Multiple Replication Simulation Results for 802.1AS Synchronization Transport with Clock Wander Generation and Updated Residence and Pdelay Turnaround Times

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Outline

- Introduction
- Review of HRM
- Review of simulation model
- Model for local clock wander generation
- Results
- Conclusions
- Future work

Introduction - 1

- References [1] presented simulation results for synchronization transport performance over a network of 802.1AS time-aware systems, using latest requirements for Sync interval, Pdelay intervals, residence time, and Pdelay turnaround time, and also considered the effect of local clock wander generation
  - Sync interval: 0.125 s
  - Pdelay interval: 1.0 s
  - Residence time and Pdelay turnaround time ≤ 10 ms
  - Clock wander generation as specified in Annex B (Figure B-1 and Table B-1) of 802.1AS [2]

Introduction - 2

- Actually, to see the impact of residence time, Pdelay turnaround time, and local clock wander generation, a several cases were considered
  - Residence and Pdelay turnaround times of 1 ms, 10 ms, and 50 ms, all with local clock wander generation
  - Residence and Pdelay turnaround time if 1 ms and no local clock wander generation
    - This case actually had been simulated previously, and was included here for comparison with the other cases (longer residence and Pdelay turnaround times and local clock wander generation)
- For each simulation case, endpoint filter bandwidths ranging from 1 mHz to 10 Hz were considered
  - Cases included 1 mHz, 10 mHz, 100 mHz, 1 Hz, 10 Hz

Introduction - 3

- However, the results were based on single simulation runs for each case
  - This was necessary because, at the point the work was begun, there was not sufficient time for 300 independent replications of each case to complete prior to the July, 2010 IEEE 802.1 meeting
    - 300 independent replications allows 99% confidence intervals for the 0.95 quantile of MTIE to be determined (see slides 12 and 13)
- The results indicated
  - No appreciable difference when local clock wander generation, at the level of the TDEV mask of Figure B-1 and Table B-1 of [2], is added
  - No appreciable difference when residence and Pdelay turnaround times are increased to 10 ms or 50 ms
- This also meant that the results confirmed that previous results, obtained for the case of 1 ms residence and Pdelay turnaround times and no local clock wander generation, hold for the cases with longer residence/Pdelay turnaround time and local clock wander generation

Introduction - 4

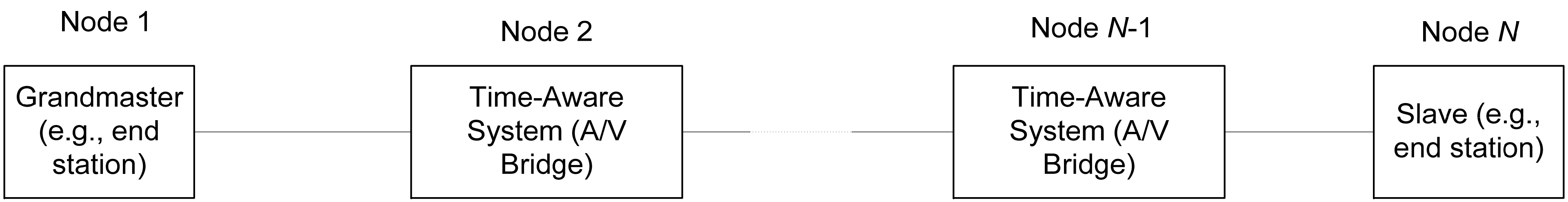
- Those previous results are
  - MTIE masks for all applications are met with a 1 mHz endpoint filter
  - MTIE masks for all applications except for uncompressed SDTV (SDI video) are met with a 10 mHz filter
  - MTIE masks for compressed video (MPEG) and digital audio are met with a 1 Hz filter
  - MTIE masks for compressed video (MPEG) and professional digital audio are met with a 10 Hz filter
    - Note that the MTIE mask for professional audio is less stringent than for consumer audio because the professional audio equipment is required to tolerate more jitter

