# New Simulation Results for dTE for an IEC/IEEE 60802 , Based on New Frequency Stability Model Version (Revision) 1

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# Introduction - 1

- Reference [1] contained single-replication simulation results, based on assumptions summarized in [2]
- Included in these assumptions is a new LocalClock phase noise model, based on new frequency stability data presented in [3] and summarized in [4]
- Reference [4] obtained time histories for frequency offset, frequency drift rate, and phase offset for the LocalClock entity, based on the frequency stability versus temperature data of [3] and the periodic temperature profile described in [5]
  - In the assumptions of [2], the temperature profile was modified to shorten the period
- The results in [1] assumed the grandmaster (GM) time error was zero
  - This means that the simulated dynamic time error (dTE) also was the dTE relative to the GM (i.e., $dTE_{R(k,0)}$, where the GM node index is 0)
- In the current presentation, the GM time error is assumed to be the same as that of the LocalClock entity of each PTP Relay Instance and the PTP End Instance
  - $dTE_{R,0}$ and $\max|dTE_{R(k,0)}|$ (relative to the GM) are computed
  - Because the sampling instants for the GM and successive PTP Instances are not necessarily the same, it was necessary to interpolate to compute $dTE_{R(k,0)}$

# Introduction - 2

- In addition, 300 multiple, independent replications of each simulation case are run
- Due to the additional run time required for 300 replications and the interpolation, only 4 selected cases of [1] were run
  - The run time was approximately 21.5 days for 101 nodes (100 hops)
- In the following slides, the assumptions are summarized (and the simulation results are presented)
  - In [1], a total of 27 cases was considered
  - For the current presentation, cases 16, 18, 22, and 27 were run (300 multiple replications with non-zero GM time error)
  - In the summary of assumptions, the assumptions for cases 16 – 27 of [1] are repeated (with the focus here on cases 16, 18, 22, and 27)
- Changes in Revision 1: fixed legend on slides 15

# Assumptions for Temperature Profile (from [2])

- The temperature history is assumed to vary between – 40°C and +85°C, at a rate of 1°C /s
- When the temperature is increasing and reaches +85°C, it remains at +85°C for 30 s
- The temperature then decreases from +85°C to – 40°C at a rate of 1°C /s; this takes 125 s
- The temperature then remains at – 40°C for 30 s
- The temperature then increases to +85°C at a rate of 1°C /s; this takes 125 s
- The duration of the entire cycle (i.e., the period) is therefore 310 s (5.166667 min)

## Assumptions for Frequency Stability due to Temperature Variation

- The dependence of frequency offset on temperature is assumed to be as described in [3] and [4]
  - Specifically, the values $a_0$, $a_1$, $a_2$, and $a_3$ computed in [4] will be used in the cubic polynomial fit, and the resulting frequency offset will be multiplied by 1.1 (i.e., a margin of 10% will be used).
- The frequency stability data that this polynomial fit is based on is contained in the Excel spreadsheet attached to [4]
  - This data was provided by the author of Reference [3]
- The time variation of frequency offset will be obtained from the cubic polynomial frequency dependence on temperature, and the temperature dependence on time described in the previous slide
  - The time variation of phase/time error at the LocalClock entity will be obtained by integrating the above frequency versus time waveform
  - The time variation of frequency drift rate at the LocalClock entity will be obtained by differentiating the above frequency versus time waveform

- Two types of assumptions are used for relative time offsets of the phase error histories at each node:
  - Choose the phase of the LocalClock time error waveform at each node randomly in the range [0,T], at initialization, where T is the period of the phase and frequency variation waveforms (i.e., 310 s, see slide 4)
  - Choose the phase of the LocalClock time error waveform at each node randomly in the range [0, 0.1T], at initialization, where T is the period of the phase and frequency variation waveforms (i.e., 310 s, see slide 4)
    - A uniform probability distribution is used for the random choice
    - 0.1T = 31 s, i.e., any periodic LocalClock time error waveform will be offset from any other such waveform by at most 31 s

# Other Assumptions - 1

- Additional assumptions
  - Mean Sync interval:  125 ms
  - Mean Pdelay interval: 31.25 ms
  - Timestamp granularity: 8 ns, 4 ns (both cases)
  - Residence times: 1 ms, 4 ms, 10 ms (all 3 cases)
  - Timestamp error ($\pm$8 ns, each with 0.5 probability)
- The above, along with the two different assumptions for random offsets for phase error waveform implies 12 simulation cases ($2 \times 2 \times 3$)
- Other assumptions are taken from [6], and are summarized on the following slides

# Other Assumptions - 2

| 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 |
| Computed performance results | (a) max$\lvert dTE_{R(k,\,0)}\rvert$ (i.e., maximum absolute relative time error between node $k$ ($k$ > 0) and GM<br>(b) Measured LocalClock rateRatio (frequency offset) relative to GM, for comparison with actual LocalClock frequency offset (results will be plotted for nodes 2, 35, 68, and 101 (where node 2 is the first node after the GM, and the GM is node 1; note that in [2], the GM was node 0, and the above nodes were 1, 34, 67, and 100)) |
| Use syncLocked mode for PTP Instances downstream of GM | Yes |
| Endpoint filter parameters | $K_pK_o$ = 11, $K_iK_o$ = 65 ($f_{3dB}$ = 2.5998 Hz, 1.288 dB gain peaking, $\zeta$ = 0.68219) |
| Simulation time | 3150 s; discard first 50 s to eliminate any startup transient before computing max$\lvert dTE_{R(k,\,0)}\rvert$ (i.e., 10 cycles of frequency variation after discard) |

