Further Simulation Results for Dynamic Time Error Performance for Transport over an IEC/IEEE 60802 Network Based on Updated Assumptions
Revision 1

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Outline

- Introduction
- Summary of Assumptions for Simulation Cases
- Results
- Conclusion and Discussion of Next Steps

Introduction - 1

- New simulations results for dynamic time error performance for transport over an IEC/IEEE 60802 network are presented in [1]
  - An initial version of this presentation was presented at the September, 2020 IEC/IEEE 60802 meeting
  - This included 6 simulation cases
    - 3 cases where GM rateRatio was measured by accumulating neighborRateRatio
    - 3 cases where GM rateRatio was measured using successive Sync messages
    - While some of the cases gave acceptable dTE_R performance (relative to the GM) for a Hypothetical Reference Model (HRM) consisting of 65 nodes (64 hops), those cases assumed residence times of either 1 ms or 4 ms
    - dTE_R performance for 10 ms residence time was either marginal or unacceptable
  - After discussion of [1], it was decided to consider two additional simulation cases
    - These cases were run, and the results were presented in a subsequent IEC/IEEE 60802 virtual meeting/call
    - However, the new results showed dTE performance that was similar to one of the cases of [1] whose results were marginal
- Based on the above results, it was decided to consider three new cases
  - Two of the new cases assume an oscillator with improved performance, and the third new case is a minor modification of one of the cases of [1] that gave acceptable performance (4 ms residence time)

Introduction - 2

- The current presentation includes simulation results for the three new cases
- In addition, when preparing the new simulations, it was found that the previous simulations did not properly account for the $\pm$ 8 ns dynamic timestamp error for event messages due to variable delays within the PHY (see slide 13 of [1] and slide 14 of [2])
  - The simulations did not add this error on receipt of a Sync message
  - This was fixed, and the previous simulation cases were re-run, in addition to the three new cases

Summary of Assumptions for Simulations - 1

- In the following slides, the assumptions are summarized, mainly by repeating the summary of [1], [2], and [10] (with some corrections)
- Detailed background on the different assumptions are given in [3] – [9], but note the following points
  - Local clock phase and frequency variation is assumed to be sinusoidal
  - 300 multiple replications of each simulation case are performed, with random (independent) initial conditions for each replication; in particular
    - Initial phases of each Local Clock (including the GM in cases where the GM time and frequency error is modeled) are chosen randomly in $[0, 2\pi]$
    - Initial frequencies of each Local Clock (including the GM in cases where the GM time and frequency error is modeled) are chosen randomly in the range $[50 - \varepsilon, 50]$ ppm, with $\varepsilon = 5$ ppm and maximum frequency drift rate of 3 ppm/s
      - This allows the modulation frequency (i.e., the frequency of the phase and frequency variation waveform to vary over a 10% range (i.e., (5 ppm/50 ppm))
- For each of 11 simulation cases (described shortly), 2 subcases were described in [1] and [2]
  - Source of GM time is assumed to be zero (though GM still has timestamp granularity), and max|dTE| is simulated
  - Source of GM time has same error as Local Clocks, and max|dTE_R| relative to GM is simulated

Summary of Assumptions for Simulations – 2

- For cases where source of GM time has non-zero error, max|dTE_R| should be computed using linear interpolation, because Sync message transmission times at the successive clocks (and therefore times at which time errors are computed at the successive clocks) are, in general, not the same
- Note that dTE_R relative the GM is actually relative to the PTP output of the GM, and therefore does not include timestamp granularity at the GM output
  - Possibly dTE_R should have included timestamp granularity at the GM output; in any case, it will be seen that timestamp granularity (2 ns) is negligible compared to max|dTE_R| results (larger than 4 μs)
- The following slides repeat the tables of assumptions from [8], and then summarize some of the details of the assumptions that were described in [1]
- Following that, we first present results, i.e., max|dTE|, for each simulation case assuming the error in the source of GM time is zero
- An approximate analysis for the case where the source of GM time has nonzero error was given in [1] and [2]
  - Based on discussion in the September 2020 IEC/IEEE 60802 meeting and in a subsequent meeting/call, the analysis has been improved, and is contained in a companion presentation [11]
  - Simulation results for the case where GM time error is nonzero will be given in a future presentation

Assumptions Common to All Simulation Cases - 1

Assumption/Parameter	Description/Value
Hypothetical Reference Model (HRM), see note following the tables	101 PTP Instances (100 hops; GM, followed by 99 PTP Relay Instances, followed by PTP End Instance
Timestamp granularity	2 ns
GM maximum frequency offset	0 (for now, the effect of a ± 50 ppm frequency offset is considered in the approximate analysis of [11])
GM maximum frequency drift rate	0 (for now, the effect of a 3 ppm/s frequency maximum frequency drift rate is considered in the approximate analysis of [11])
PTP End/Relay Instance maximum frequency offset (Local Clock)	± 50 ppm
PTP End/Relay Instance maximum frequency drift rate (Local Clock)	3 ppm/s (cases 1 – 9) 0.3 ppm/s (case 10) 3 ppm/s and 0.3 ppm/s alternating (case 11)
GM and Local Clock frequency variation	sinusoidal
Relative phases of GM and Local Clock frequency waveforms	Chosen randomly from a uniform distribution over [0, 2π] rad at initialization
Relative frequencies of Local Clock frequency waveforms	Choose randomly at initialization by allowing waveform amplitude to be random over a range [50 - ε, 50] ppm; choose ε = 5 ppm, so that the waveform frequency varies over a 10% range

Assumptions Common to All Simulation Cases - 2

Assumption/Parameter	Description/Value
Computed performance results	max|$dTE_{R(k,\ 0)}$| (i.e., maximum absolute relative time error between node k (k > 0) and GM; here, GM time error is 0, so max|$dTE_{R(k,\ 0)}$| = max|dTE|)
Use syncLocked mode for PTP Instances downstream of GM	Yes
Window size for successive Sync messages method, when used	7 (take difference between respective timestamps of current Sync message and 7th previous message)
Compute median for successive Sync messages method, when used	Yes
Endpoint filter parameters	K_pK_o = 11, K_iK_o = 65 (f_{3dB} = 2.5998 Hz, 1.288 dB gain peaking, ζ = 0.68219)
Simulation time	1050 s; discard first 50 s to eliminate any startup transient before computing max|$dTE_{R(k,\ 0)}$|
Number of independent replications, for each simulation case	300
GM rateRatio and neighborRateRatio computation granularity	0
Mean link delay	500 ns
Link asymmetry	0

Assumptions Common to All Simulation Cases - 3

Assumption/Parameter	Description/Value
Dynamic timestamp error for event messages (Sync, Pdelay-Req, Pdelay_Resp) due to variable delays within the PHY	±8 ns; for each timestamp taken, a random error is generated. The error is + 8 ns with probability 0.5, And – 8 ns with probability 0.5. The errors are independent for different timestamps and different PTP Instances. Note: This error was not properly accounted for in the simulations of [1] and [2]
Window Size for mean link delay averaging (i.e., how many mean link delay samples are averaged over, assuming a sliding window)	16

Summary of Simulation Cases (parameters that are different for each case) - 1

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)
1	Accumulate neighborRateRatio	3	1	1	125	31.25
2	Accumulate neighborRateRatio	3	4	4	125	31.25
3	Accumulate neighborRateRatio	3	10	10	125	31.25
4	Use successive Sync messages	3	1	10	31.25	1000
5	Use successive Sync messages	3	4	10	31.25	1000
6	Use successive Sync messages	3	10	10	31.25	1000

Note that the mean Sync interval in cases 1 – 3 was mistakenly indicat ed as 0.125 ms in [10]; this was an error (typo)

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

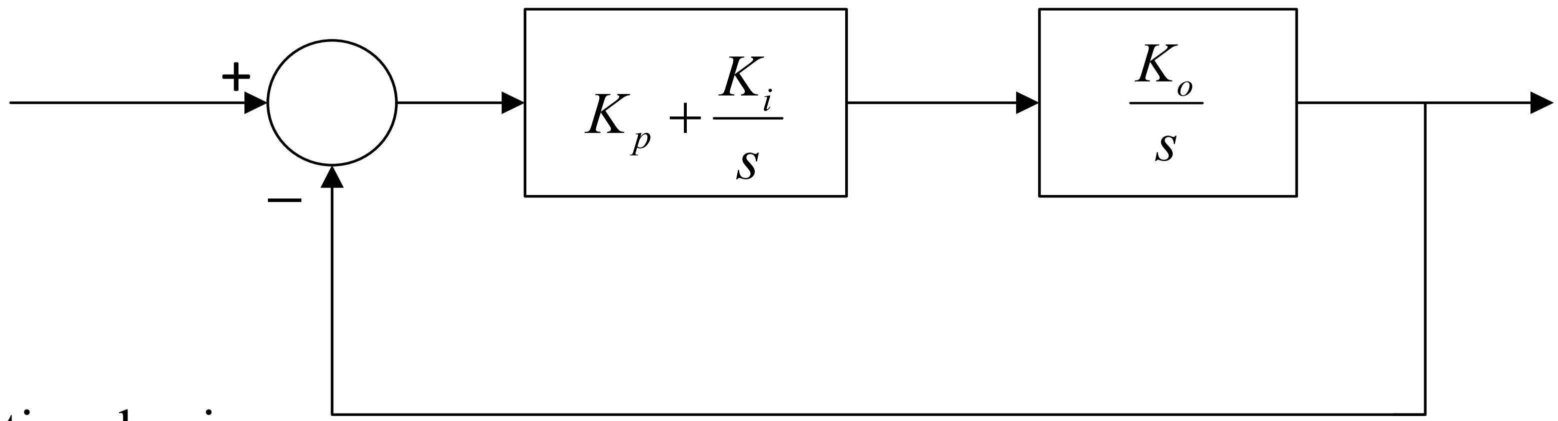
Review of Assumptions for HRM – 1

- As in previous simulations, the HRM is a linear chain that consists of 101 PTP Instances, and therefore with 100 PTP links connecting each successive pair of PTP Instance
  - The first PTP Instance in the chain is the Grandmaster PTP Instance
  - The next 99 PTP Instances are PTP Relay Instances
  - The last PTP Instance is a PTP End Instance
  - The PTP End Instance contains an endpoint filter, through which the transported time is computed

Assumptions for HRM – 2

- As in previous simulations, the GM and each PTP Relay Instance do not filter the timestamps with an endpoint filter when computing the value of the originTimestamp and correctionField of each transmitted Sync message
  - Rather, these fields are computed using the same fields of the most recently received Sync message, the <syncEventIngressTimestamp> of the most recently received Sync message, the <syncEventEgressTimestamp of the Sync message being transmitted, and the current value of rateRatio (i.e., cumulative rateRatio)
- However, the information at each PTP Relay Instance is used to separately compute a filtered (recovered) time, which could be used, e.g., by a co-located end application
  - This is equivalent to having a PTP End Instance collocated with the PTP Relay Instance

Review of 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

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

Review of 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] of reference [2] here):

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

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

where

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

Endpoint Filter Model and Assumptions – 3

- As in previous simulation models, the VCO gain was folded into the proportional gain and integral gain (this is equivalent to setting the VCO gain to 1)
- Filter assumption:
  - $K_p K_o = 11$, $K_i K_o = 65$
  - Using the equations on the previous slides, we obtain
    - $\zeta = 0.68219$
    - $\omega_n = 8.06226$ rad/s ≈ 8.06 rad/s
    - H_p (gain peaking) = 1.28803 dB = (approx) 1.3 dB
    - $f_{3\mathrm{dB}} = 2.5998$ Hz ≈ 2.6 Hz
- Note that this filter is underdamped, and has appreciable gain peaking
  - However, the damping ratio (ζ) is close to $1/\sqrt{2}$ = (approx) 0.707); this is often used to obtain a fast response with small overshoot, in cases where the filters are not cascaded (the endpoint filters are not cascaded)