Introduction - 5

- The current presentation presents results for 300 independent replications
  - Since the single-replication results of [1] initialized the local clock frequency offsets randomly within $\pm$100 ppm, it is expected that the 99% confidence interval for the 0.95 quantile of MTIE will, in general, exceed the corresponding single-replication result
- Since the results of [1] indicated that the addition of local clock wander generation and the varying of residence and Pdelay turnaround time from 1 ms to 50 ms had small impact, it was not necessary to run multiple replications for all the cases of [1]
  - Instead, only the case corresponding to the current 802.1AS requirement, i.e., residence and Pdelay turnaround time of 10 ms and local clock wander generation as specified in Annex B of [2], was run
  - Endpoint filter bandwidths of 10 Hz, 1 Hz, 100 mHz, 10 mHz, and 1 mHz were considered

Review of Hypothetical Reference Model (HRM) (from [1])

- Number of hops = $N - 1 = 7$
  - i.e., N = 8 nodes (time aware systems) numbered from 1 to 8, with the grandmaster as node 1



Simulation model

- See [1] and the references given there for details on
  - Simulation model
  - Local clock wander generation model

Model Parameters - 1

- Endpoint filter gain peaking = 0.1 dB
- Sync interval = 0.125 s
- Pdelay interval = 1.0 s
- Link propagation delay = 500 ns (fixed)
  - Links are symmetric
  - PHY latency is assumed symmetric
- Phase (time) measurement granularity = 40 ns
- Frequency measurement granularity = 2.328×10^{-10} (i.e., computations assumed to be done with 32-bit arithmetic)
- LocalClock entity frequency tolerance = $\pm$100 ppm
  - Frequencies of free-running oscillators in nodes are chosen randomly at initialization within their tolerance range (a uniform distribution is assumed)
- Number of time-aware systems = 8 (7 hops; see HRM on slide 8)
- Simulation time = 10 010 s
- Maximum time step = 0.001 s

Model Parameters - 2

- ❑Residence time = 10 ms
- ❑Pdelay turnaround time = 10 ms
- ❑Local clock wander generation model as described in [1]
  - ▪TDEV meets the mask of Figure B-1 and Table B-1 of 802.1AS [2]
  - ▪Clock noise samples generated as described in [1]
- ❑Endpoint filter bandwidths: 10 Hz, 1 Hz, 100 mHz, 10 mHz, 1 mHz (5 cases simulated)
- ❑Endpoint filter gain peaking = 0.1 dB
  - ▪Endpoint filter model is linear, second-order, with 20 dB/decade roll-off

Confidence Intervals for MTIE - 1

- MTIE(S), for each observation interval S, is the peak-to-peak time interval error (TIE), i.e., peak-to-peak phase error, measured over all intervals of duration S
- TIE is a random process, and MTIE is a function of TIE for each observation interval S
  - Therefore, MTIE(S) for each S is a random variable, and has a probability distribution
  - Here, MTIE(S) is estimated by giving a confidence interval for a certain quantile of this probability distribution, based on measurement samples from a set of independent replications of each respective simulation case
- It is well-known (see [3], p.254 and [4], p.238) that confidence interval for a quantile of a distribution is given by a partial binomial sum, assuming the measurement samples are independent (note that they are, by definition, identically distributed because they are measured from the same population, i.e., generated by the same simulation model but with different initial random number generator seed in this case)

Confidence Intervals for MTIE - 2

- Let X_1 , X_2 , …, X_M , be independent samples of MTIE, for the same observation interval
- Assume the samples have been placed in ascending order, i.e.,

$$X_1 \le X_2 \le \cdots \le X_M$$

- Let x_β be the βth quantile of the distribution of MTIE, for that observation interval
- Then a confidence interval for x_β, expressed as the probability that x_β falls between the samples x_r and x_s (with $r < s$), is given by (where $P\{\cdot\}$ denotes probability) [4]

$$P\{X_r \le x_\beta \le X_s\} = \sum_{k=r}^{s-1} \frac{M!}{k!(M-k)!} \beta^k (1-\beta)^{M-k}$$