# Other Assumptions - 3

| Assumption/Parameter | Description/Value |
|---|---|
| Number of independent replications, for each simulation case | 300 |
| GM rateRatio and neighborRateRatio computation granularity | 0 |
| Mean link delay | 500 ns |
| Link asymmetry | 0 |
| 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. |
| Any variable PHY delay in addition to the dynamic timestamp error described above is assumed to be zero | 0 |

# Other Assumptions - 4

- neighborRateRatio was computed using a window size of 7 was used, i.e., the difference was taken between respective timestamps of current Pdelay exchange and $7^{th}$ previous Pdelay exchange
  - In addition, the current estimate of neighborRateRatio was taken as the median of the most recent 7 measurements (including the current measurement)
- The above assumptions were used in cases 16 – 27 of [1]
- For convenience, cases 16 – 27 of [1] are summarized on the following slides, though of these, only cases 16, 18, 22, and 27 were simulated for the results here
  - The cases here use the same numbering as in [1]; however, cases 1 – 15 of [1] are not of interest here (these cases did not use the window of size 7, with median, for computing neighborRateRatio)

## Summary of Simulation Cases (highlighted cases were the ones simulated)

| Case | Residence time (ms) | Timestamp gran (ns) | Fract of cycle over which initial time error waveforms are randomized (%) | Compute neighborRateRatio averaging over window of size 7 and taking median |
|---|---|---|---|---|
| 16 | 1 | 8 | 100 | Yes |
| 17 | 1 | 4 | 100 | Yes |
| 18 | 4 | 8 | 100 | Yes |
| 19 | 4 | 4 | 100 | Yes |
| 20 | 10 | 8 | 100 | Yes |
| 21 | 10 | 4 | 100 | Yes |
| 22 | 1 | 8 | 10 | Yes |
| 23 | 1 | 4 | 10 | Yes |
| 24 | 4 | 8 | 10 | Yes |
| 25 | 4 | 4 | 10 | Yes |
| 26 | 10 | 8 | 10 | Yes |
| 27 | 10 | 4 | 10 | Yes |

# Results - 1

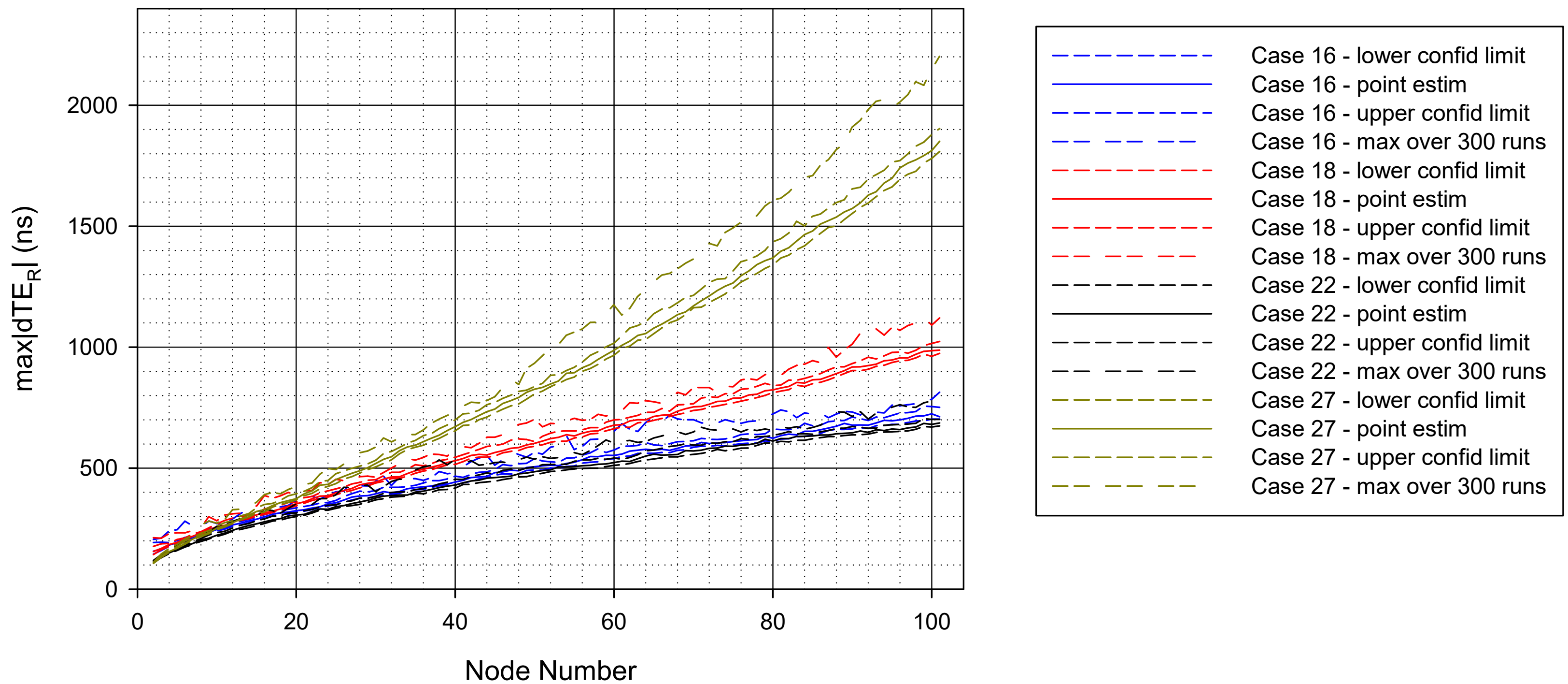
- Results for max|$dTE_R$|, relative to the GM, versus node number are summarized on the next two slides, for cases 16, 18, 22, and 27, respectively; for comparison, this is followed by the results from [1]
- The first max|$dTE_R$| plot shows, for each of the four cases:
  - 99% confidence intervals for the 0.95 quantile, for each of nodes 2 through 101
    - The 99% confidence interval for the 0.95 quantile is obtained by ordering the 300 max|$dTE_R$| samples (at a node) from smallest to largest
    - The interval extends from the $275^{th}$ through $294^{th}$ smallest samples (i.e., the $26^{th}$ and $7^{th}$ largest samples, respectively)
    - This is obtained using the result that order statistics have a binominal distribution (see section 9-2 and Eq. (9-25 of [7])
  - Maximum over the 300 replications of the simulation, for each of nodes 2 through 101
- The second max|$dTE_R$| plot shows only the maximum values (this plot is supplied because it is less cluttered than the first plot)

