Summary of the simulation results and agreements

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March Simulation Results (Ref #3)

- **Oscillator model 1 (802.1AS-2020 Annex B model) was found to be too optimistic**
- **The decision was to run the next set of simulations with model 3 (triangular), as it was the most conservative model**

Case	Clock Model	Relative phase of clock frequency modulation (models 2 and 3)
1	1	Not applicable
2	2	0
3	2	random
4	3	0
5	3	random

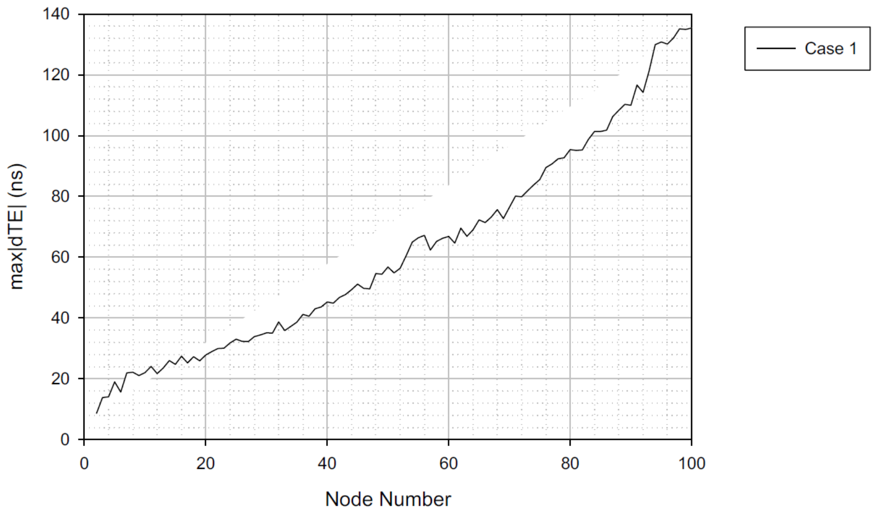
Simulation Cases - 1

❑In the simulation cases, the clock model designation is (models 1, 2, and 3):

- **Model 1**: flicker frequency modulation (FFM) at level of 802.1AS-2020, Annex B TDEV mask (Figure B-1 of 802.1AS-2020) (see the Appendix for details on how this is simulated, and see [4] for details on the requirement
- **Model 2**: Sinusoidal phase and frequency variation, with frequency zero-to-peak amplitude of 100 ppm and maximum frequency rate of change of 3 ppm/s
  - Corresponding phase/time offset variation: $x(t) = A \sin(2\pi f t)$, with A = 3.33 ms and f = 4.7746 mHz (see [4])
- **Model 3**: Triangular wave frequency variation, with 100 ppm zero-to-peak frequency modulation amplitude and 133.3 s frequency modulation frequency (see [4] for details, and corresponding phase/time offset variation)

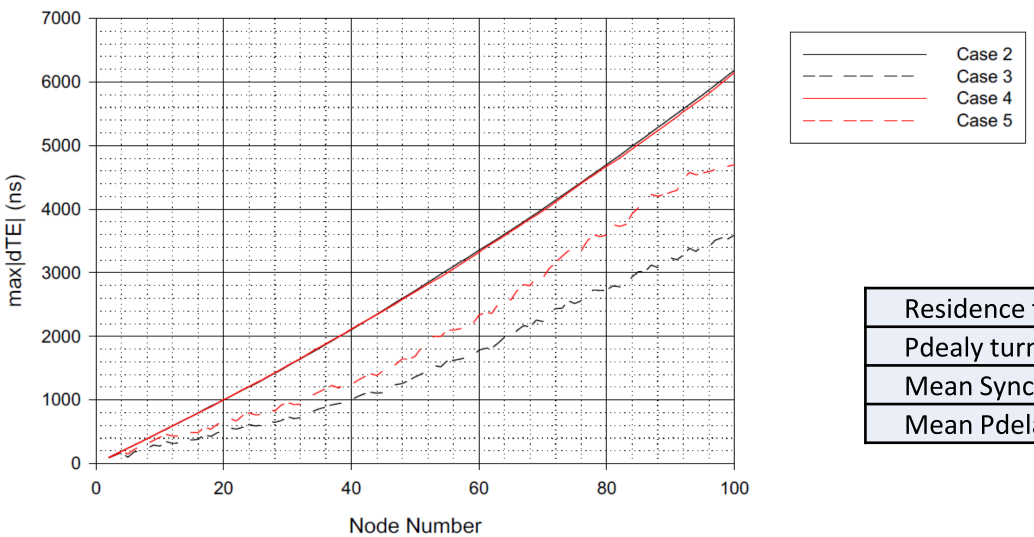
Max|dTE| results - 1

Simulation Case 1
Single replication of simulation
Clock Model 1 (FFM)



