile
- ❑The asymmetry of the PTP Link between Port 1 and Port 2 (on which Sync messages are sent from the test set to the EUT) is negligible compared to max|TE| for the EUT
- ❑The delay from the EUT to the test set for the PTP Link between Port 3 and Port 4 (on which Sync messages are sent from the EUT to the test set) is calibrated and known

Possible Tests - PTP Relay Instance - 2



Possible Tests – PTP Relay Instance – 3

- The timestamp granularity and timestamp error on egress for PTP event messages sent from the test set to the EUT on Port 1 are set to the worst-case timestamp granularity and timestamp error that must be tolerated
- The timestamp granularity and timestamp error on ingress for PTP event messages sent from the EUT to the test set on Port 4 are set to be much smaller than the values to be tolerated (i.e., than the values set on Port 1)
- The intent is to test the PTP Relay Instance, under the conditions of specified GM time error and upstream (Port 1) timestamp granularity and timestamp error, for:
  - dTE_R, relative to test set
  - While it would be desirable to test the neighborRateRatio measurement, it will be explained shortly that this is not practical
- To do this, the following errors must be small compared to dTE_R:
  - Port 1 to Port 2 link asymmetry
  - Timestamp granularity and timestamp error at Port 4
- In addition, the delay of the Port 3 to Port 4 link (in the direction from Port 3 to Port 4) must be known, to eliminate errors that could arise if it is measured using peer delay messages

Possible Tests - PTP Relay Instance - 4

- The PTP Relay Instance measures neighborRateRatio relative to test set, and places the value in the cumulativeScaledRateOffset field of the Follow_Up information TLV
  - Since this is the first PTP Relay Instance after the GM, there is no accumulated value, and the cumulativeScaledRateOffset field carries neighborRateRatio measured by Port 3
  - This means that measured neighborRateRatio of Port 2 relative to Port 1 is known to the test set
  - Measured frequency offset is equal to measured neighborRateRatio minus 1

Possible Tests – PTP Relay Instance – 5

- Unfortunately, it is not practical to measure actual neighborRateRatio or frequency offset of the PTP Relay Instance relative to the GM
  - In principle, actual frequency offset of the EUT free-running clock relative to the GM (test set) is equal to the derivative of the phase/time difference between the EUT and GM free-running clocks
  - The EUT free-running clock (i.e., LocalClock) time can, in principle, be determined at the test set as the sum of the responseOriginTimestamp field and correctionField of the Pdelay_Response_Follow_Up message and the known link delay of the calibrated PTP Link from Port 3 to Port 4.
  - The test set time (modulator output) corresponding to the EUT free-running clock time is equal to the pdelayRespEventIngressTimestamp of the Pdelay_Resp message received at Port 4 (i.e., the timestamp T_4.
  - The measured frequency offset is, in principle, the derivative of the difference between the times computed in the above two bullet items
  - However, a discrete sequence cannot be differentiated exactly; a filtering operation is necessary (e.g., a differencing scheme or a least-squares approach)
  - Errors arise because the above schemes are imperfect; there can be additional errors due to the T_4 and EUT free-running clock time samples not being taken at the same instant
  - It is not clear how large these errors would be relative to the desired accuracy of the frequency offset measurement