# Results - 2

- Following the max|$dTE_R$| plots, detailed time history results for each of the four cases, for nodes 2, 35, 68, and 101 (GM is node 1), are given:
  - Due to the potentially large number of plots, detailed time history results are not presented for every node of every case; however, results for additional nodes and cases can be supplied if desired

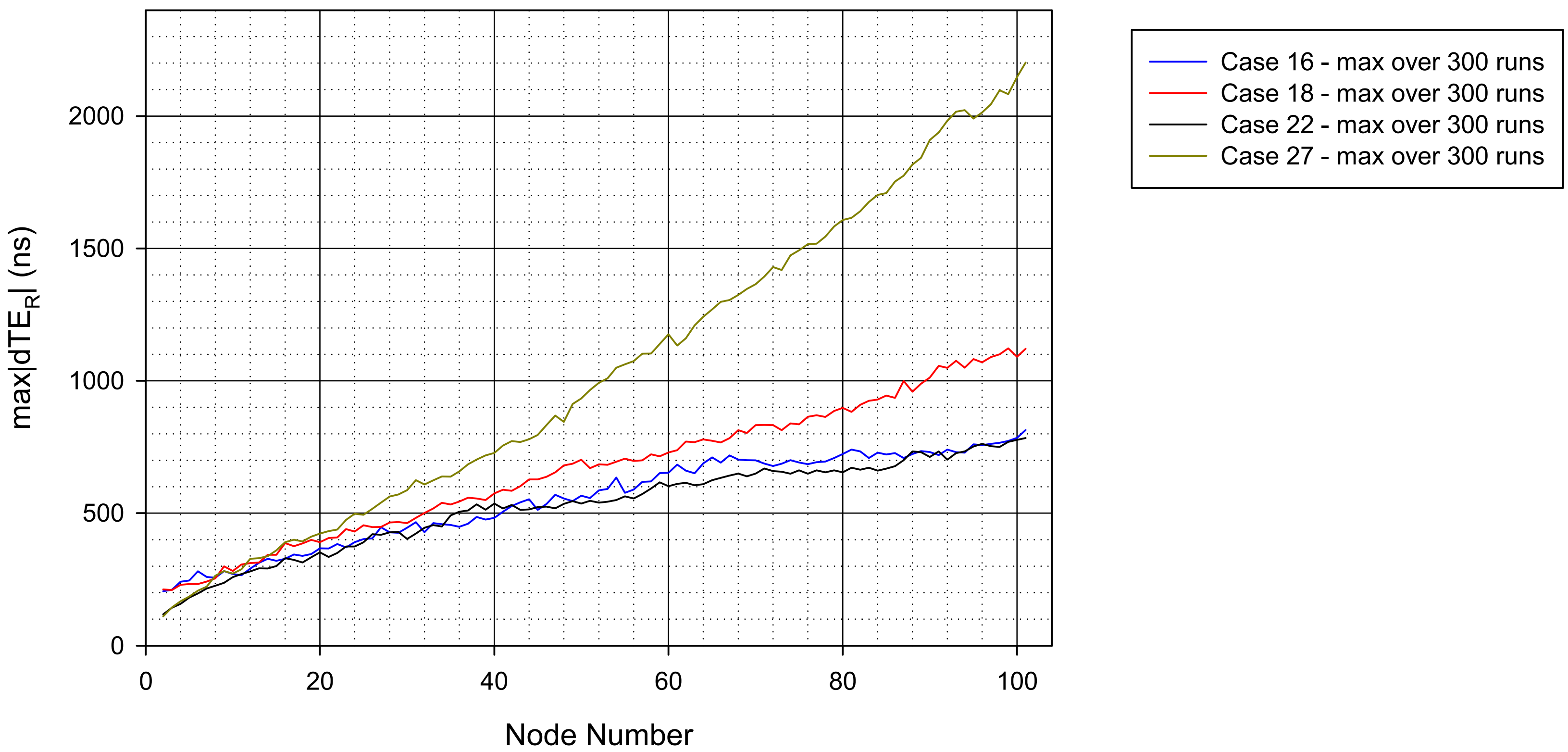
# max|dTE$_R$| Results - 1

Cases 16, 18, 22, 27 - multiple replication results