Max|dTE| results - 2

Simulation Cases 2, 3, 4, and 5
Single replication of simulation
Clock Model 2 (sinusoidal frequency variation, cases 2 and3)
Clock Model 3 (triangular wave freqeuncy variation, cases 4 and 5)

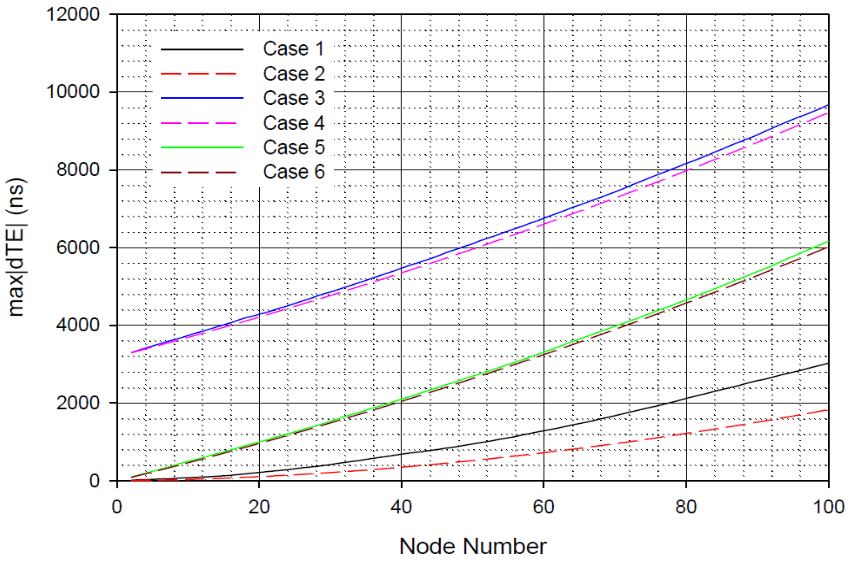


Residence time	10ms
Pdealy turnaround time	10ms
Mean Sync Interval	31.25ms
Mean Pdelay interval	1000ms

May Simulation Results (Ref #4)

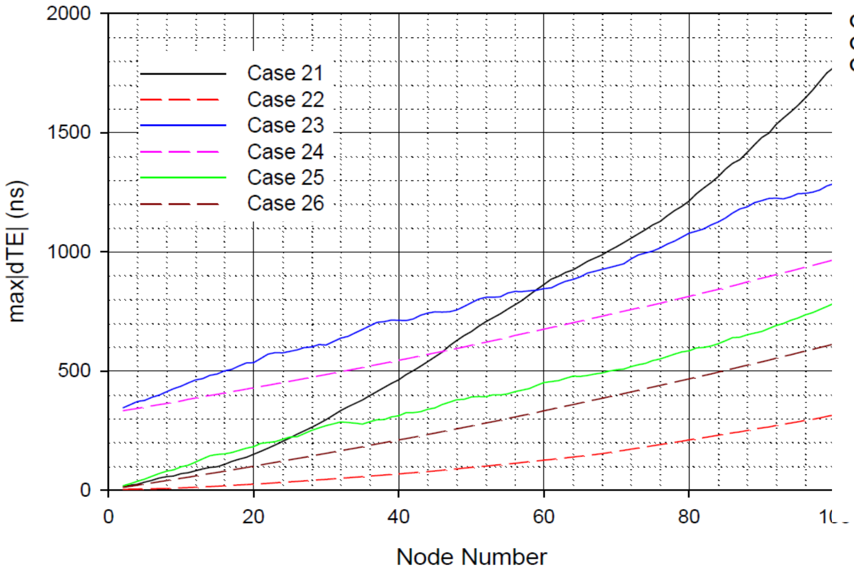
Obtain GM rateRatio via accumulation of neighborRateRatio				
Case	Max Freq Drift Rate (ppm/s)	Mean Sync Rate (messages/s)	Mean Pdelay Rate (messages/s)	Timestamp Granularity (ns)
1	3	32	32	8
2	3	32	32	2
3	3	1	1	8
4	3	1	1	2
5	3	32	1	8
6	3	32	1	2

Simulation Cases 1 - 6
Single replication of simulation
Clock Model: triangular wave freqeuncy variation
+/- 100 ppm amplitude, 3 ppm/s maximum drift rate
Cases 1 and 2: 32 Sync msgs/s, 32 Pdelay exchanges/s
Cases 3 and 4: 1 Sync msg/s, 1 Pdelay exchange/s
Cases 5 and 6: 32 Sync msgs/s, 1 Pdelay exchange/s