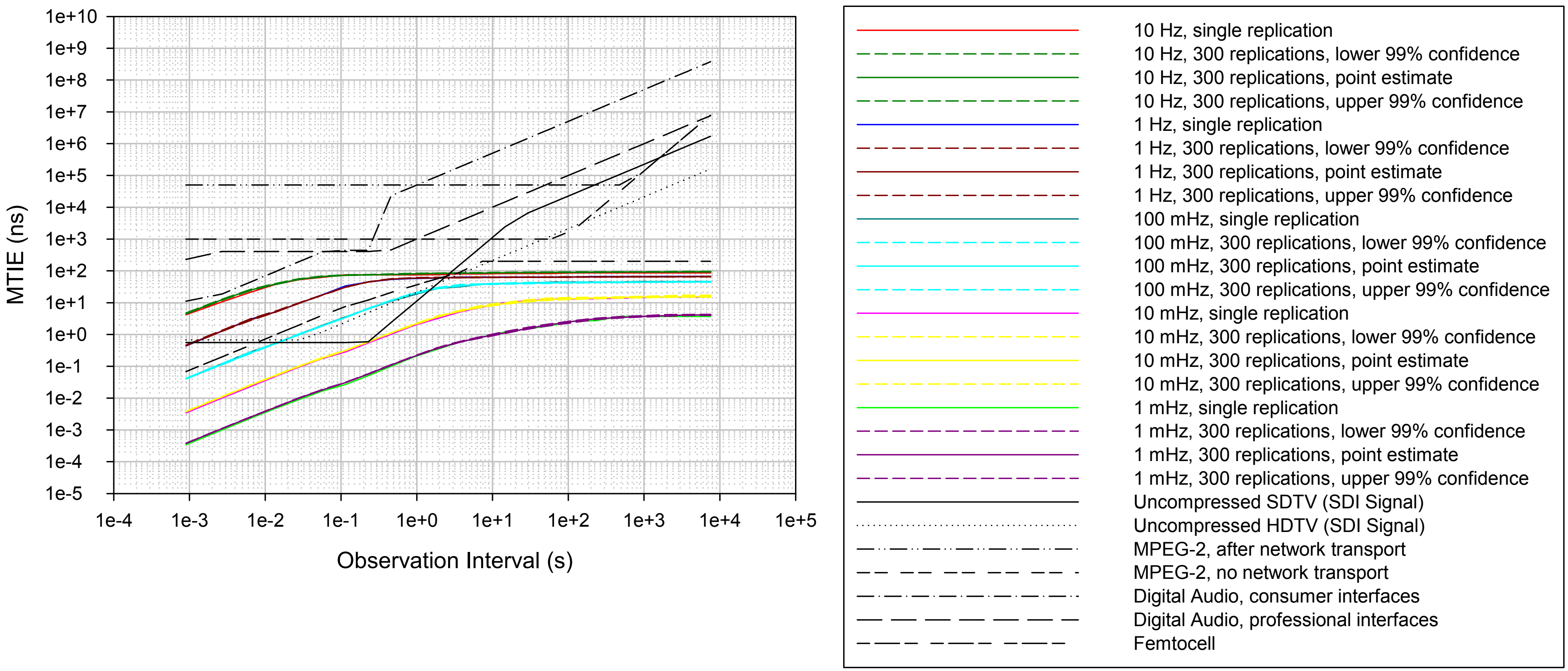
- For β = 0.95 (i.e. 0.95 quantile), $M = 300$, $r = 275$, and $s = 294$, the above sum is 0.99085, i.e., a 99% confidence interval for the 0.95 quantile is given by the interval that extends from the 275th through 294th smallest samples of a set of 300 samples

Simulation Results

- The following slides present MTIE results for time-aware systems (nodes) 2 and 8
- The single-replication results from [1] are included for comparison
- The 300 runs for each of the 5 endpoint filter bandwidths required approximately 9 days to complete
  - The machine used an Intel Core i7 Extreme Processor with 4 GB RAM and an ASUS P6T Deluxe motherboard
  - The operating system was Fedora Core 10