Review of computation of GM rateRatio using successive Sync messages - 1

- These assumptions are used in cases 4, 5, and 6 for measurement of GM rateRatio using successive Sync messages (but not for new cases 9, 10, and 11)
- Assume the computation is done every Sync message, using a window of size n (i.e., a sliding window)
  - The computation is done on ingress of a Sync message at a PTP Instance
  - The window size n includes the current Sync message (e.g., a window of size 8 consists of the current Sync message and the previous 7 Sync messages)
- Let C_{kn} be the correctedMasterTime carried by Sync message kn
- Let S_{kn} be the SyncEventIngressTimestamp for Sync message kn
- Then the initial computed $\mathrm{rateRatio}$ is

$$\mathrm{rateRatio}_{kn} = \frac{C_{kn} - C_{(k-1)n}}{S_{kn} - S_{(k-1)n}}$$

- Note that frequency offset is equal to $\mathrm{rateRatio} - 1$
- The above computation is performed for every Sync message that arrives at a PTP Instance

Review of computation of GM rateRatio using successive Sync messages - 2

- Finally, the median of the current and previous $n - 1$ computed values of initial GM rateRatio is obtained
  - The median is computed by sorting the n values from smallest to largest and taking the p^{th} smallest value, where $p = \text{floor}\,(n) + 1$
- For the simulations, we use the median

Computation of neighborRateRatio (new)

- In computing neighborRateRatio, the same methodology is used as described in the previous two slides for the computation of GM rateRatio, except
  - C_{kn} is replaced by correctedResponderEventTimestamp (see 11.2.19.3.3 of IEEE Std 802.1AS-2020) of peer delay exchange kn
  - S_{kn} is replaced by the pdelayRespEventIngressTimestamp of the Pdelay_Resp message of peer delay exchange kn
- The median of the current and previous $n - 1$ computed values of initial neighborRateRatio is obtained
  - The median is computed by sorting the n values from smallest to largest and taking the p^{th} smallest value, where $p = \text{floor}\,(n) + 1$
- For the simulations, we use the median

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

- The following plots show results for cases 1 – 8 (results for cases 9 – 11 are in subsequent slides)
  - Max|dTE_R|, cases 1 – 6, nodes 2 – 100, 99% confidence intervals for 0.95 quantile, and maximum over 300 replications
  - Max| dTE_R |, cases 1 – 6, nodes 2 – 100, maximum over 300 replications (less cluttered than previous plot)
  - Max| dTE_R |, cases 1 – 6, nodes 2 – 65, 99% confidence intervals for 0.95 quantile, and maximum over 300 replications
  - Max| dTE_R |, cases 1 – 6, nodes 2 – 65, maximum over 300 replications (less cluttered than previous plot)
  - Max|dTE_R|, cases 7 – 8, nodes 2 – 100, 99% confidence intervals for 0.95 quantile, and maximum over 300 replications
  - Max| dTE_R |, cases 7 – 8, nodes 2 – 100, maximum over 300 replications (less cluttered than previous plot)
  - Max| dTE_R |, cases 1, 2, 3, 7, 8, nodes 2 – 100, maximum over 300 replications (these cases are shown on the same plot, for comparison; only maximum is shown so that the plot is less cluttered)

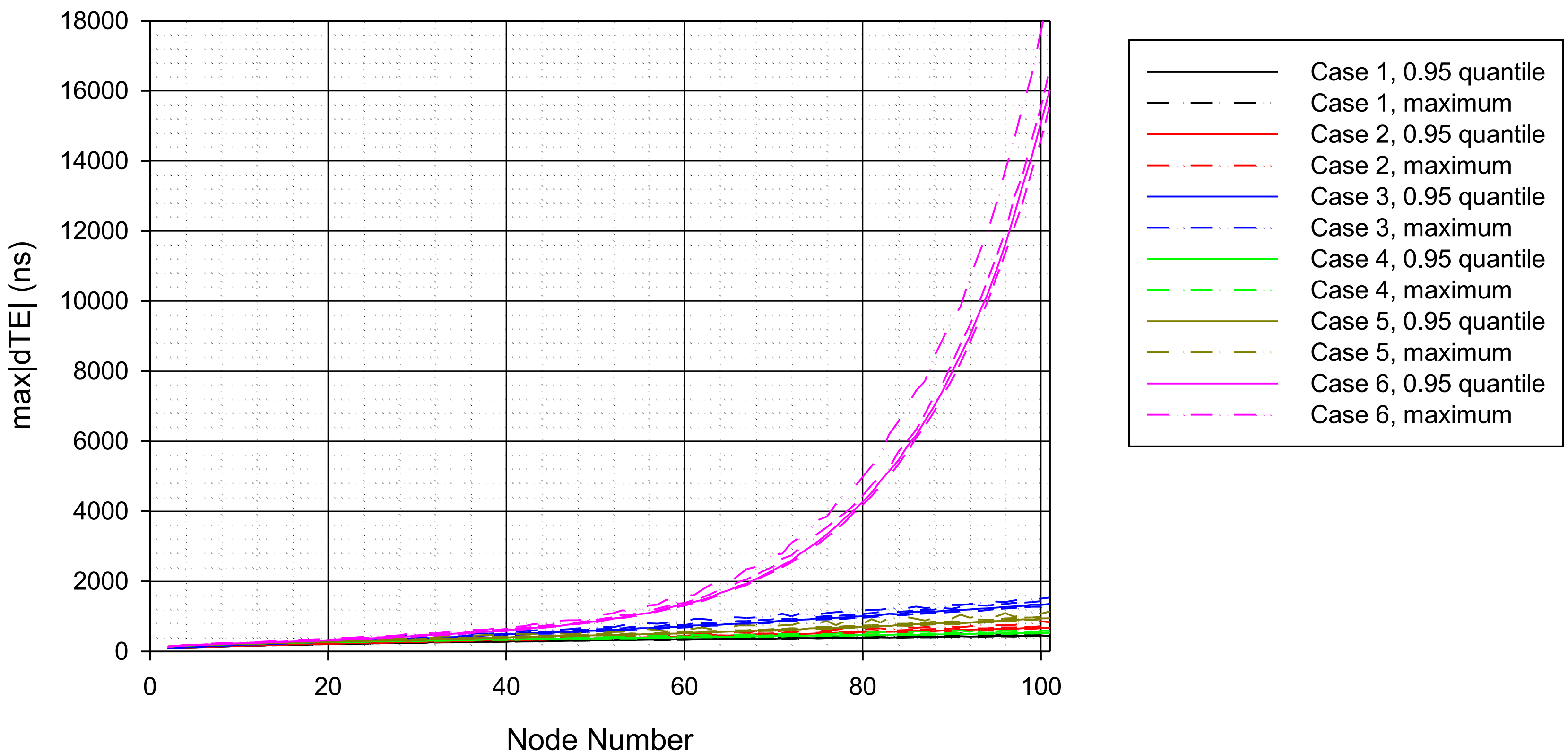
Revised Results for dTE_R for Previous Cases (1 - 8) - 2

- There are two plots for each of the above
  - The first plot contains the new (revised) results
  - The second plot contains the results from [1] and [2]
- As indicated in the Introduction (slide 4) and in the table of assumptions (slide 9), the results in [1] and [2] did not properly account for the ± 8 ns dynamic timestamp error for event messages due to variable delays within the PHY
  - Also, the results in [1] and [2] for cases 1 – 6 used an incorrect PLL (endpoint filter) integral gain parameter(249 instead of 65; see [1] and [2]) for the endpoint filter

Revised Results for dTE_R for Previous Cases (1 - 8) - 3

Simulation Cases 1 - 6
300 replications of simulation
Upper and lower 99% confidence intervals shown via short dashed lines
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]

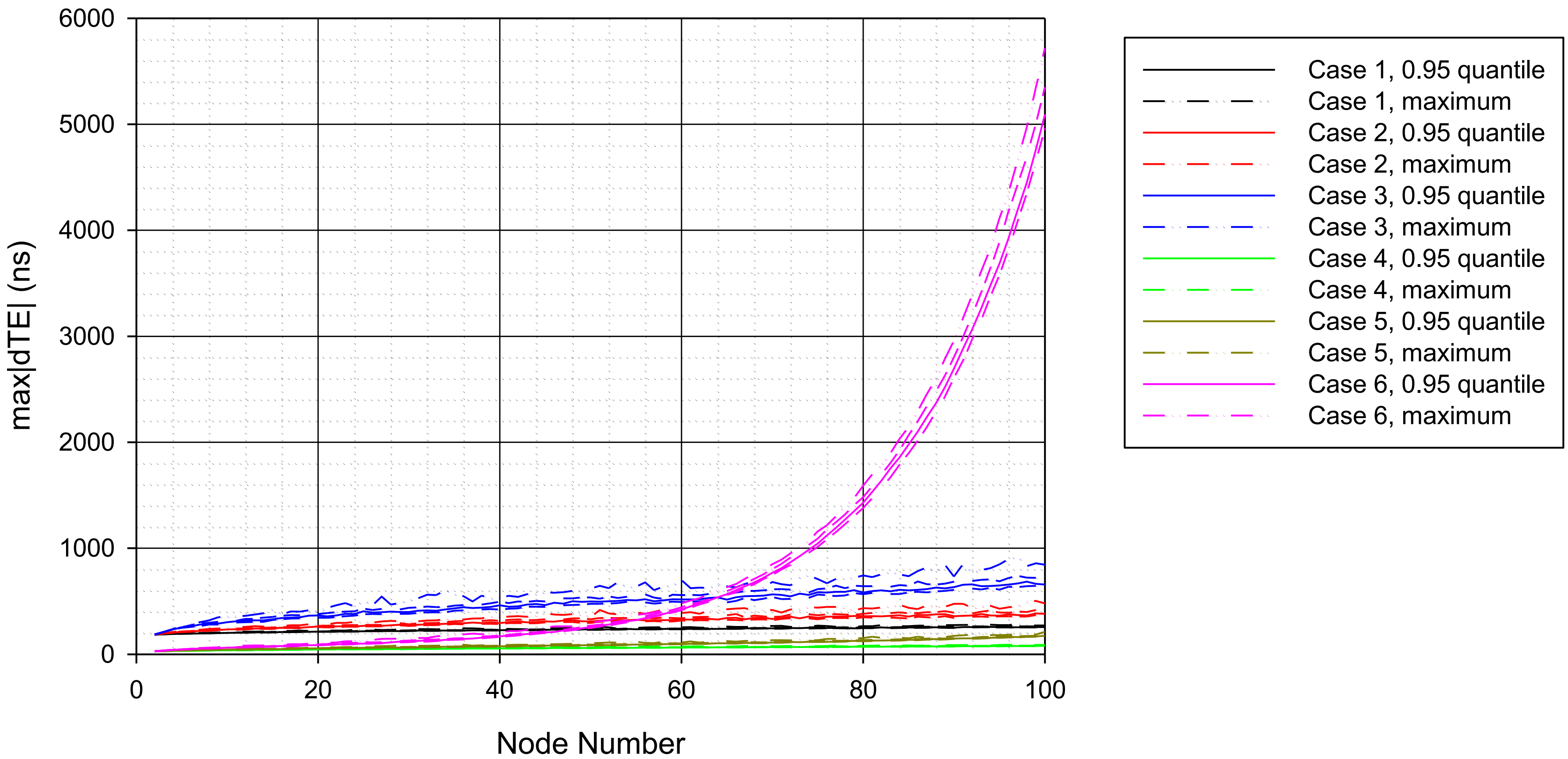
Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