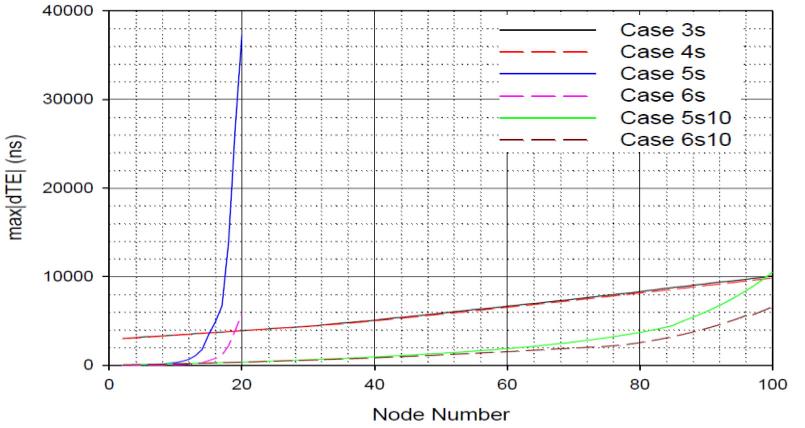
Obtain GM rateRatio via accumulation of neighborRateRatio				
Case	Max Freq Drift Rate (ppm/s)	Mean Sync Rate (messages/s)	Mean Pdelay Rate (messages/s)	Timestamp Granularity (ns)
21	0.3	32	32	8
22	0.3	32	32	2
23	0.3	1	1	8
24	0.3	1	1	2
25	0.3	32	1	8
26	0.3	32	1	2

Simulation Cases 21 - 26
Single replication of simulation
Clock Model: triangular wave freqeuncy variation
+/- 100 ppm amplitude, 0.3 ppm/s maximum drift rate
Cases 21 and 22: 32 Sync msgs/s, 32 Pdelay exchanges/s
Cases 23 and 24: 1 Sync msg/s, 1 Pdelay exchange/s
Cases 25 and 26: 32 Sync msgs/s, 1 Pdelay exchange/s



Obtain GM rateRatio using successive Sync messages					
Case	Max Freq Drift Rate (ppm/s)	Mean Sync Rate (messages/s)	Mean Pdelay Rate (messages/s)	Timestamp Granularity (ns)	Use every n^{th} Sync message when computing rateRatio (value of n)
3s	3	1	1	8	1
4s	3	1	1	2	1
5s	3	32	1	8	1
6s	3	32	1	2	1
5s10	3	32	1	8	10
6s10	3	32	1	2	10

Simulation Cases 3s - 6s
Single replication of simulation
Measure GM rate ratio using successive Sync messages
Clock Model: triangular wave freqeuncy variation
+/- 100 ppm amplitude, 3 ppm/s maximum drift rate
Cases 3s and 4s: 1 Sync msg/s, 1 Pdelay exchange/s
Cases 5s and 6s: 32 Sync msgs/s, 1 Pdelay exchange/s
Cases 5s10 and 6s10: 32 Sync msgs/s, 1 Pdelay exchange/s, measure
GM rate ration using every 10th Sync message, jumping v

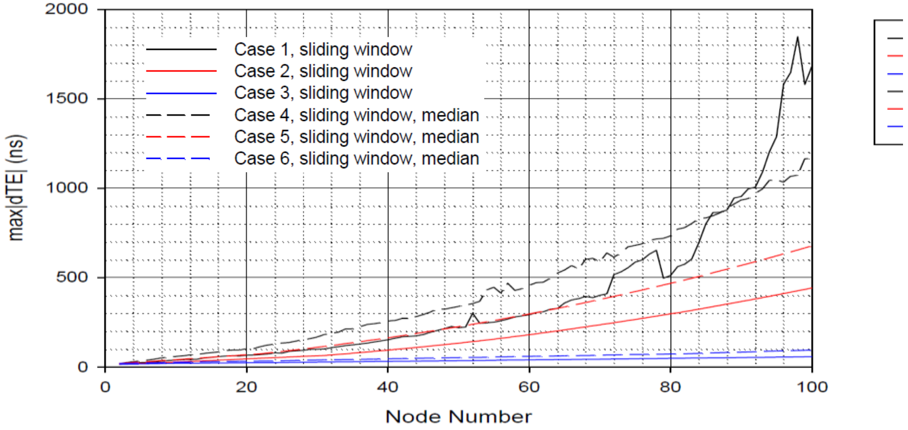


- **Based on these simulation results, it was decided to use a timestamp granularity of 2ns**
- **It was decided to use successive Sync messages for computing GM rateRatio for the next set of simulations**
- **The residence time for the May simulation was 10ms, the next set of simulations will include residence time of 1ms, 4ms, and equal probability of 1 ms, 4 ms, 10 ms (chosen independently for each Sync message)**
- **Based on discussion and later updated in contribution [1], it was decided to use +/-50 ppm for the clock model**