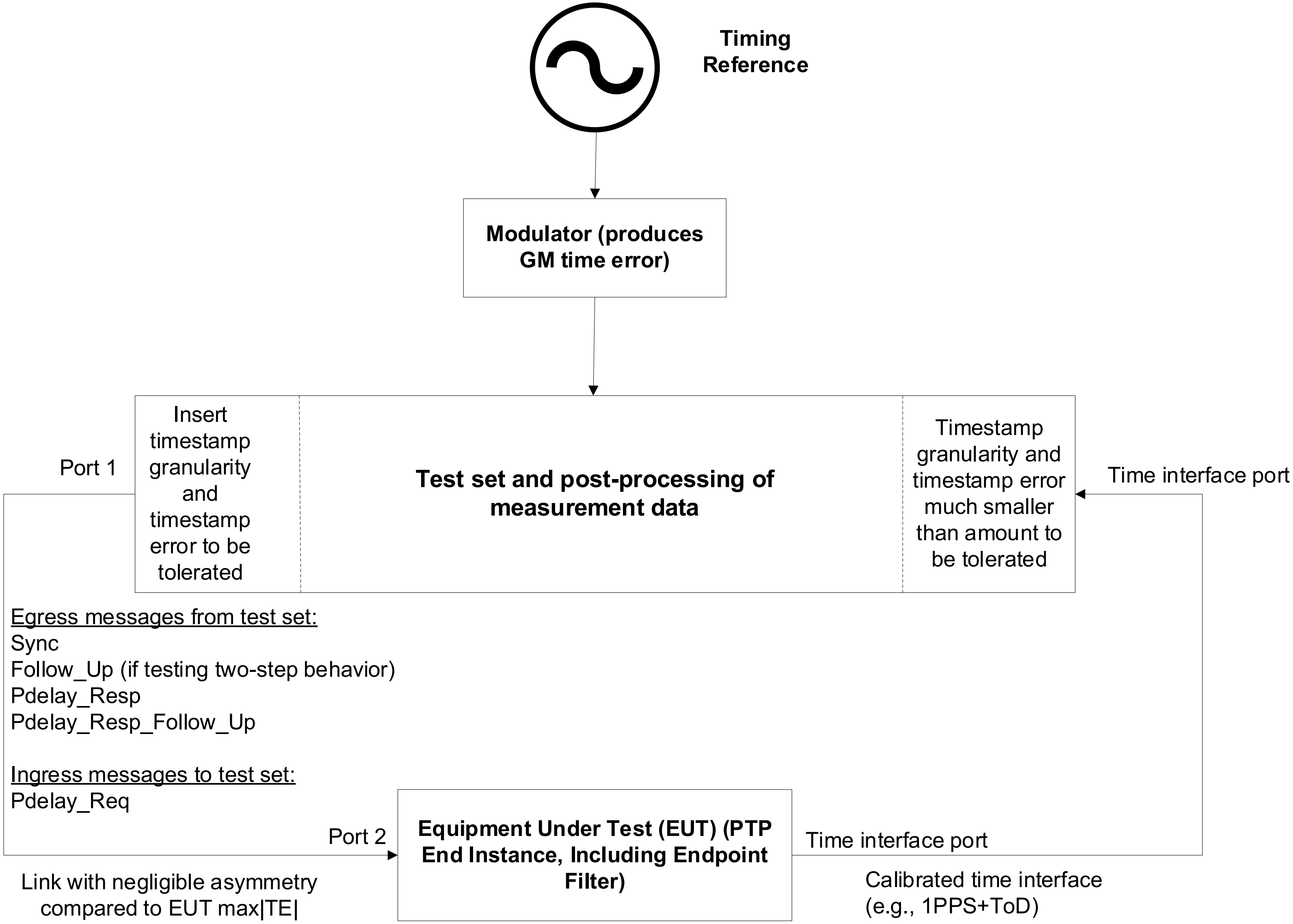
Possible Tests – PTP Relay Instance – 6

- Given the above difficulties in measuring actual frequency offset of the EUT, and therefore obtaining the error in the neighborRateRatio measurement, the measurement of the error in recovered synchronized time, relative to the test test, is straightforward
- The Sync (or Follow_Up, in the two-step case) messages sent by the EUT from Port 3 to Port 4 carry the estimate of GM (test set) time in the originTimestamp and Sync correctionField (or preciseOriginTimestamp and Follow_Up correctionField in the two-step case)
  - The EUT estimate of the test set time, at the time when the Sync message arrives at the test set, is equal to the sum of the originTimestamp (or preciseOriginTimestamp), Sync (or Follow_Up) correctionField, and known delay of the calibrated link in the direction from Port 3 to Port 4
  - The test set time when the Sync message arrives is equal to the syncEventIngressTimestamp for the arrival of the Sync message at Port 4
  - The time error (TE) is equal to the difference between the above two times; max|TE| can be computed as the maximum of the sequence of the absolute values of these TE samples
  - Note that, since a PTP Relay Instance does not include filtering, the TE sequence is not filtered before taking the maximum

Possible Tests - PTP End Instance - 1

- A test setup schematic for the case where the EUT is a PTP End Instance is shown on the next slide
- This is similar to the PTP Relay Instance schematic (slide 8), except:
  - The PTP Link between Port 3 and Port 4 is replaced by a time interface, e.g., 1PPS+ToD, and Ports 3 and 4 are now time interfaces
  - The EUT is a PTP End Instance, and contains an endpoint filter that meets the requirements of IEC/IEEE 60802 (e.g., bandwidth and gain peaking requirements)
- The time error samples are computed at the test set as in slide 12, except that now the GM time (i.e., synchronized time) at the EUT is given by the 1PPS+ToD samples input to the test set (properly compensated to account for delay in the 1PPS+ToD interface)
- max|TE|, and any other desired statistics, are computed from the time error samples