Results for dTE, Zero Error in GM Time Source (previous results, from [2]) – 4

Simulation Cases 1 - 6
300 replications of simulation
Upper and lower 99% confidence intervals shown via short dashed lines
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]

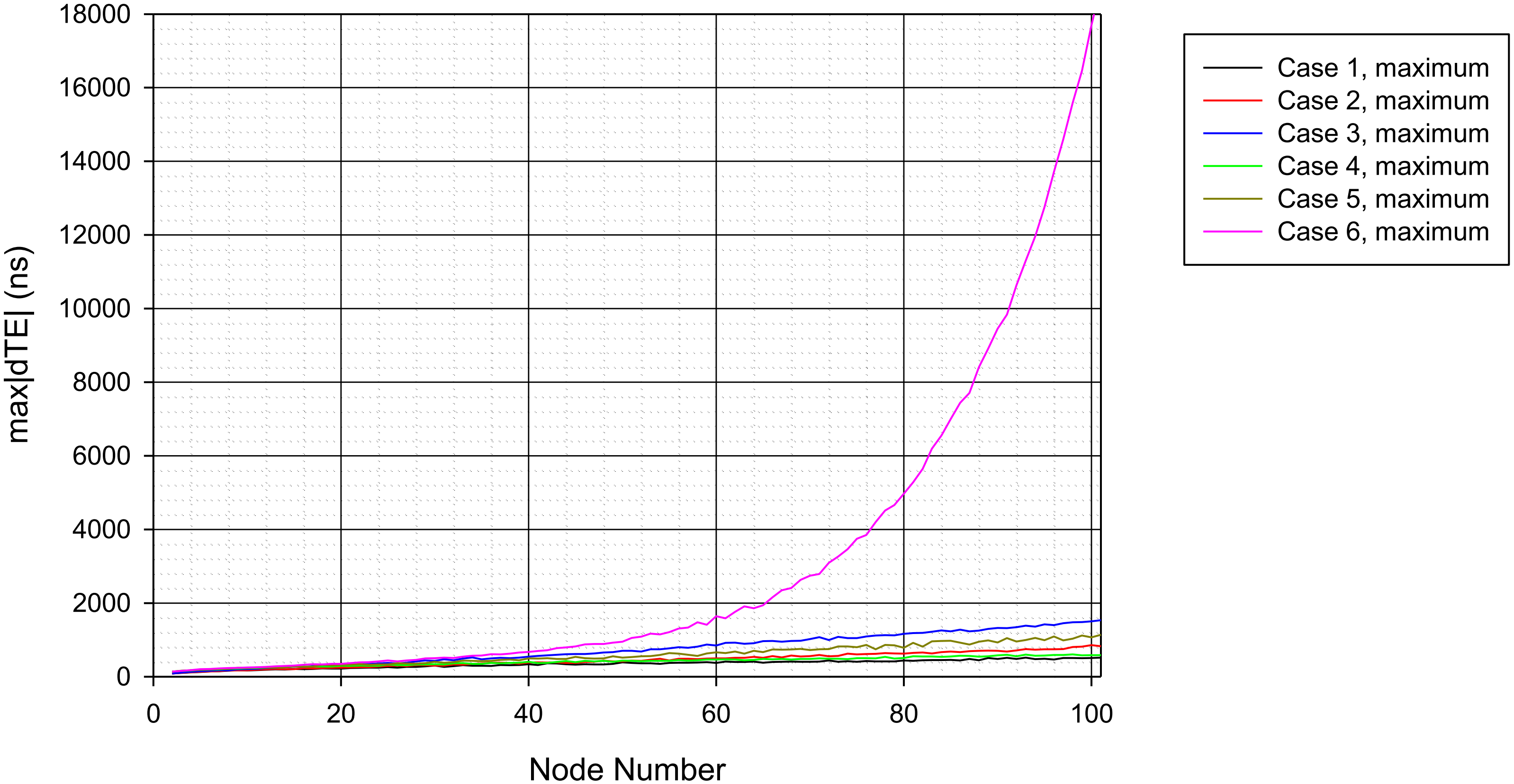
Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



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

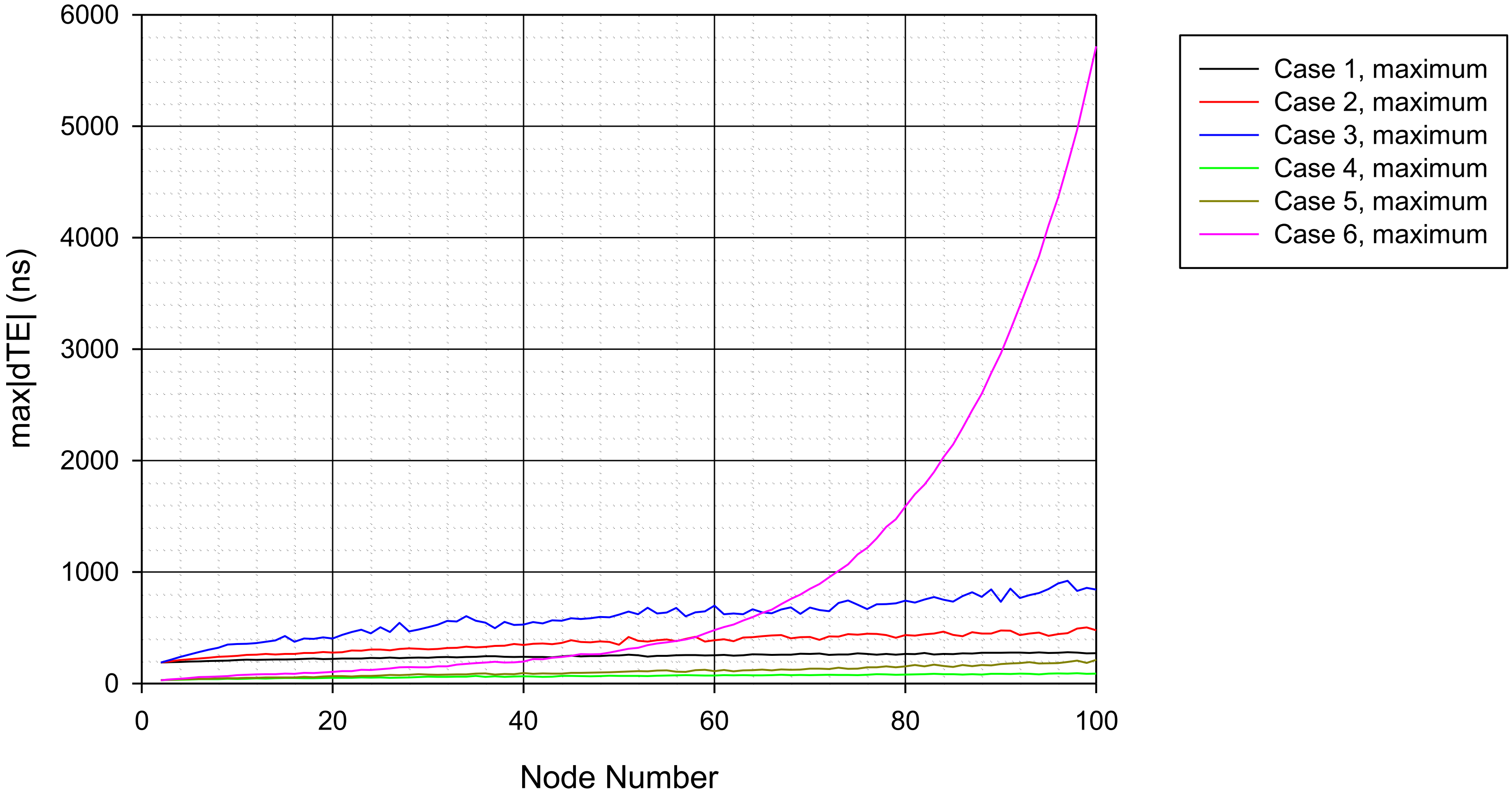
Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



Results for dTE, Zero Error in GM Time Source (previous results, from [2]) - 6

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]

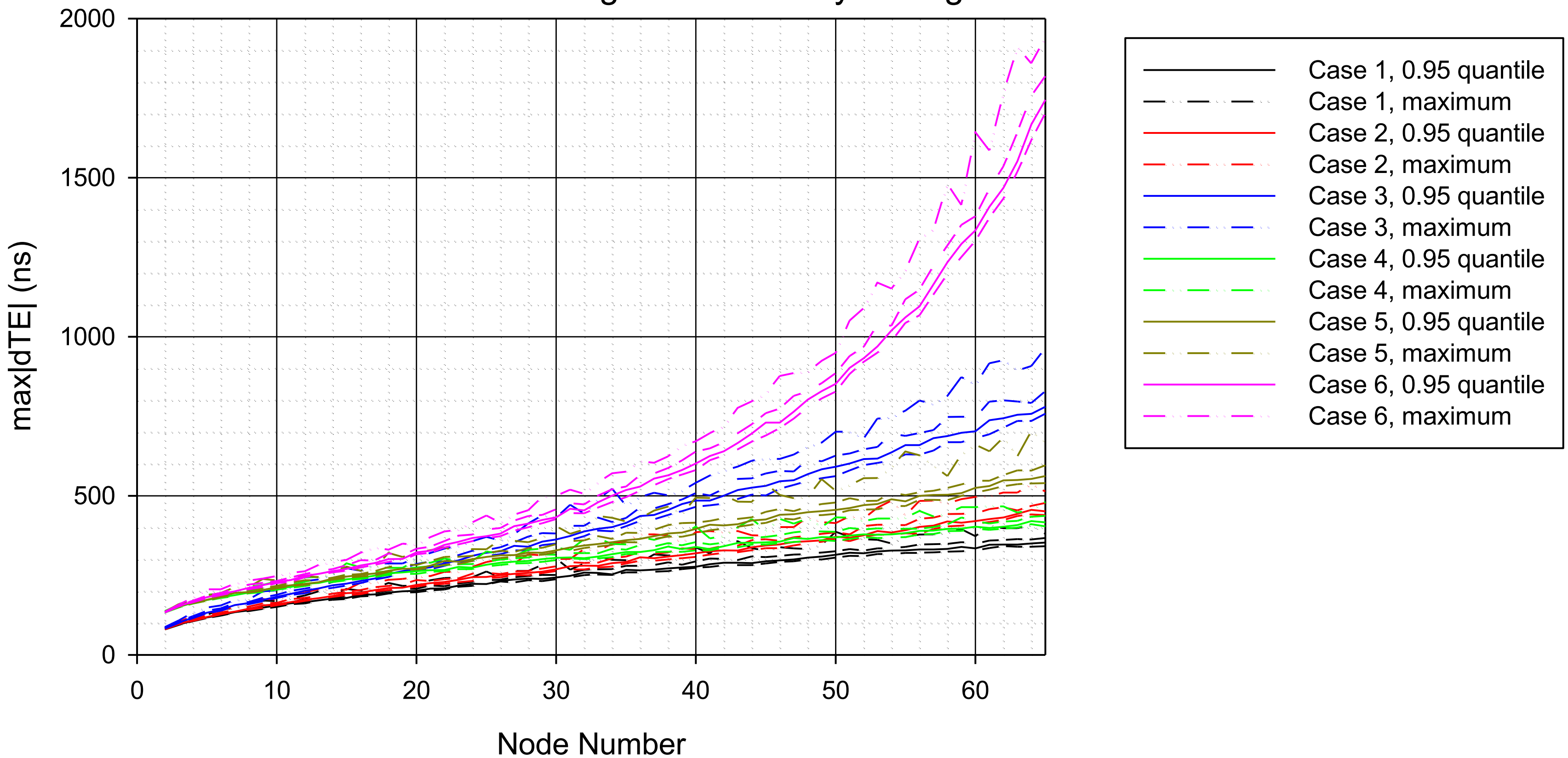
Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