July Simulation Results (Ref #5)

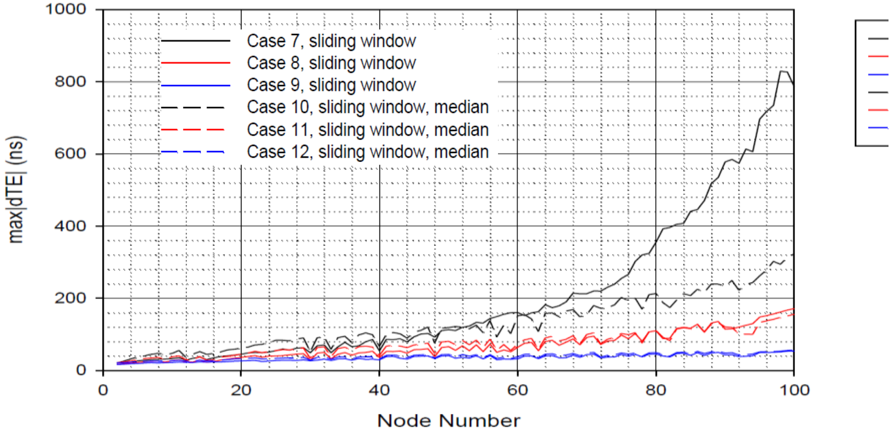
Obtain GM rateRatio via accumulation of neighborRateRatio			
Case	Residence time (ms)	Compute median for GM rateRatio computation (Yes/No)	Relative phases of triangular waves at each node
1	1, 4, 10 (with equal prob)	No	zero
2	4	No	zero
3	1	No	zero
4	1, 4, 10 (with equal prob)	Yes	zero
5	4	Yes	zero
6	1	Yes	zero

Simulation Cases 1 - 6
Single replication of simulation
Clock Model: triangular wave freqeuncy variation
+/- 50 ppm amplitude, 3 ppm/s maximum drift rate, in phase
Cases 1 and 4: 1 ms, 4 ms, 10 ms residence times with equal probability (chosen independently for each Sync message)
Cases 2 and 5: 4 ms residence time
Cases 3 and 6: 1 ms residence time
Window size is 8 (current plus prev 7 Sync msgs) in all cases, for computing GM freq offset



Obtain GM rateRatio via accumulation of neighborRateRatio			
Case	Residence time (ms)	Compute median for GM rateRatio computation	Relative phases of triangular waves at each node
7	1, 4, 10 (with equal prob)	No	random
8	4	No	random
9	1	No	random
10	1, 4, 10 (with equal prob)	Yes	random
11	4	Yes	random
12	1	Yes	random

Simulation Cases 7 - 12
Single replication of simulation
Clock Model: triangular wave freqeuncy variation
+/- 50 ppm amp, 3 ppm/s max drift rate, out of phase
Cases 7 and 10: 1 ms, 4 ms, 10 ms residence times with equal probability (chosen independently for each Sync message)
Cases 8 and 11: 4 ms residence time
Cases 9 and 12: 1 ms residence time
Window size is 8 (current plus prev 7 Sync msgs) in all cases, for computing GM freq offset