GM time error modeled
GM labeled node 1
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)



# max|$dTE_R$| Results - 2

Cases 16, 18, 22, 27 - multiple replication results
GM time error modeled
GM labeled node 1
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)



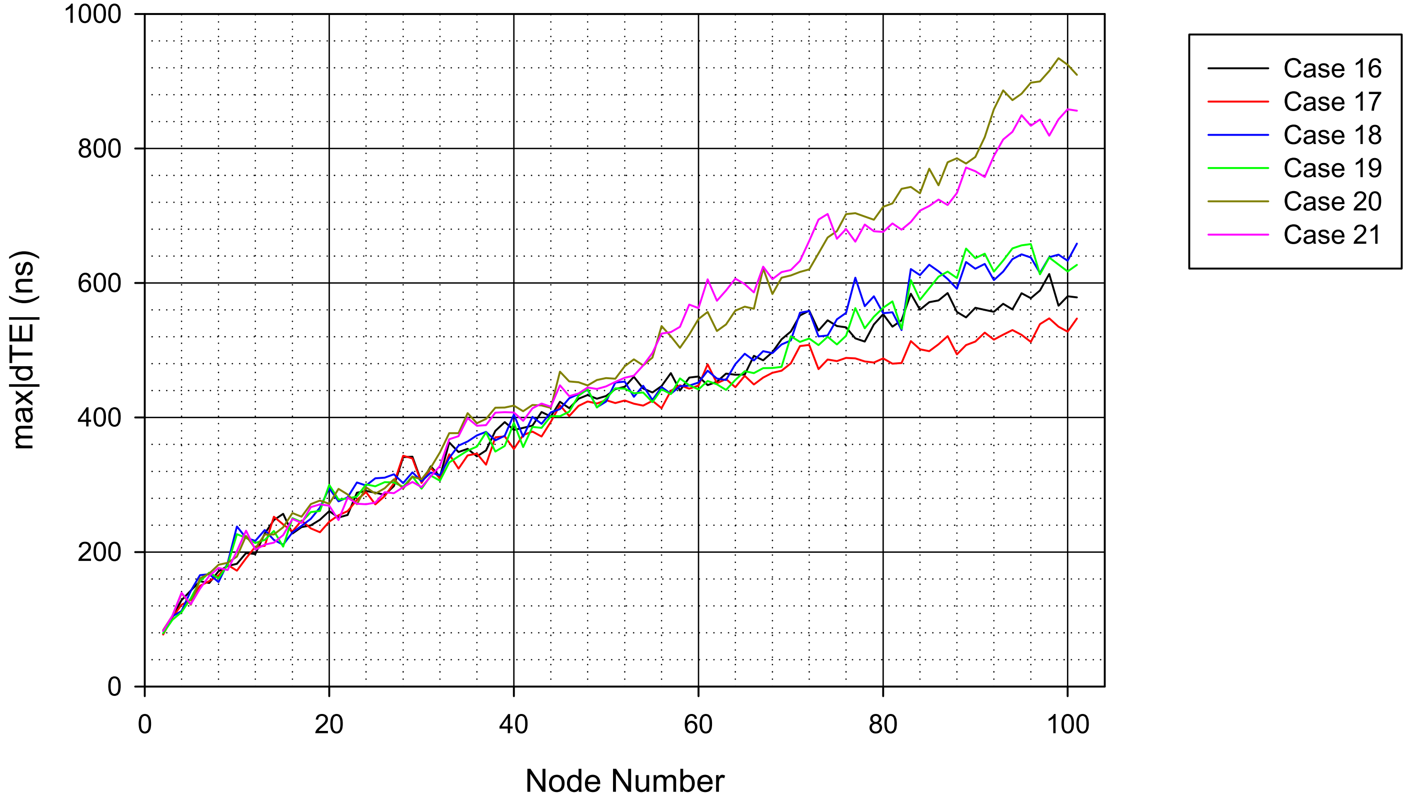
# max|$dTE_R$| Results - 3

| Case | max\|$dTE_R$\|, 64 hops (ns) | max\|$dTE_R$\|, 100 hops (ns) |
|---|---|---|
| 16 | 710 | 815 |
| 18 | 774 | 1121 |
| 22 | 625 | 784 |
| 27 | 1270 | 2202 |