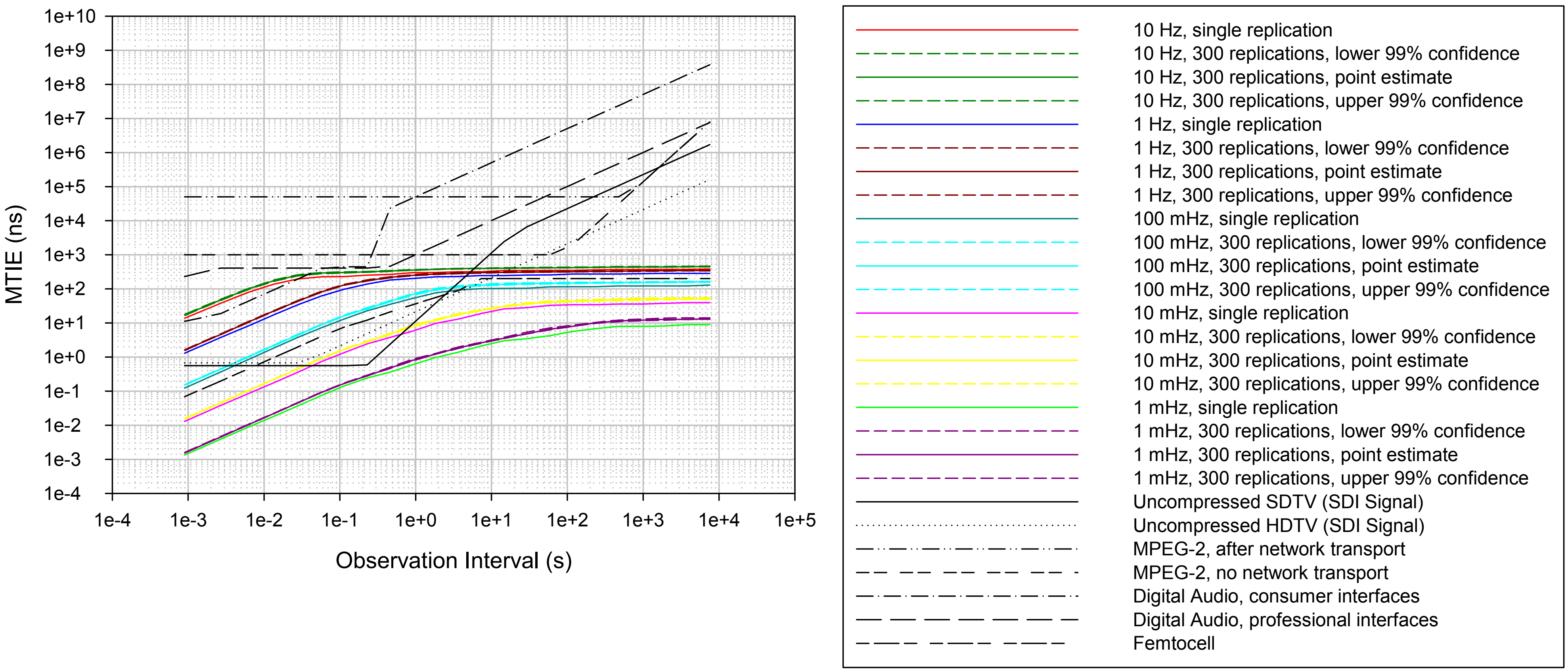
MTIE Results – Node 2

Time-aware system (node) 2
Comparison of jitter/wander accumulation MTIE results for single replication
and 300 independent replications of simulation
10 Hz, 1 Hz, 100 mHz, 10 mHz, and 1 mHz endpoint filter bandwidths
10 ms residence time and Pdelay turnaround time, with clock wander generation
Sync Interval = 0.125 s
Pdelay Interval = 1.0 s