Revised Results for dTE_R for Previous Cases (1 - 8) - 7

Simulation Cases 1 - 6
300 replications of simulation
Upper and lower 99% confidence intervals shown via short dashed lines
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]

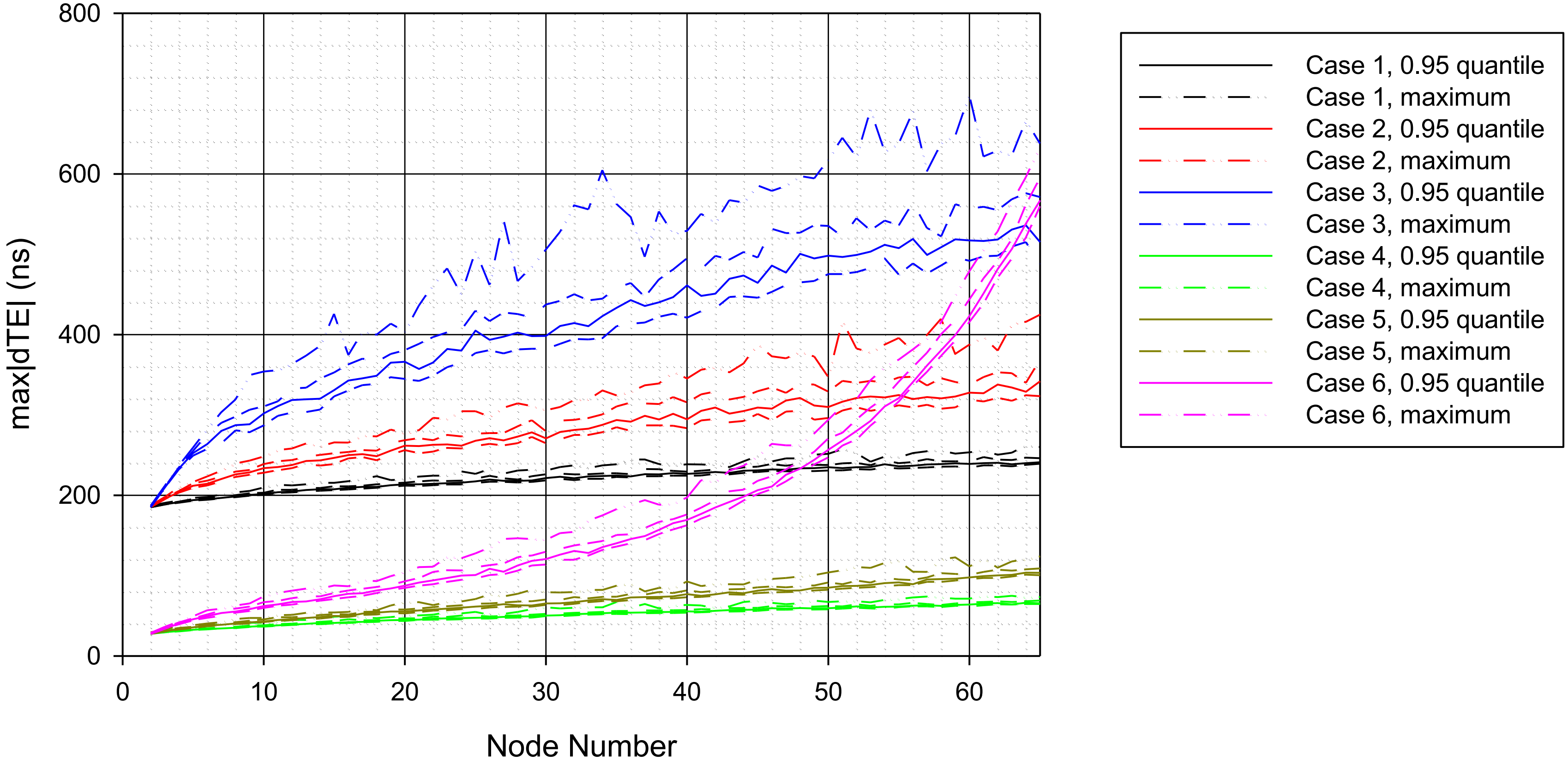
Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



Results for dTE, Zero Error in GM Time Source (previous results, from [2]) – 8

Simulation Cases 1 - 6
300 replications of simulation
Upper and lower 99% confidence intervals shown via short dashed lines
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]

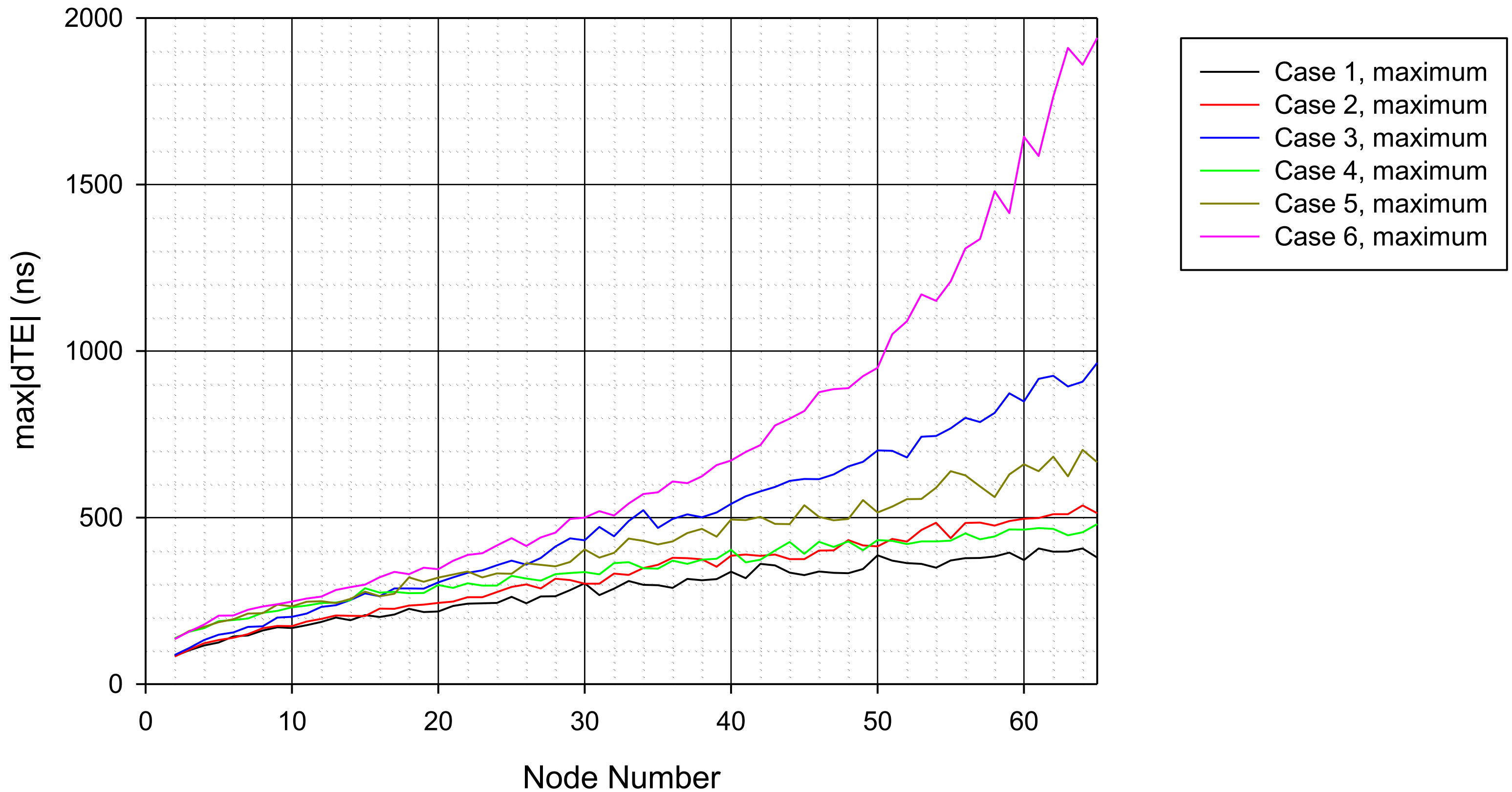
Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



Revised Results for dTE_R for Previous Cases (1 - 8) - 9

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]

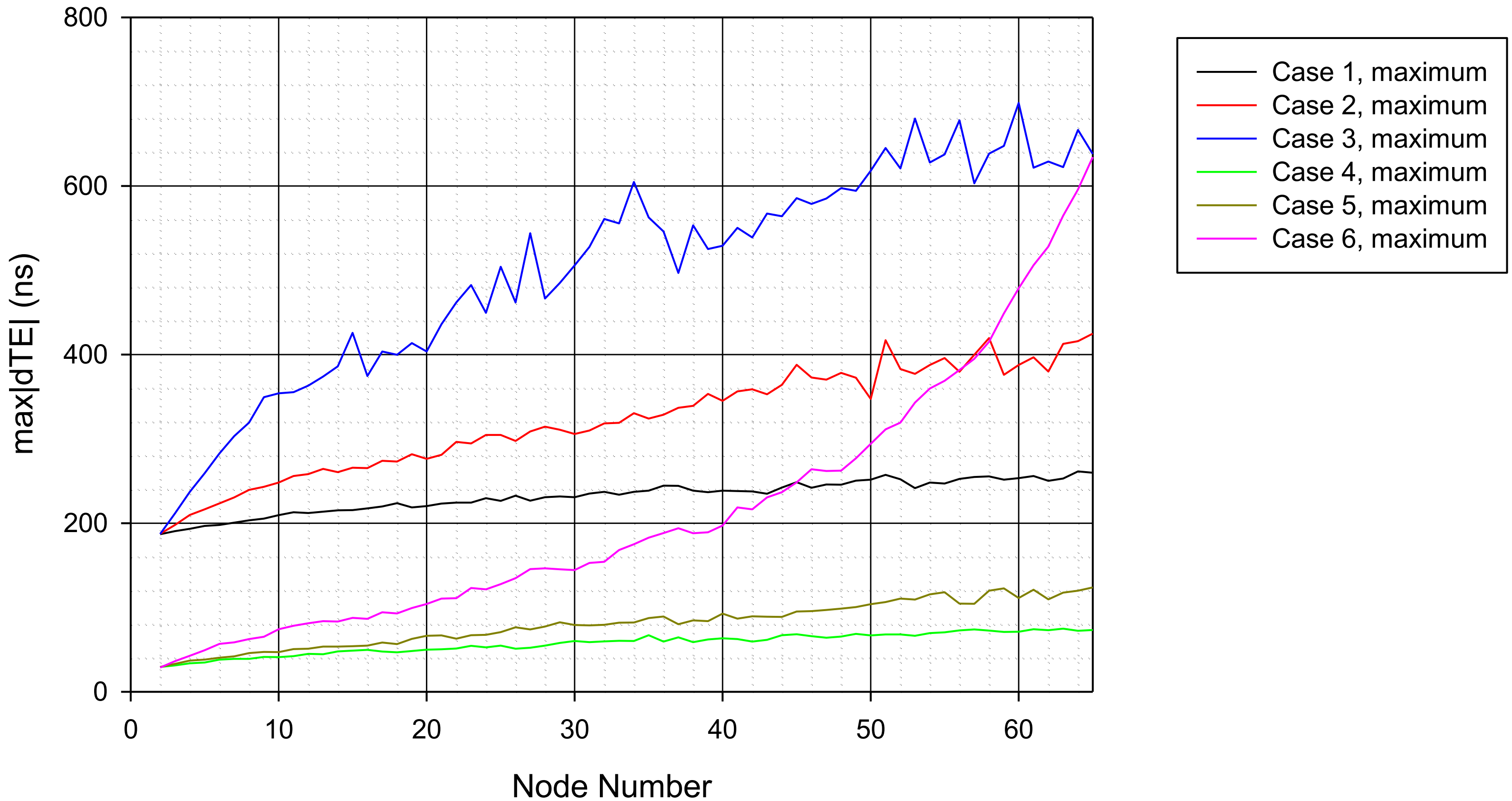
Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