64 hops results are for node 65
100 hops results are for node 101

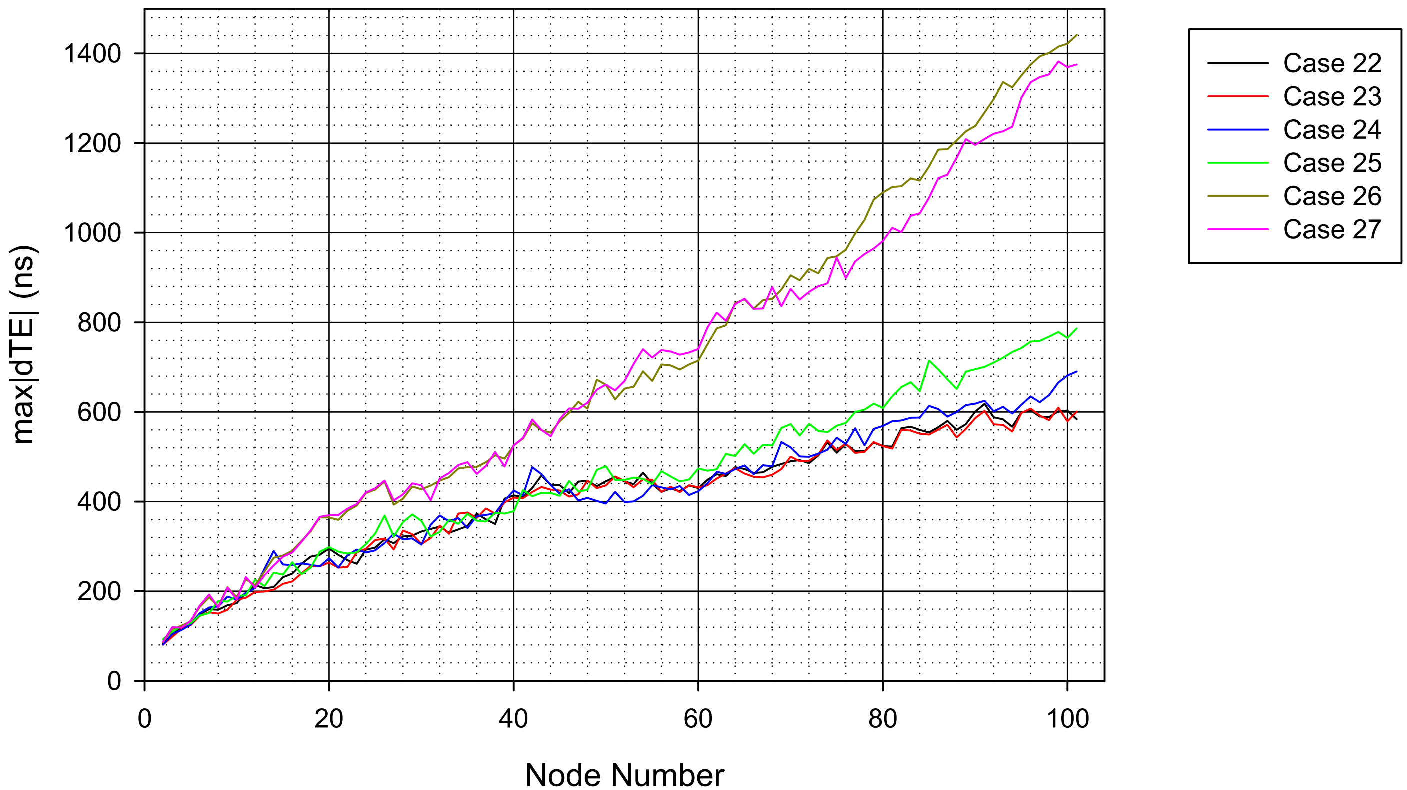
# Recap of max|dTE$_R$| results from [1] (cases 16 -21)

Simulation Cases 16, 17, 18, 19, 20, 21
Single replication of simulation
Clock model: stability and temp vs time profile from [1]
Accumulate neighborRateRatio; measure using size 10 window and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over entire cycle
Residence times: 1 ms (cases 16,17), 4 ms (cases 18,19), 10 ms (cases 20,21)
Timestamp granularities: 8 ns (cases 16,18,20), 4 ns (cases 17,19,21)



# Recap of max|dTE$_R$| results from [1] (cases 22 -27)

Simulation Cases 22, 23, 24, 25, 26, 27
Single replication of simulation
Clock model: stability and temp vs time profile from [1]
Accumulate neighborRateRatio; measure using size 10 window and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence times: 1 ms (cases 22,23), 4 ms (cases 24,25), 10 ms (cases 26,27)
Timestamp granularities: 8 ns (cases 22,24,26), 4 ns (cases 23,25,27)



# Recap of max|$dTE_R$| results from [1] (slide 55)

| Case | max\|dTE\|, 64 hops (ns) | max\|dTE\|, 100 hops (ns) | Case | max\|dTE\|, 64 hops (ns) | max\|dTE\|, 100 hops (ns) |
|---|---|---|---|---|---|
| 16 | 464 | 579 | 22 | 473 | 584 |
| 17 | 462 | 547 | 23 | 463 | 601 |
| 18 | 495 | 658 | 24 | 480 | 690 |
| 19 | 469 | 627 | 25 | 528 | 787 |
| 20 | 565 | 909 | 26 | 851 | 1441 |
| 21 | 598 | 856 | 27 | 853 | 1376 |