MTIE Results - Node 8

Time-aware system (node) 8
Comparison of jitter/wander accumulation MTIE results for single replication
and 300 independent replications of simulation
10 Hz, 1 Hz, 100 mHz, 10 mHz, and 1 mHz endpoint filter bandwidths
10 ms residence time and Pdelay turnaround time, with clock wander generation
Sync Interval = 0.125 s
Pdelay Interval = 1.0 s



Discussion of Results - 1

- At the final time-aware system (node 8), the 99% confidence interval for the 0.95 quantile of MTIE for each endpoint filter bandwidth exceeds the corresponding single-replication MTIE
- The actual exceedance for node 8 is in the range of 20 – 60% (this was observed by examining the numerical MTIE results)
  - In the plot, the exceedance appears to be very small due to the log scale
- In spite of the increase compared to the single replication results, each MTIE mask that was met by the single-replication results is met by the multiple-replication results
- For node 2, the difference between the single and multiple-replication results is much smaller (and less than 20% in all cases)

Discussion of Results - 2

- This means the conclusions for the single-replication results, given on slide 6, hold for the multiple-replication results
  - MTIE masks for all applications are met with a 1 mHz endpoint filter
  - MTIE masks for all applications except for uncompressed SDTV (SDI video) were met with a 10 mHz filter
  - MTIE masks for compressed video (MPEG) and digital audio were met with a 1 Hz filter
  - MTIE masks for compressed video (MPEG) and professional digital audio were met with a 10 Hz filter (this case must still be run)
    - Note that the MTIE mask for professional audio is less stringent than for consumer audio because the professional audio equipment is required to tolerate more jitter

Summary and Conclusions - 1

- Jitter/Wander accumulation simulation results have been presented, based on current P802.1AS specifications [2] and 300 independent replications of each simulation case
- Five different endpoint filter bandwidths were considered
  - Endpoint filter bandwidths of 1 mHz, 10 mHz, 100 mHz, 1 Hz, and 10 Hz
- 99% confidence intervals for the 0.95 quantile of MTIE was obtained for each observation interval
- The results were compared with the single-replication results obtained in [1]
- At the final time-aware system (node 8), the 99% confidence interval for the 0.95 quantile of MTIE exceeded the corresponding single-replication MTIE result by 20 – 60% (depending on the observation interval and endpoint filter bandwidth)
- At the second time-aware system (i.e., after 1 hop), the multiple-replication results exceeded the single-replication results by a much smaller amount (and always by less than 20%)

Summary and Conclusions - 2

- The previous conclusions, obtained from the single-replication results, hold for the multiple-replication results:
  - MTIE masks for all applications are met with a 1 mHz endpoint filter
  - MTIE masks for all applications except for uncompressed SDTV (SDI video) were met with a 10 mHz filter
  - MTIE masks for compressed video (MPEG) and digital audio were met with a 1 Hz filter
  - MTIE masks for compressed video (MPEG) and professional digital audio were met with a 10 Hz filter (this case must still be run)
    - Note that the MTIE mask for professional audio is less stringent than for consumer audio because the professional audio equipment is required to tolerate more jitter

References

1. Geoffrey M. Garner, *Simulation Results for 802.1AS Synchronization Transport with Clock Wander Generation and Updated Residence and Pdelay Turnaround Times*, Samsung presentation to July, 2010 IEEE 802.1 AVB TG meeting, San Diego, CA, USA, July 12, 2010. Available at http://www.ieee802.org/1/files/public/docs2010/as-garner-simulation-results-wander-gen-new-res-time-0710.pdf
2. IEEE P802.1AS/D7.2, *Draft Standard for Local and Metropolitan Area Networks – Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks*, August 18, 2010.
3. Athanasios Papoulis, *Probability, Random Variables, and Stochastic Processes*, 3rd edition, McGraw-Hill, 1991 (see Section 9-2).
4. Stefano Bregni, *Synchronization of Digital Telecommunications Networks*, Wiley, 2002 (see section 5.8.8).