Results for dTE, Zero Error in GM Time Source (previous results, from [2]) - 10

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]

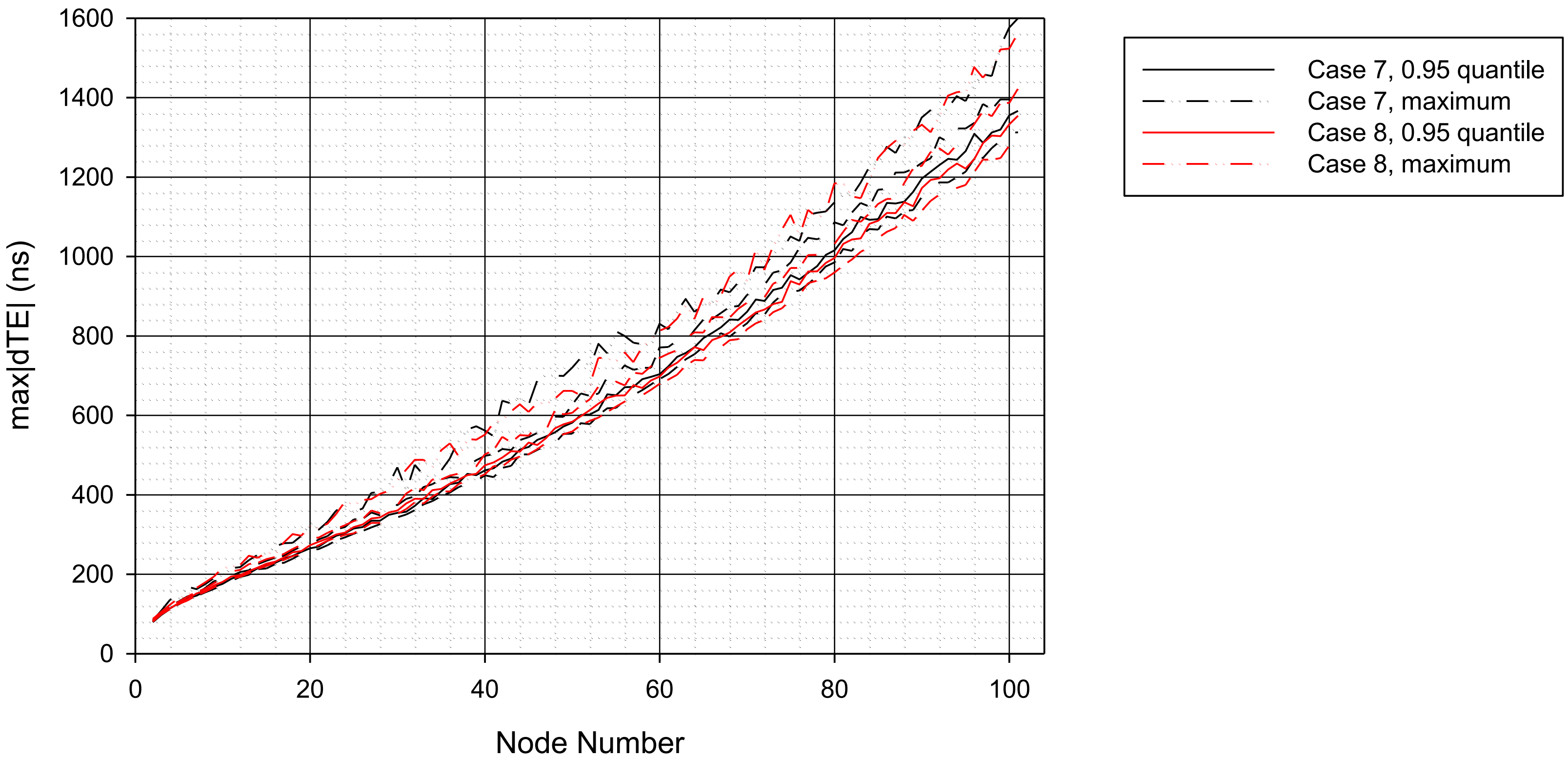
Cases 1 - 3: accumulate neighborRateRatio
Cases 4 - 6: measure GM rate ratio using successive Sync msgs



Revised Results for dTE_R for Previous Cases (1 - 8) - 11

Simulation Cases 7 - 8
300 replications of simulation
Upper and lower 99% confidence intervals shown via short dashed lines
Clock Model: sinusoidal phase and freqeuncy variation
- 50 ppm max freq offset
- 3 ppm/s max drift rate
- relative phases of modulation chosen randomly over [0,2*pi] on init
- Actual modulation amplitude chosen randomly over [45 ppm, 50 ppm]

Accumulate neighborRateRatio
Endpoint filter: KiKo = 65, KpKo = 11
Resid time = 10 ms, Pdelay turn time = 1ms (case7),4ms (case8)

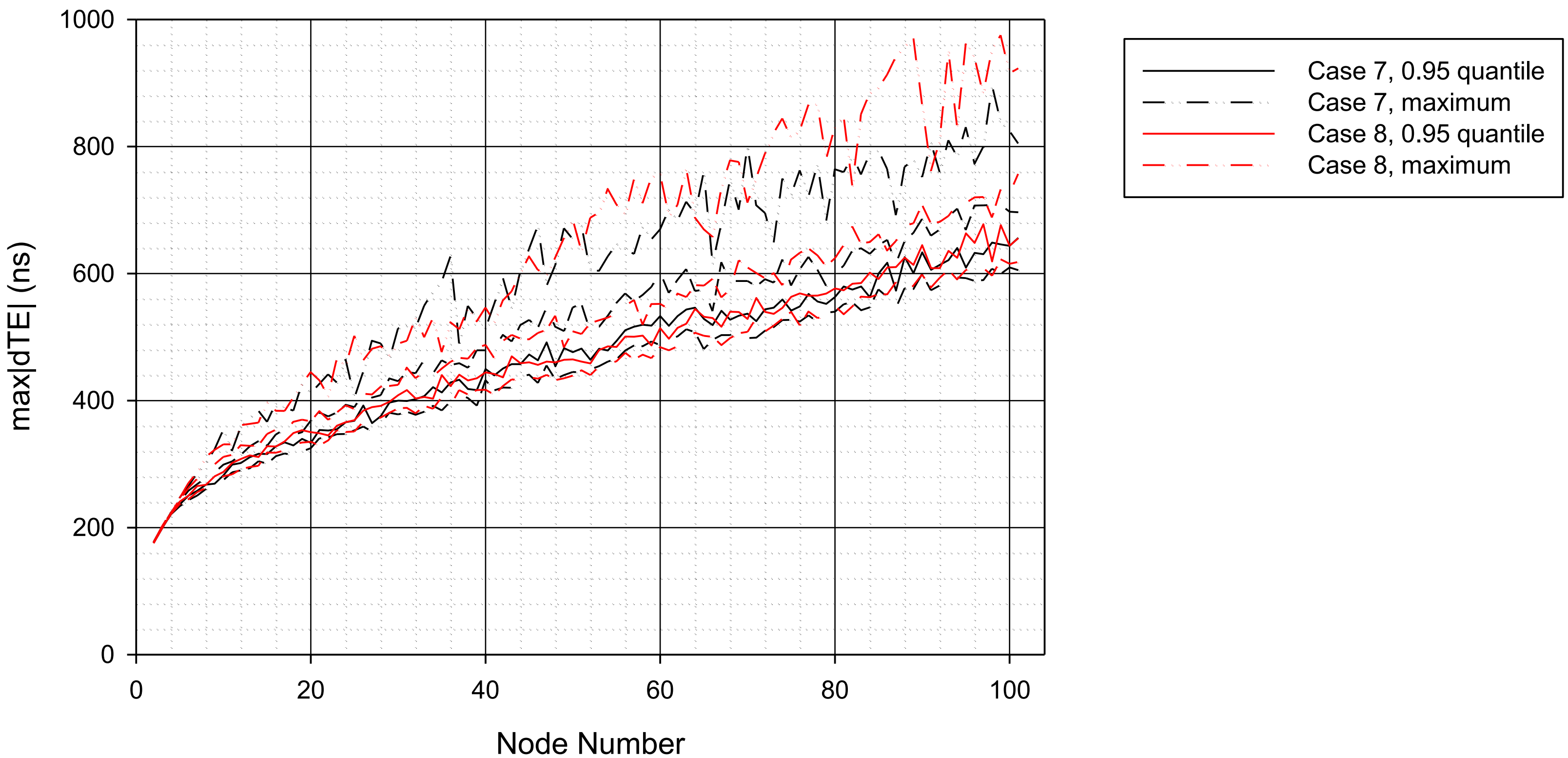


Results for dTE_R, Zero Error in GM Time Source (previous results, from [2]) – 12

Simulation Cases 7 - 8
300 replications of simulation
Upper and lower 99% confidence intervals shown via short dashed lines
Clock Model: sinusoidal phase and freqeuncy variation

- 50 ppm max freq offset
- 3 ppm/s max drift rate
- relative phases of modulation chosen randomly over [0,2*pi] on init
- Actual modulation amplitude chosen randomly over [45 ppm, 50 ppm]