64 hops results are for node 65
100 hops results are for node 101

# Comparison of Results Obtained Here with those of [1]

| Case | $\max\lvert dTE_R \rvert$, 64 hops (ns) | | $\max\lvert dTE_R \rvert$, 100 hops (ns) | |
|---|---|---|---|---|
| | Current Results | Results of [1] | Current Results | Results of [1] |
| 16 | 710 | 464 | 815 | 579 |
| 18 | 774 | 495 | 1121 | 658 |
| 22 | 625 | 473 | 784 | 584 |
| 27 | 1270 | 853 | 2202 | 1376 |

64 hops results are for node 65
100 hops results are for node 101

# Discussion of max|$dTE_R$| Results - 1

- The new results follow the same trend as the results of [1], except that the overall magnitudes are larger, due to:
  - Modeling the effect of GM time error variation
  - Running multiple replications (i.e., 300) of each simulation case
- Residence time has the largest effect on the different cases, i.e., max|$dTE_R$| is largest in case 27 (10 ms residence time), second largest in case 18 (4 ms residence time), and smallest in cases 16 and 18 (1 ms residence time)
  - The effects of timestamp granularity (4 ns versus 8 ns) and magnitude of the variation of the phase of the LocalClock frequency waveform (10% versus 100% of the cycle) are much smaller

# Discussion of max|$dTE_R$| Results - 2

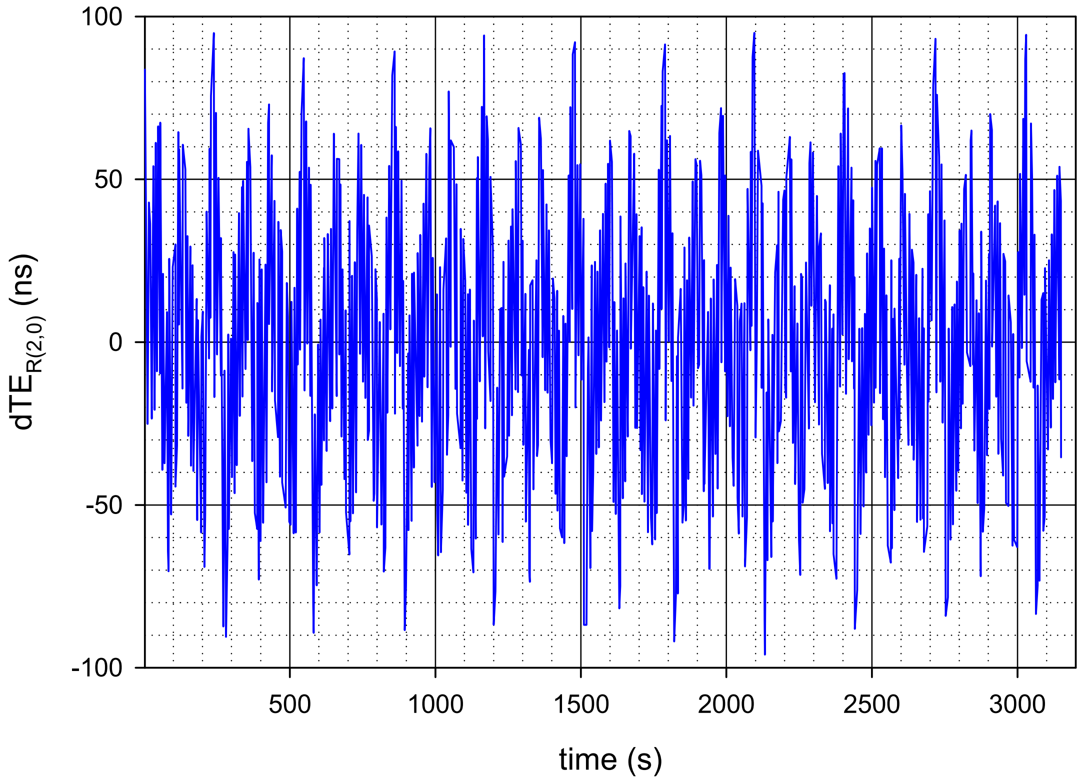
- ❑Cases 16 and 22 (1 ms residence time) meet the 1 μs objective for max|TE|, over 64 hops with sufficient margin to allow for constant time error (cTE)
- ❑Case 18 (4 ms residence time) possibly meets the 1 μs objective for max|TE|, over 64 hops with sufficient margin to allow for constant time error (cTE)
  - This depends on how much margin is required for cTE
- ❑Cases 16 and 22 (1 ms residence time) possibly meet the 1 μs objective for max|TE|, over 100 hops with sufficient margin to allow for constant time error (cTE)
  - This depends on how much margin is required for cTE
- ❑Case 18 (4 ms residence time) exceeds the 1 μs objective for max|TE|, over 100 hops
- ❑Case 27 (10 ms residence time) exceeds the 1 μs objective for max|TE|, over both 64 hops and 100 hops