Pdelay turnaround time	10ms
Mean Sync Interval	30ms
Mean Pdelay interval	1000ms

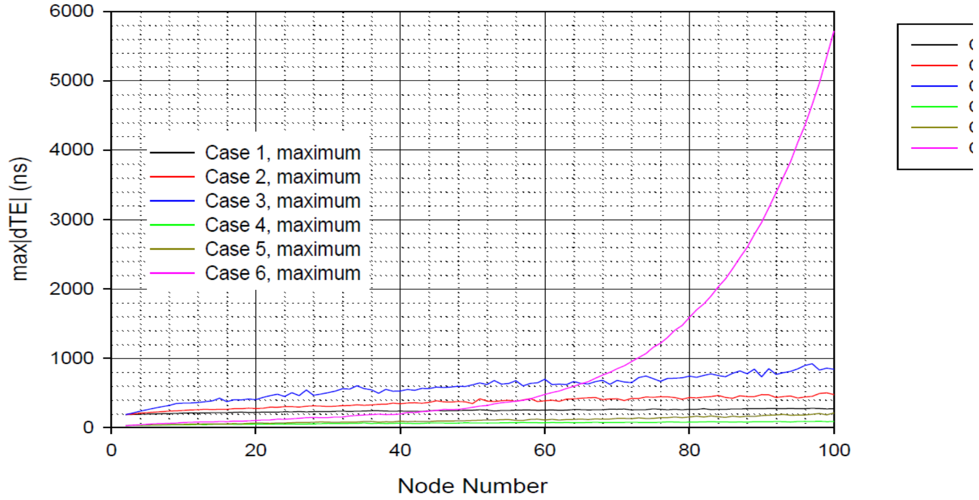
- **It was found that clock model using triangular wave frequency variation was too conservative, it was decided to use sinusoidal wave frequency variation for the clock model for the next set of simulations, and use relative random phases and random frequencies of sinusoidal waves at each node.**
- **It was decided to use sliding window for the computation of GM rateRatio using successive Sync messages with residence time of 1ms, 4ms and 10ms**
- **It was decided to include Accumulate neighborRateRatio using pDelay messages for computing GM rateRatio with residence time and Pdelay turnaround time of 1ms, 4ms and 10ms**

September Simulation Results (Ref #6)

Case	Method of computing GM rateRatio	Residence time (ms)	Pdelay turnaround time (ms)	Mean Sync Interval (ms)	Mean Pdelay Interval (ms)
1	Accumulate neighborRateRatio	1	1	125	31.25
2	Accumulate neighborRateRatio	4	4	125	31.25
3	Accumulate neighborRateRatio	10	10	125	31.25
4	Use successive Sync messages	1	10	31.25	1000
5	Use successive Sync messages	4	10	31.25	1000
6	Use successive Sync messages	10	10	31.25	1000

Simulation Cases 1 - 6
300 replications of simulation
Clock Model: sinusoidal phase and freqeuncy variation
- 50 ppm max freq offset
- 3 ppm/s maximum drift rate
- relative phases of modulation chosen randomly over [0,2*pi] on initialization
- Actual modulation amplitude chosen randomly over [45 ppm, 50 ppm]

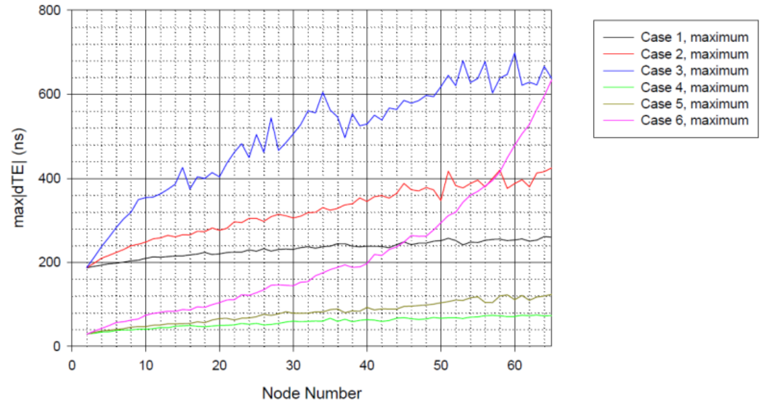
Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



Results for dTE, Zero Error in GM Time Source - 5

Simulation Cases 1 - 6
300 replications of simulation
Clock Model: sinusoidal phase and freqeuncy variation
- 50 ppm max freq offset
- 3 ppm/s maximum drift rate
- relative phases of modulation chosen randomly over [0,2*pi] on initialization
- Actual modulation amplitude chosen randomly over [45 ppm, 50 ppm]

Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



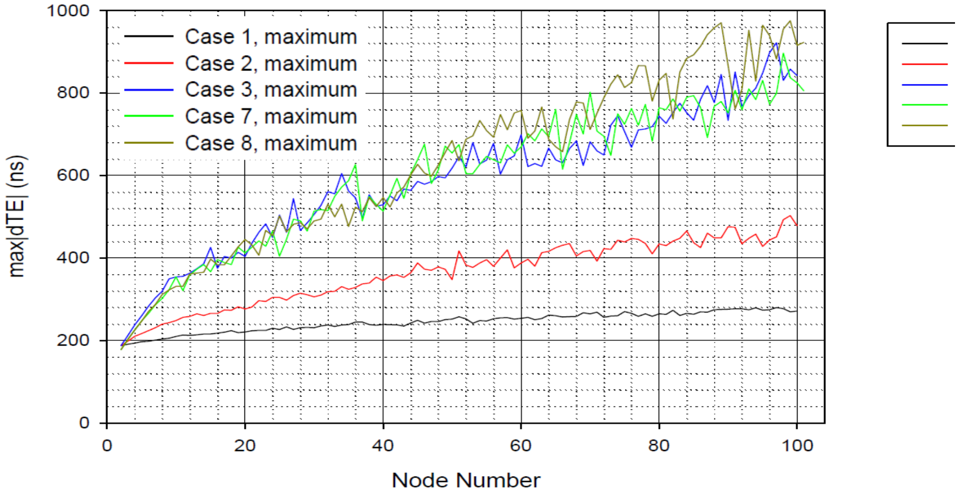
- **It was concluded that residence time needs to be below 4ms for an oscillator of 3ppm/s max drift rate. Residence time of 10ms causes instability for network greater than 60 nodes when using successive Sync message method**
- **Through email discussions was decided to add 2 more use-cases with Pdelay turnaround time of 1 ms and 4ms to the simulation**

October Simulation Results (Ref #7)

Case	Method of computing GM rateRatio	Residence time (ms)	Pdelay turnaround time (ms)	Mean Sync Interval (ms)	Mean Pdelay Interval (ms)
1	Accumulate neighborRateRatio	1	1	125	31.25
2	Accumulate neighborRateRatio	4	4	125	31.25
3	Accumulate neighborRateRatio	10	10	125	31.25
4	Use successive Sync messages	1	10	31.25	1000
5	Use successive Sync messages	4	10	31.25	1000
6	Use successive Sync messages	10	10	31.25	1000

Case	Method of computing GM rateRatio	Residence time (ms)	Pdelay turnaround time (ms)	Mean Sync Interval (ms)	Mean Pdelay Interval (ms)
7	Accumulate neighborRateRatio	10	1	125	31.25
8	Accumulate neighborRateRatio	10	4	125	31.25

Simulation Cases 1, 2, 3, 7, 8
300 replications of simulation
Clock Model: sinusoidal phase and freqeuncy variation
50 ppm max freq offset
3 ppm/s maximum drift rate
relative phases of modulation chosen randomly over [0,2*pi] on initialization
Actual modulation amplitude chosen randomly over [45 ppm, 50 ppm]
accumulate neighborRateRatio
Endpoint filter: KiKo = 249 (cases 1-3), 65 (cases 7-8)



- There were concerns about residence time to be too strict, and therefore it was agreed to run the next set of simulations with 2 different oscillators:
  1. Residence time of 4ms with an oscillator drift of 3ppm/s
  2. Residence time of 10ms with an oscillator drift of 0.3ppm/s
  3. A mix of case 1 and 2, splitting the network with 50% of the network using the parameters of case 1 and 50% of the network using the parameters of case 2
- Based on email discussions, it was agreed to add ±8 ns error due to dynamic PHY delay asymmetries and dynamic timestamp error.
- At the meeting on October 12, 2020, it was agreed to use the technique where neighborRateRatio is measured using Pdelay messages and then accumulated.

November Simulation Results (Ref #8)

Summary of Simulation Cases (parameters that are different for each case) - 2

Case	Method of computing GM rateRatio	Maximum frequency drift rate of local clock (ppm/s)	Residence time (ms)	Pdelay turnaround time (ms)	Mean Sync Interval (ms)	Mean Pdelay Interval (ms)
7	Accumulate neighborRateRatio	3	10	1	125	31.25
8	Accumulate neighborRateRatio	3	10	4	125	31.25
9	Accumulate neighborRateRatio	3	4	10	125	31.25
10	Accumulate neighborRateRatio	0.3	10	10	125	31.25
11	Accumulate neighborRateRatio	3 and 0.3, alternating (after node 1 (GM), nodes 2, 4, 6, …, 100 have 3 ppm/s, and nodes 3, 5, …, 101 have 0.3 ppm/s)	4 and 10, alternating (after node 1 (GM), nodes 2, 4, 6, …, 100 have 4 ms, and nodes 3, 5, …, 101 have 10 ms)	10	125	31.25