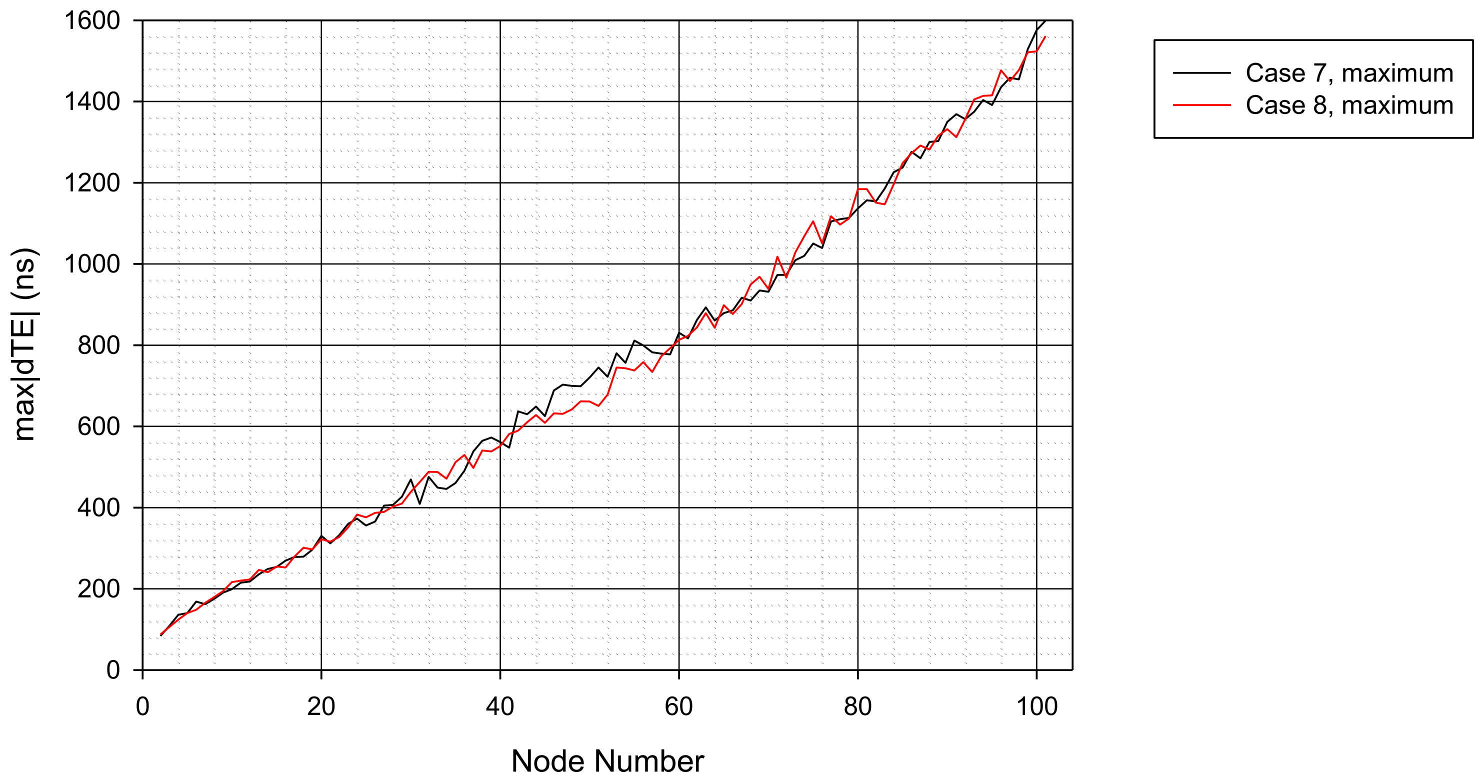
Accumulate neighborRateRatio
Endpoint filter: KiKo = 65, KpKo = 11
Resid time = 10 ms, Pdelay turn time = 1ms (case7),4ms (case8)



Revised Results for dTE_R for Previous Cases (1 - 8) - 13

Simulation Cases 7 - 8
300 replications of simulation
Upper and lower 99% confidence intervals shown via short dashed lines
Clock Model: sinusoidal phase and freqeuncy variation
- 50 ppm max freq offset
- 3 ppm/s max drift rate
- relative phases of modulation chosen randomly over [0,2*pi] on init
- Actual modulation amplitude chosen randomly over [45 ppm, 50 ppm]

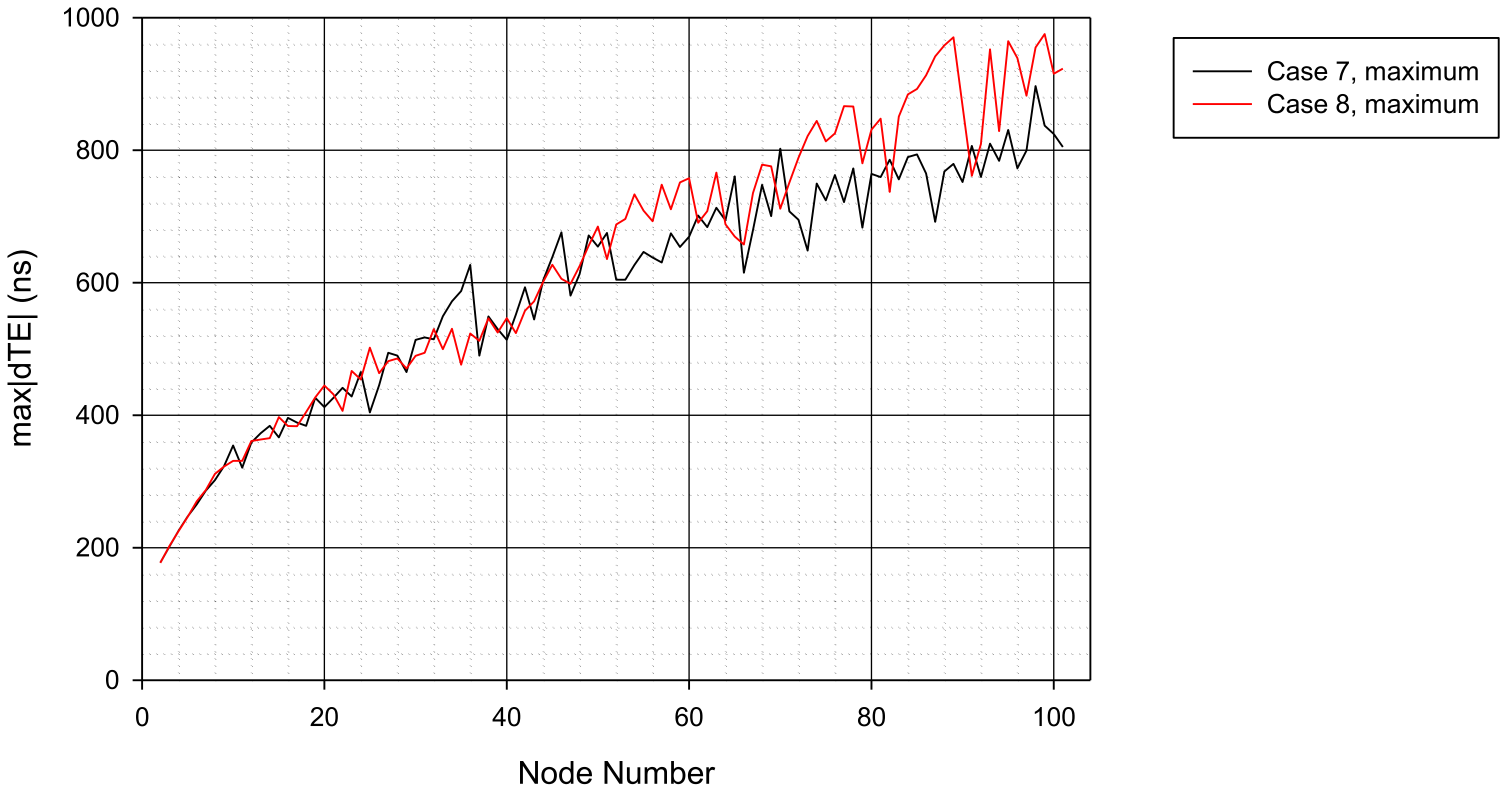
Accumulate neighborRateRatio
Endpoint filter: KiKo = 65, KpKo = 11
Resid time = 10 ms, Pdelay turn time = 1ms (case7),4ms (case8)



Results for dTE_R, Zero Error in GM Time Source (previous results, from [2]) - 14

Simulation Cases 7 - 8
300 replications of simulation
Upper and lower 99% confidence intervals shown via short dashed lines
Clock Model: sinusoidal phase and freqeuncy variation
- 50 ppm max freq offset
- 3 ppm/s max drift rate
- relative phases of modulation chosen randomly over [0,2*pi] on init
- Actual modulation amplitude chosen randomly over [45 ppm, 50 ppm]

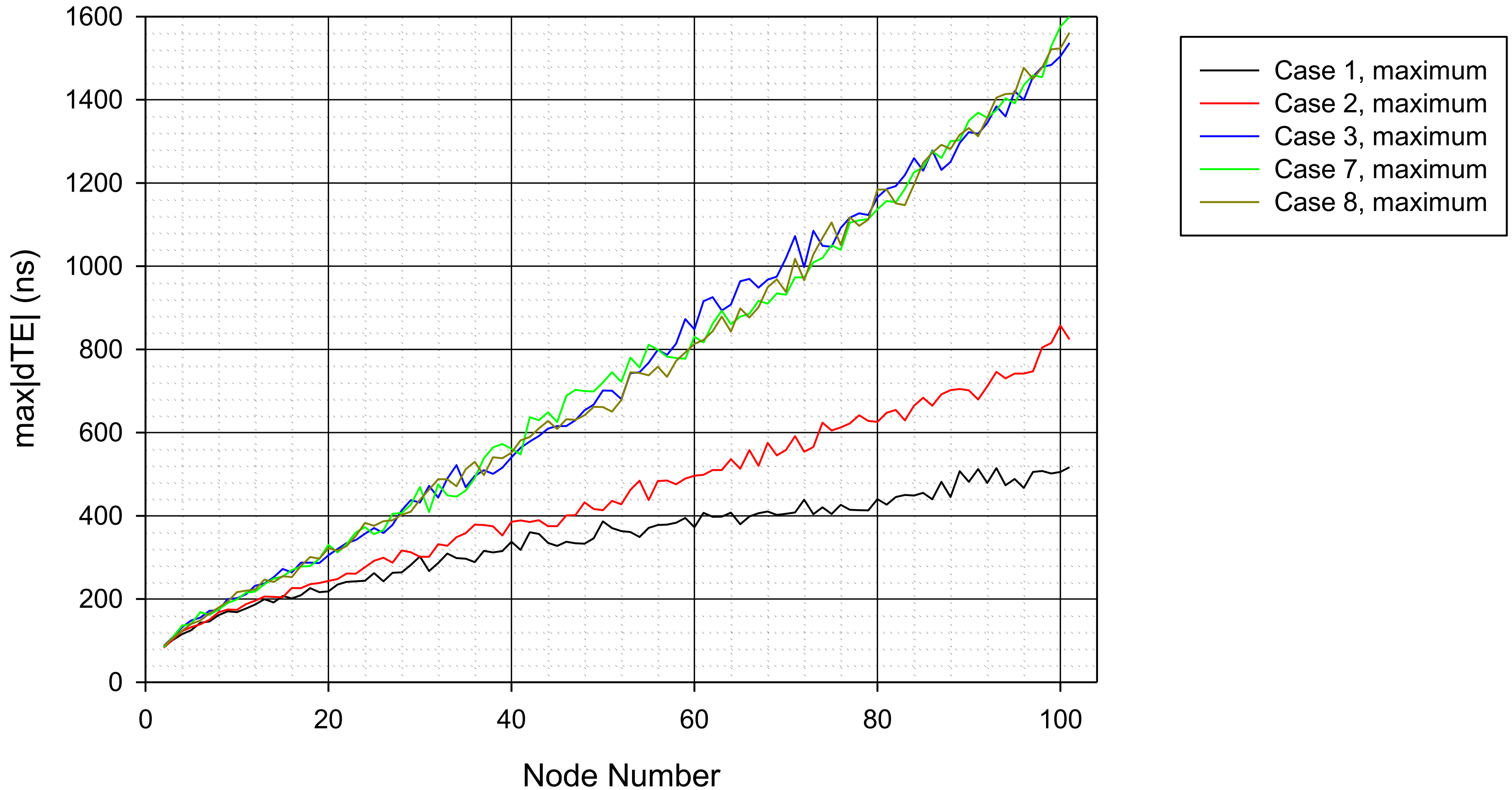
Accumulate neighborRateRatio
Endpoint filter: KiKo = 65, KpKo = 11
Resid time = 10 ms, Pdelay turn time = 1ms (case7),4ms (case8)



Revised Results for dTE_R for Previous Cases (1 – 8) – 15

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]