Possible Tests – PTP End Instance – 2



Discussion of Possible Requirements - 1

- Tolerance requirement
  - The maximum timestamp granularity and worst-case timestamp error that a PTP Relay Instance or Grandmaster PTP Instance is allowed to produce on output must be specified; this is what a PTP Instance must tolerate on input
  - The desired statistics (e.g., max|TE|, MTIE, TDEV) must be decided on, and the limits and respective time intervals (e.g., time interval over which max|TE| is measured, minimum and maximum observation intervals for MTIE and/or TDEV, etc.) must be specified
- A test is performed for the specified time duration, as described in slides 7 – 14
  - TE samples are collected, and the statistics are computed and compared with the limits

Discussion of Possible Requirements - 2

- Generation requirement
  - The details of the generation requirement are similar to those of the tolerance requirement, except that the input is “ideal”
  - This means that the timestamp granularity, timestamp error, and GM time error are made as small as possible (ideally zero)
  - As for the tolerance requirement, the desired statistics (e.g., max|TE|, MTIE, TDEV) must be decided on, and the limits and respective time intervals (e.g., time interval over which max|TE| is measured, minimum and maximum observation intervals for MTIE and/or TDEV, etc.) must be specified
  - Since the input is ideal, the limits will be lower than for the tolerance requirement
- A test is performed for the specified time duration, as described in slides 7 – 14
  - TE samples are collected, and the statistics are computed and compared with the limits

Discussion of Possible Requirements - 3

- The tolerance requirements are determined by considering the time error accumulation simulation cases where the timestamp granularity, timestamp error, and GM time error assumptions corresponded to the tolerance requirements
- The limits for a PTP Relay Instance correspond to the simulation results for the first PTP Relay Instance after the GM, using unfiltered dTE samples
- The limits for a PTP End Instance correspond to the simulation results for the first PTP Relay Instance after the GM, using filtered dTE samples
- Since the previous simulations for the case of varying Sync and Pdelay interval were for single replications, it may be necessary to run additional simulations
- For generation requirements, simulations must be run with zero GM error and zero timestamp granularity and timestamp error
- It is expected that generation requirements will be tighter than tolerance requirements

Next Steps

- It must be decided what types of requirements are needed for IEC/IEEE 60802 network equipment
  - Tolerance, generation, both?
  - Statistics for which limits will be set (e.g., max|TE|, MTIE, TDEV, etc.)
- Note that even if it is decided that formal tolerance requirements are not needed, the maximum amount of timestamp error and maximum timestamp granularity that can be produced on output must be decided (it has already been decided to have a requirement for maximum GM error)
  - This is because, if timestamp granularity and/or timestamp error on egress are allowed to be arbitrarily large, the resulting time error can be arbitrarily large
- After the above are decided, limits must be decided
  - These can be based on previous simulations and, if necessary, new simulations
  - Note that any new simulations needed would likely be for a GM followed by a single PTP Instance (which means run times will be shorter than for previous simulations)

References

[1] Geoffrey M. Garner, *New Simulation Results for dTE for an IEC/IEEE 60802 Network, with Variable Inter-Message Intervals*, Revision2, IEC/IEEE 60802 presentation, July 1, 2021 (available at https://www.ieee802.org/1/files/public/docs2021/60802-garner-single-replic-simul-results-variable-intermsg-intervals-0621-v02.pdf)

[2] Geoffrey M. Garner, *New Simulation Results for dTE for an IEC/IEEE 60802 , Based on New Frequency Stability Model, Version (Revision) 1*, IEC/IEEE 60802 presentation, May 3, 2021 (available at https://www.ieee802.org/1/files/public/docs2021/60802-garner-multipe-replic-simulation-results-new-freq-stab-model-0421-v01.pdf)

[3] Geoffrey M. Garner, *Analysis of Constant Time Error Accumulation and Budgeting in an IEC/IEEE 60802 Network*, IEC/IEEE 60802 presentation, July 7,2021 (available at https://www.ieee802.org/1/files/public/docs2021/60802-garner-analysis-of-cTE-and-budgeting-in-60802-network-0721-v00.pdf)

Thank you