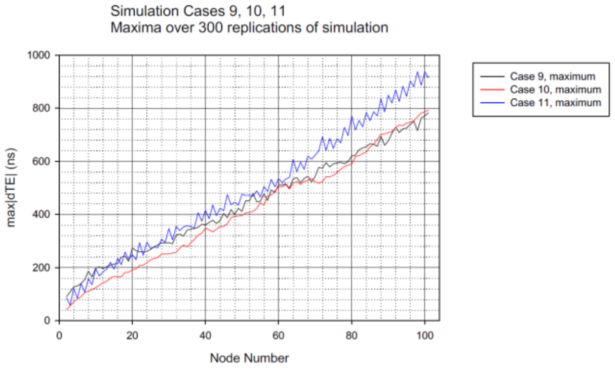
Results for dTE_R (Cases 9 - 11) - 6

Case	Syntonization Method, mean message intervals (ms), and Pdelay turnaround time (ms)	Local clock maximum frequency drift rate (ppm/s)	Residence time (ms)	Max|dTE_R|, 100 nodes (ns) Prev/revised	Max|dTE_R|, 65 nodes (ns) Prev/revised
9	Accumulate neighborRateRatio Mean Sync Interval = 125, Mean Pdelay Interval = 31.25, Pdelay turnaround time = 10	3	4	783	538
10		0.3	10	793	524
11		3 and 0.3, alternating	4 and 10, alternating	913	561

- Results for cases 9 and 10 are similar, and also are similar to case 2 results
  - Case 2 has same parameters, except for Pdelay turnaround time, which is 4 ms instead of 10 ms for cases 9 and 10
- It appears that increasing the residence time to 10 ms and decreasing the maximum frequency drift rate to 0.3 ppm/s approximately compensate for each other, resulting in similar performance
- Case 11, which alternates the case 9 and 10 clock stability and residence time, gives slightly worse performance than either case 9 or case 10, but examining the performance for all 3 cases for nodes 2 – 101 indicates the difference could be due to statistical variability

Case	Syntonization Method and mean message intervals (ms)	Residence time (ms)	Pdelay turn-around time (ms)	Max|dTE_R|, 100 nodes (ns) Prev/revised	Max|dTE_R|, 65 nodes (ns) Prev/revised
1	Accumulate neighborRateRatio Mean Sync Interval = 125, Mean Pdelay Interval = 31.25	1	1	300 / 520	250 / 380
2		4	4	500 / 820	420 / 510
3		10	10	850 / 1540	680 / 960
4	Use successive Sync messages Mean Sync Interval = 31.25, Mean Pdelay Interval = 1000	1	10	100 / 580	40 / 480
5		4	10	200 / 1140	80 / 670
6		10	10	5700 / 18800	630 / 1940
7	Accumulate neighborRateRatio Mean Sync Interval = 125, Mean Pdelay Interval = 31.25	10	1	810 / 1600	760 / 880
8		10	4	920 / 1560	670 / 900

Results for dTE_R (Cases 9 - 11) - 3



- **Through email discussion was decided to add 3 more use-cases using successive Sync messages method of computing GM rateRatio.**
- **Based on contribution [2] it was decided to run the simulations with the GM Time Error (TE).**

December Simulation Results
(Ref #9)

Summary of Simulation Cases (parameters that are different for each case) - 3

Case	Method of computing GM rateRatio	Maximum frequency drift rate of local clock (ppm/s)	Residence time (ms)	Pdelay turnaround time (ms)	Mean Sync Interval (ms)	Mean Pdelay Interval (ms)
12	Use successive Sync messages (Notes 1, 2)	3	1	10	31.25	1000
13	Use successive Sync messages (Note 1, 2)	3	4	10	31.25	1000
14	Use successive Sync messages (Note 1, 2)	3	10	10	31.25	1000

Note 1: In cases 12, 13, and 14, the window size for both Sync (rate ratio calculation) and Pdelay (neighborRateRatio calculation, needed to correct meanLinkDelay for neighborRateRatio) is 12 (current message and previous 11 messages) rather than 8 (current message and previous 7 messages) used in Cases 4 – 6.

Note 2: Single replications of simulations were run for cases 9 – 14, for both The cases of zero and non-zero GM Time error, with the corrected endpoint Filter (see slides 6 and 7)

Results for cases 12 - 14, with corrected endpoint filter (no GM time error), comparison of cases with and without GM time error - 6

Case	Syntonization Method and mean message intervals (ms)	Residence time (ms)	Pdelay turn-around time (ms)	Max|dTE_R|, 100 nodes (ns) without/with GM time error	Max|dTE_R|, 65 nodes (ns) without/with GM time error
12	Use successive Sync messages Mean Sync Interval = 31.25, Mean Pdelay Interval = 1000	1	10	620/880	500/750
13		4	10	900/1200	680/950
14		10	10	2400/3600	900/1750

In general, non-zero GM time error causes max|dTE_R| to increase, as expected.