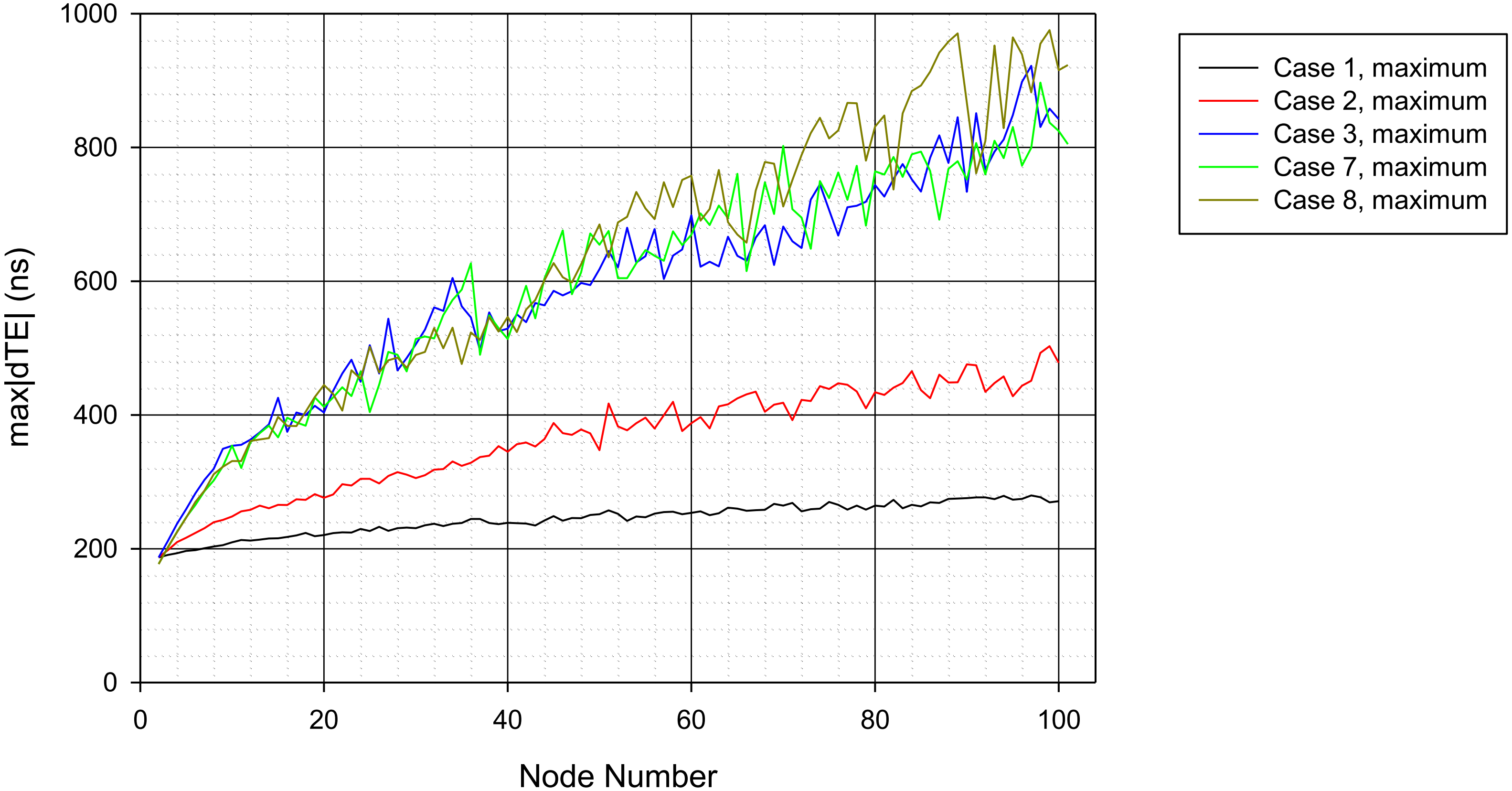
accumulate neighborRateRatio
Endpoint filter: KiKo = 249 (cases 1-3), 65 (cases 7-8)



Results for dTE, Zero Error in GM Time Source (previous results, from [2]) – 16

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)



Revised Results for dTE_R for Previous Cases (1 - 8) - 17

- The new (i.e., revised) results for cases 1 – 8 are summarized in the table on the next slide (rounded to 2 or 3 significant digits), and compared with the results obtained in [1] and [2]
- The 50 ns error due to dynamic error of the GM, which was added to the previous results ([1] and [2]) has been subtracted, because it is not included in the new results
  - As indicated in the introduction, an improved analysis of this error is contained in the companion presentation [11]
- The new results are considerably larger than the previous results
  - This is mainly due to the ± 8 ns dynamic timestamp error for event messages due to variable delays within the PHY being included properly in the new simulations
- The 1 μs objective for $\max|TE_R|$ can likely be met for cases 1 and 4 (but not 2 and 5, as for the previous simulations) for 100 nodes, and for cases 1, 2, 4, and 5 for 65 nodes
- For other cases, either the 1 μs objective is exceeded, or it is met but with insufficient margin for other error budget components (i.e., cTE and effect of GM dynamic time error)
- As for the previous results, the results for cases 7 and 8 are similar to the results for case 3 (i.e., the smaller Pdelay turnaround time has small effect)

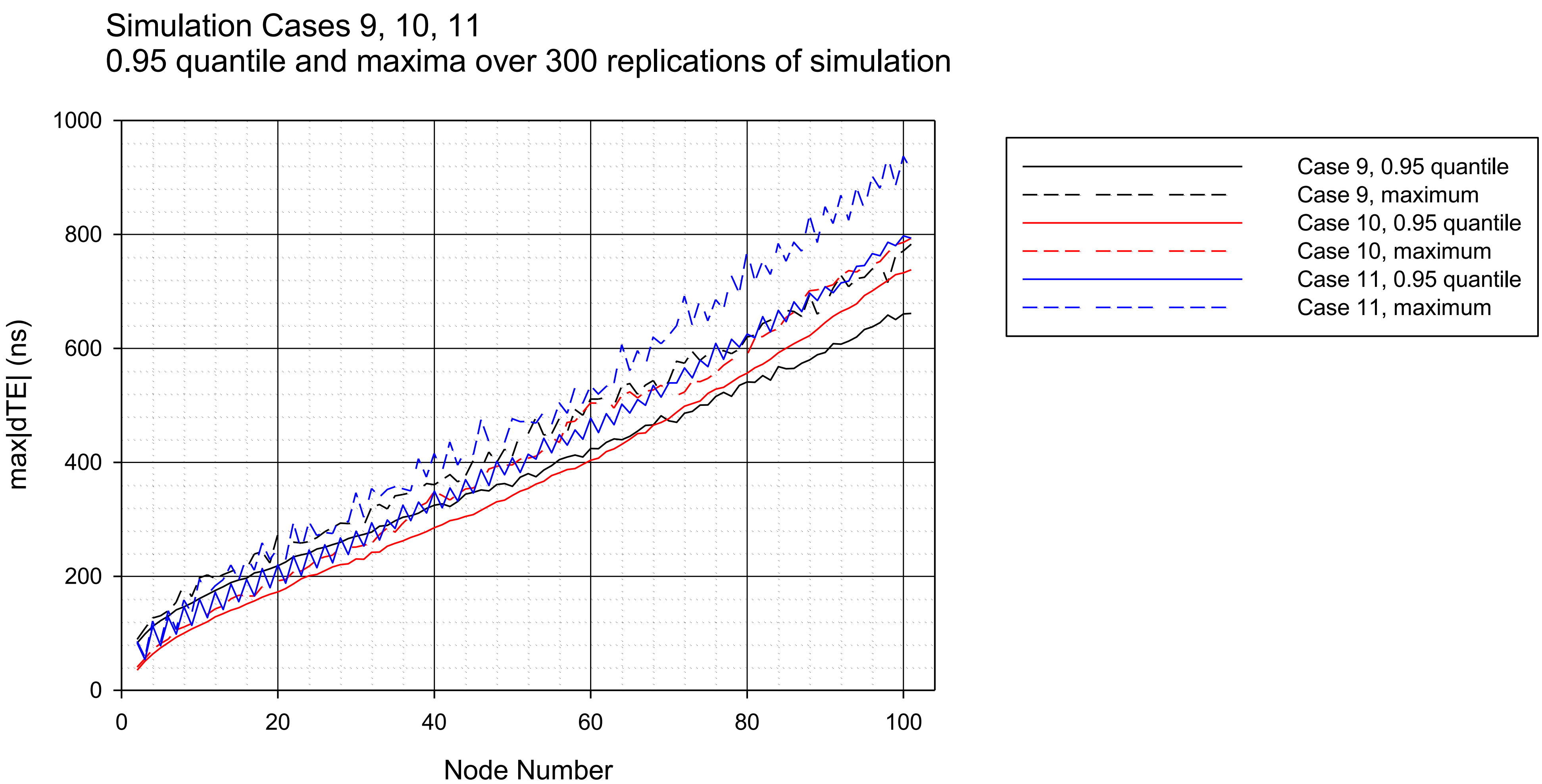
Revised Results for dTE_R for Previous Cases (1 - 8) - 18

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

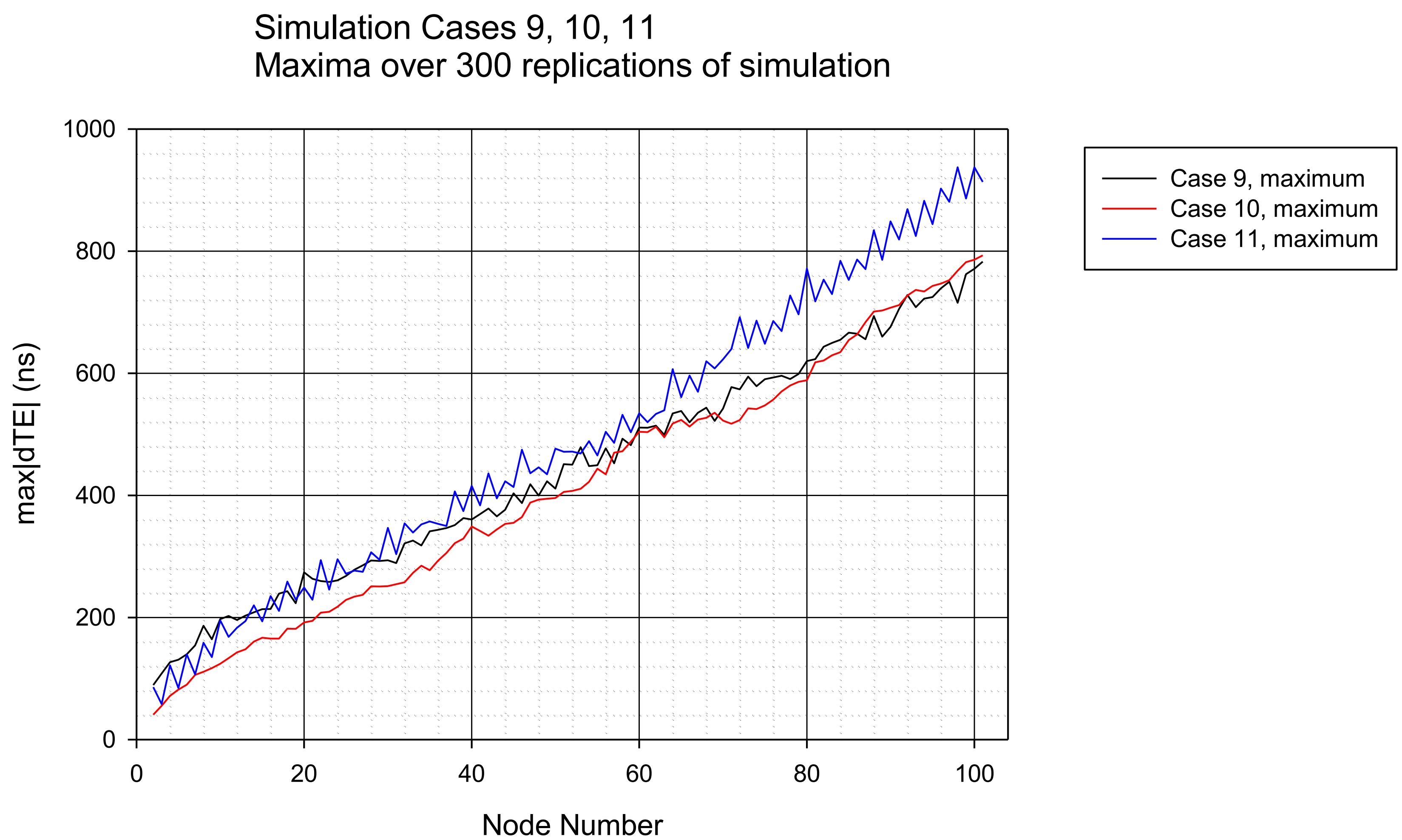
Results for dTE_R (Cases 9 - 11) - 1

- The following plots show results for cases 9 – 11
  - Max|dTE_R|, cases 9 – 11, nodes 2 – 100, 99% confidence intervals for 0.95 quantile, and maximum over 300 replications
  - Max| dTE_R |, cases 9 – 11, nodes 2 – 100, maximum over 300 replications (less cluttered than previous plot)
  - Max|dTE_R|, cases 9 – 811, nodes 2 – 65, 99% confidence intervals for 0.95 quantile, and maximum over 300 replications
  - Max| dTE_R |, cases 9 – 11, nodes 2 – 165, maximum over 300 replications (less cluttered than previous plot)

Results for dTE_R (Cases 9 - 11) - 2

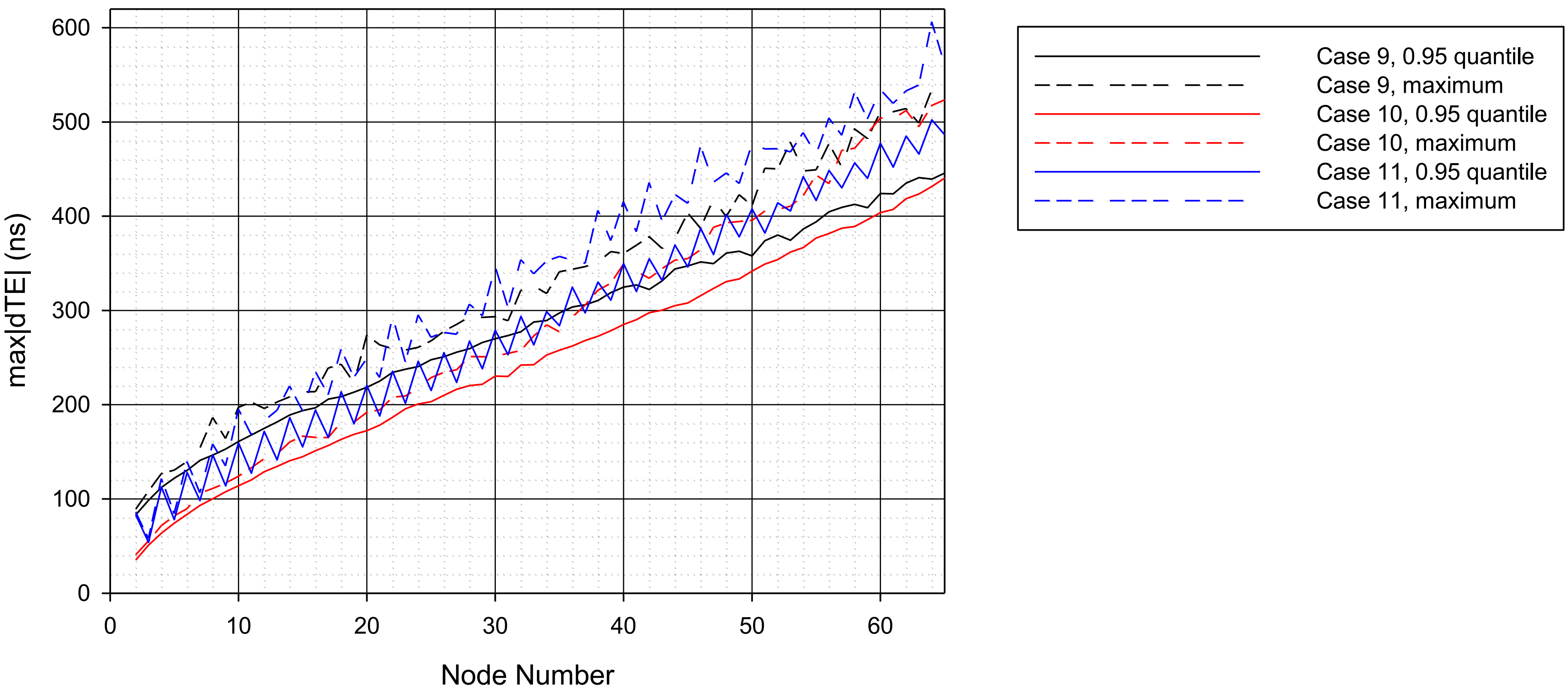


Results for dTE_R (Cases 9 - 11) - 3

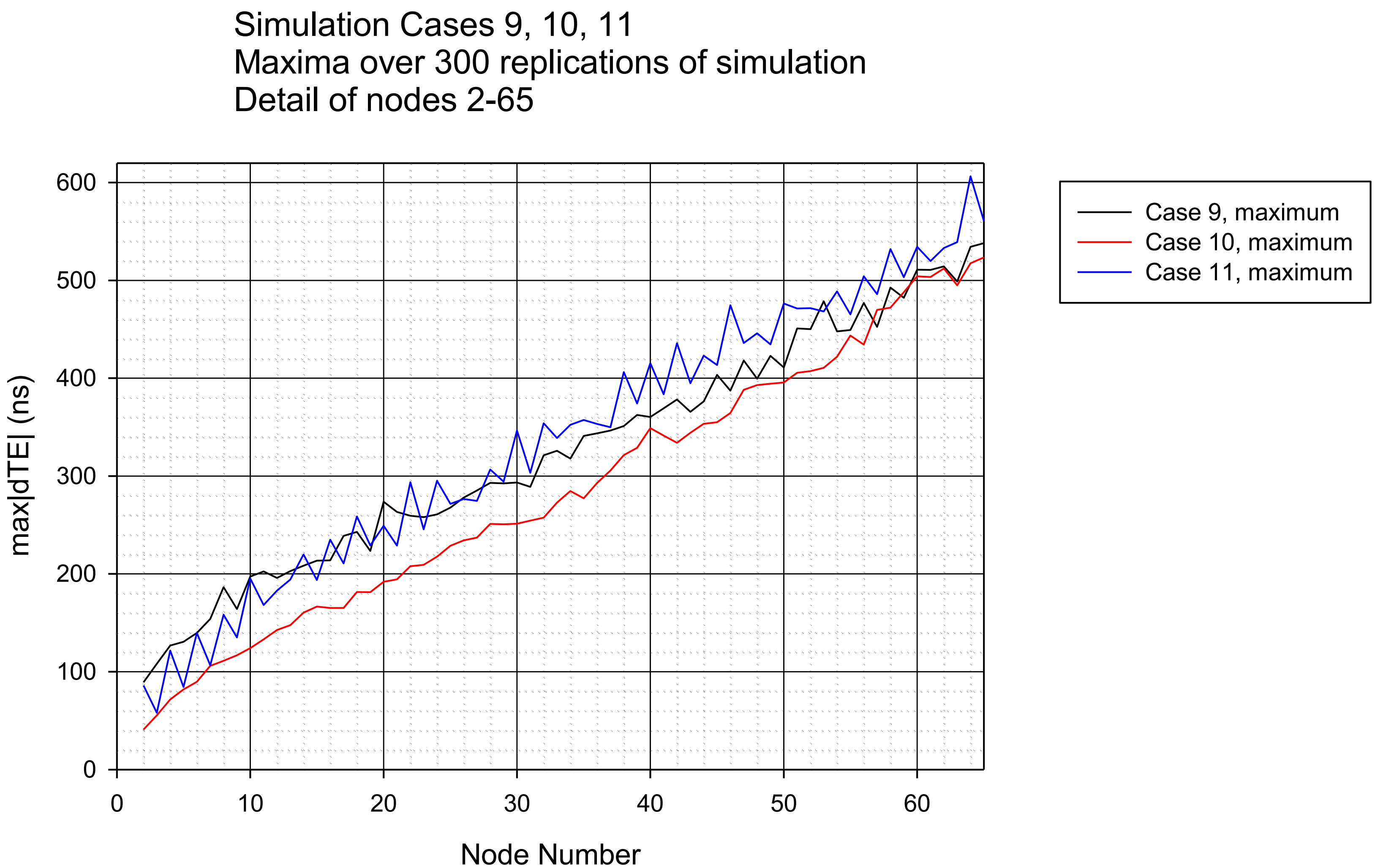


Results for dTE_R (Cases 9 - 11) - 4

Simulation Cases 9, 10, 11
0.95 quantile and maxima over 300 replications of simulation
Detail of nodes 2-65



Results for dTE_R (Cases 9 - 11) - 5



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

Results for dTE_R (Cases 9 – 11) – 7

- It appears that the 1 μs objective can be met over 65 nodes (64 hops), as approximately 400 – 500 ns margin remains for cTE and the effect of GM dynamic time error on $\max|TE_R|$
- The effect of GM dynamic time error on $\max|TE_R|$ is analyzed in [11]

Conclusion and Discussion of Next Steps

- The results for cases 9 – 11 indicate that the 1 μs objective for max|TE_R| can likely be met over 65 nodes (64 hops), though it must be checked whether there is sufficient margin for cTE and the effect of GM dynamic time error
- The results for cases 9 – 11 indicate that the 1 μs objective for max|TE_R| likely cannot be met over 101 nodes (65 hops)
- The new results for cases 1 – 8, based on revised analyses that properly account for the ± 8 ns dynamic timestamp error for event messages due to variable delays within the PHY are considerably larger than the previous results (in [1] and [2]) for these cases
- However, the main change to the conclusions of [2] is that, whereas the 1 μs objective for max|TE_R| could likely be met over 101 nodes for cases 1, 2, 4, and 5 for the results of [1] and [2], it is only met for cases 1 and 4 over 101 nodes for the new results
- There is no change to the conclusion for 65 nodes; the 1 μs objective for max|TE_R| is met for cases 1, 2, 4, and 5
- The effect of GM dynamic time error on max|TE_R| must also be considered
    - It is analyzed in [11]

Thank you

References - 1

[1] 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, September 2020.

[2] 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.

[3] 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.

[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, *Initial Simulation Results for Time Error Accumulation in an IEC/IEEE 60802 Network*, IEEE 802.1 presentation, March 2020.

References - 2

[6] Geoffrey M. Garner, *Discussion of Assumptions Needed for 60802 Network Simulations*, IEEE 802.1 presentation, January 2020.

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

[8] Guenter Steindl, *IEC/IEEE 60802 Synchronization requirements and solution examples*, IEEE 802.1 presentation, available at http://www.ieee802.org/1/files/public/docs2020/60802-Steindl-SynchronizationModels-0620-v1.pdf.

[9] Guenter Steindl, *IEC/IEEE 60802 Synchronization requirements and solution examples, Update after July 2020 plenary*, IEEE 802.1 presentation, July 30, 2020 available at https://www.ieee802.org/1/files/public/docs2020/60802-Steindl-SynchronizationModels-0720-v2.pdf

References - 3

[10] Geoffrey M. Garner, *Summary of Assumptions for Further Simulations of Time Error Performance for Transport over an IEC/IEEE 60802 Network*, IEEE 802.1 presentation, July 29, 2020, available at https://www.ieee802.org/1/files/public/docs2020/60802-garner-summary-of-assumptions-for-further-simulations-0720-v00.pdf.

[11] 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.