Revised Results for dTE_R for Previous Cases (1 - 8) - 18

Case	Syntonization Method and mean message intervals (ms)	Residence time (ms)	Pdelay turn-around time (ms)	Max|dTE_R|, 100 nodes (ns) Prev/revised	Max|dTE_R|, 65 nodes (ns) Prev/revised
1	Accumulate neighborRateRatio Mean Sync Interval = 125, Mean Pdelay Interval = 31.25	1	1	300 / 520	250 / 380
2		4	4	500 / 820	420 / 510
3		10	10	850 / 1540	680 / 960
4	Use successive Sync messages Mean Sync Interval = 31.25, Mean Pdelay Interval = 1000	1	10	100 / 580	40 / 480
5		4	10	200 / 1140	80 / 670
6		10	10	5700 / 18800	630 / 1940
7	Accumulate neighborRateRatio Mean Sync Interval = 125, Mean Pdelay Interval = 31.25	10	1	810 / 1600	760 / 880
8		10	4	920 / 1560	670 / 900
9	Accumulate neighborRateRatio Mean Sync Interval = 125, Mean Pdelay Interval = 31.25, Pdelay turn-around time = 10	3	4	783/840	538/600
10		0.3	10	793/1080	524/610
11		3 and 0.3	4 and 10	913/1220	561/720

Results for dTE_R (Cases 9 - 11), comparison of cases with and without GM time error - 9

Case	Syntonization Method, mean message intervals (ms), and Pdelay turnaround time (ms)	Local clock maximum frequency drift rate (ppm/s)	Residence time (ms)	Max|dTE_R|, 101 nodes (ns) without/with GM time error	Max|dTE_R|, 65 nodes (ns) without/with GM time error
9	Accumulate neighborRateRatio Mean Sync Interval = 125, Mean Pdelay Interval = 31.25, Pdelay turnaround time = 10	3	4	840/1300	600/900
10		0.3	10	1080/1250	610/700
11		3 and 0.3, alternating	4 and 10, alternating	1220/1080	720/700

Summary

- So far, the following seems to be the agreements achieved:
  - Timestmap granularity of 2ns
  - To use +/-50 ppm for the clock model
  - The use of sinusoidal wave frequency variation for the clock model
  - Residence time of 4ms with an oscillator drift of 3ppm/s
  - Residence time of 10ms with an oscillator drift of 0.3ppm/s
    - Message rates should be the same for the 2 cases above to allow interworking between equipment using different oscillators
  - To use Pdelay messages to accumulate neighborRateRatio
  - To consider the GM TE in the simulations
  - Turnaround time does not influence the results of the simulation, then 10ms may be sufficient

References

[1] Guenter Steindl, IEC/IEEE 60802 Synchronization requirements and solution examples , IEEE 802.1 presentation, available at https://www.ieee802.org/1/files/public/docs2020/60802-Steindl-SynchronizationModels-0720-v1.pdf

[2] Geoffrey M. Garner, Improved Analysis of Component of dTE_R for Synchronization Transport over an IEC/IEEE 60802 Network due to GM Time Error , IEEE 802.1 presentation, November 2, 2020, available at: https://www.ieee802.org/1/files/public/docs2020/60802-garner-improved-analysis-component-dTER-due-to-GM-time-error-1120-v00.pdf

[3] Geoffrey M. Garner, Initial Simulation Results for Time Error Accumulation in an IEC/IEEE 60802 Network , IEEE 802.1 presentation, March 2020.

[4] Geoffrey M. Garner, New Simulation Results for Time Error Performance for Transport over an IEC/IEEE 60802 Network , Revision 1, IEEE 802.1 presentation, May 2020.

[5] Geoffrey M. Garner, Further Simulation Results for Time Error Performance for Transport over an IEC/IEEE 60802 Network, Revision 1, IEEE 802.1 presentation, July 2020.

[6] Geoffrey M. Garner, New Simulation Results for Time Error Performance for Transport over an IEC/IEEE 60802 Network Based on Updated Assumptions, IEEE 802.1 presentation, September2020.

[7] Geoffrey M. Garner, New Simulation Results for Time Error Performance for Transport over an IEC/IEEE 60802 Network Based on Updated Assumptions, Revision 3, IEEE 802.1 presentation, October 2020.

[8] Geoffrey M. Garner, Further Simulation Results for Dynamic Time Error Performance for Transport over an IEC/IEEE 60802 Network Based on Updated Assumptions, Revision 1, November 2020

[9] Geoffrey M. Garner, Further Simulation Results for Dynamic Time Error Performance for Transport over an IEC/IEEE 60802 Network Based on Updated Assumptions, Revision 2, December 2020

Thank you.