# Detailed Results

- In the detailed results that follow, the following required interpolation, to compute values relative to the GM (node 1):
  - Max|$dTE_R$| (plot 1 for each node of each case)
  - Actual frequency of the LocalClock entity relative to the GM ($2^{nd}$ curve of plot 2 for each node of each case)
  - Difference between actual frequency of the LocalClock entity relative to the GM and the measured difference (plot 3 for each node of each case)
  - Interpolation was not needed for the measured difference (i.e., measured GM rateRatio) between the LocalClock entity relative to the GM
- Note that plots of interpolated results have fewer data points
  - Therefore, these plots appear more sparse
- For frequency results, only the first 500 s is plotted (with the first 10 s omitted to eliminate any startup transient) so that the overall detailed periodic behavior can be seen more readily
- Note that the frequency results are frequency offsets of each node relative to the GM; therefore, each waveform is the difference between the LocalClock waveform and version of it shifted by a random amount (since the GM time error is the same as that of each subsequent PTP Instance)

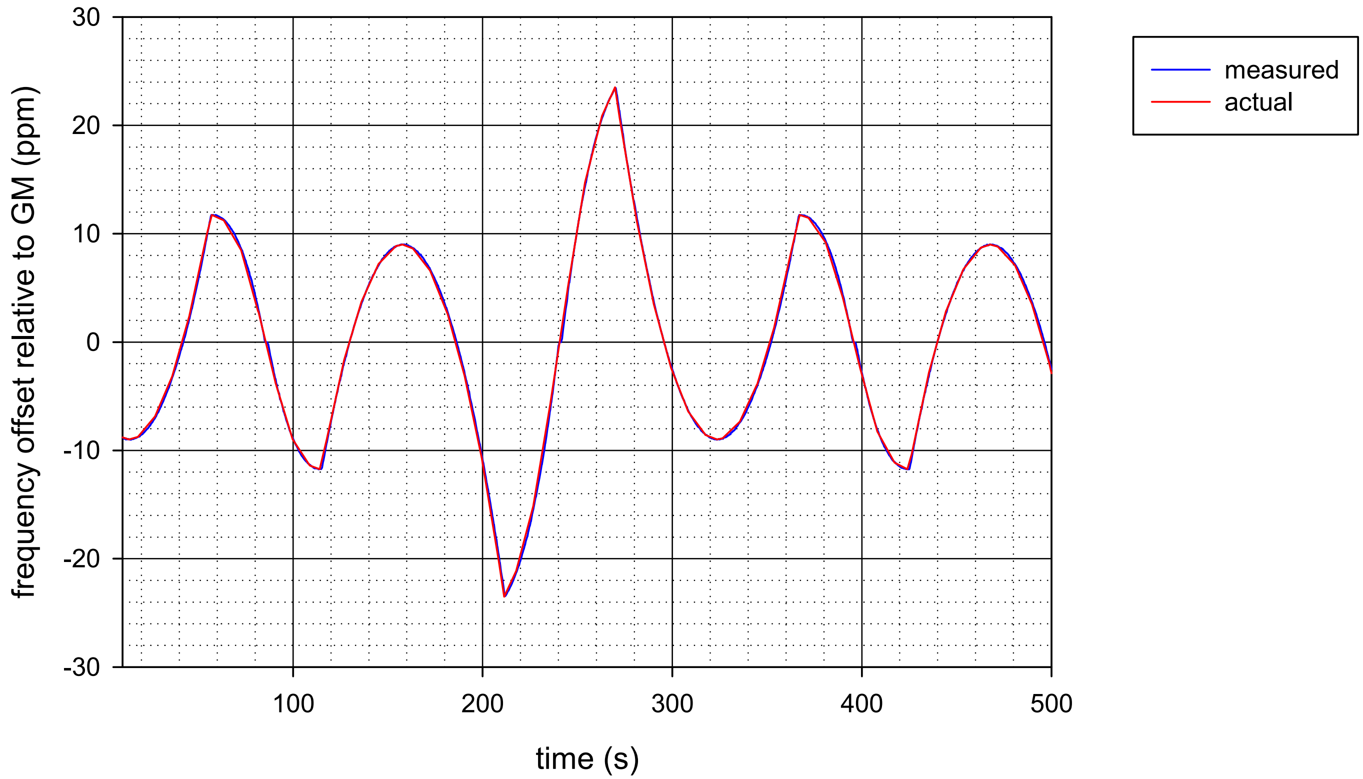
# Case16, Node 2 Detailed Results - 1

Simulation Case 16, Node 2
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



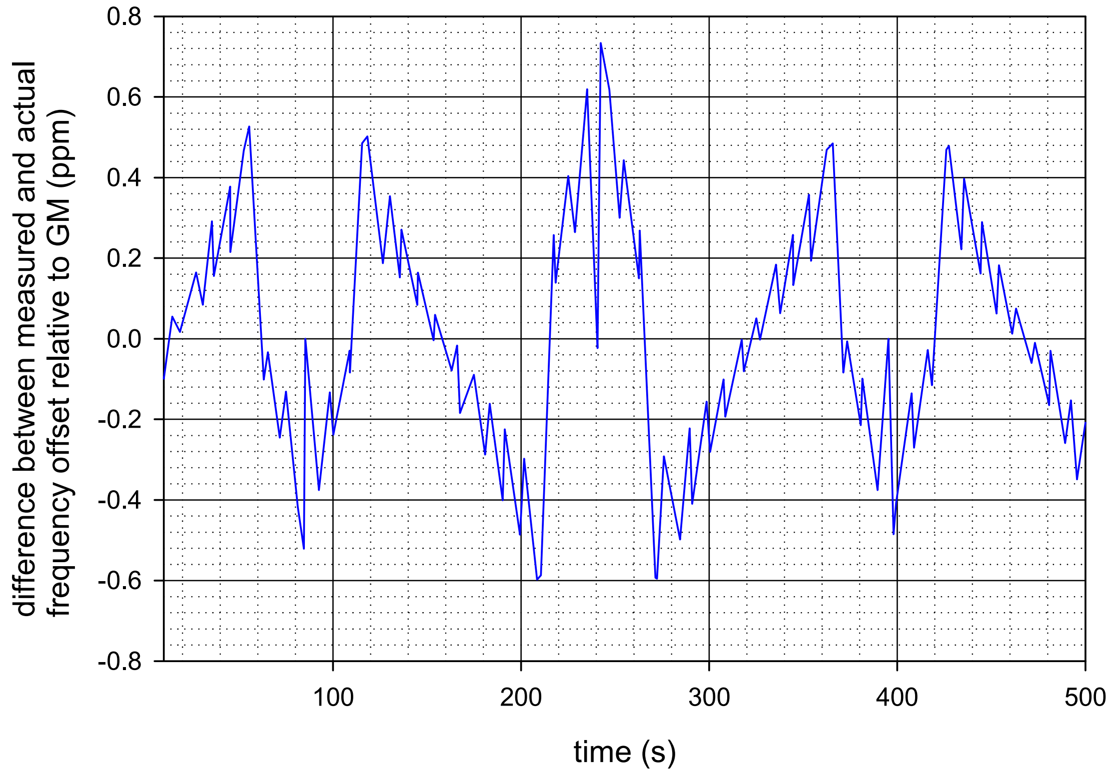
# Case16, Node 2 Detailed Results - 2

Simulation Case 16, Node 2
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



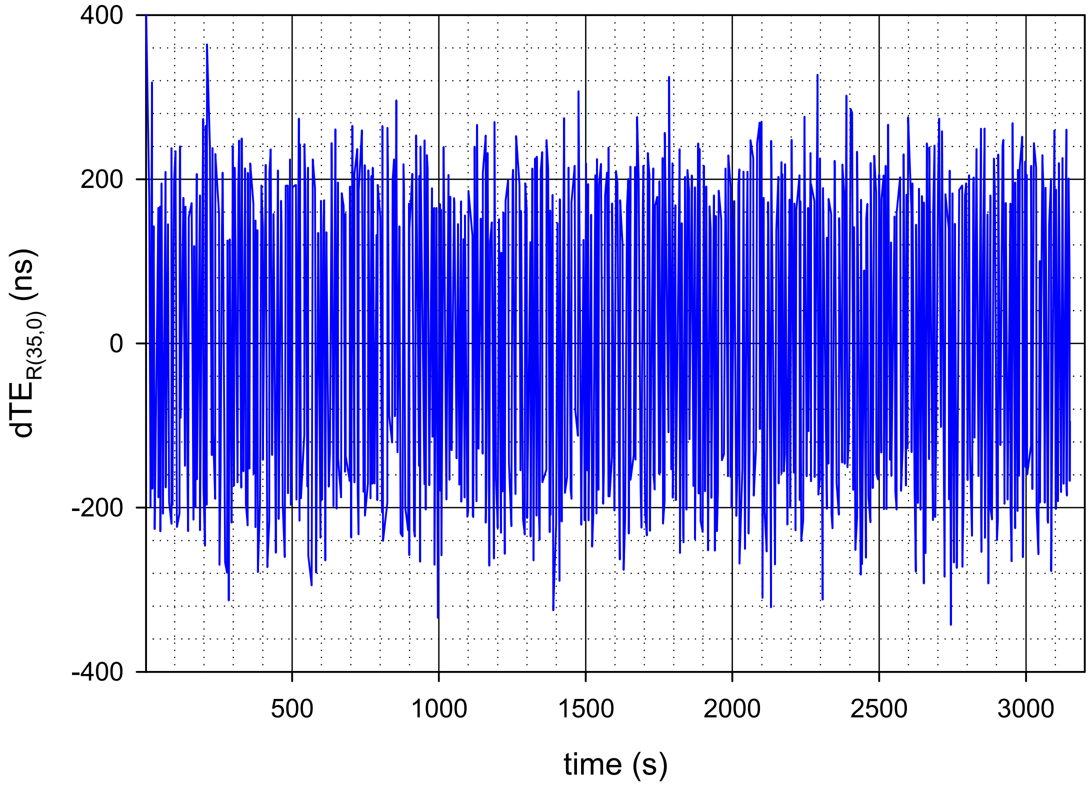
# Case16, Node 2 Detailed Results - 3

Simulation Case 16, Node 2
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



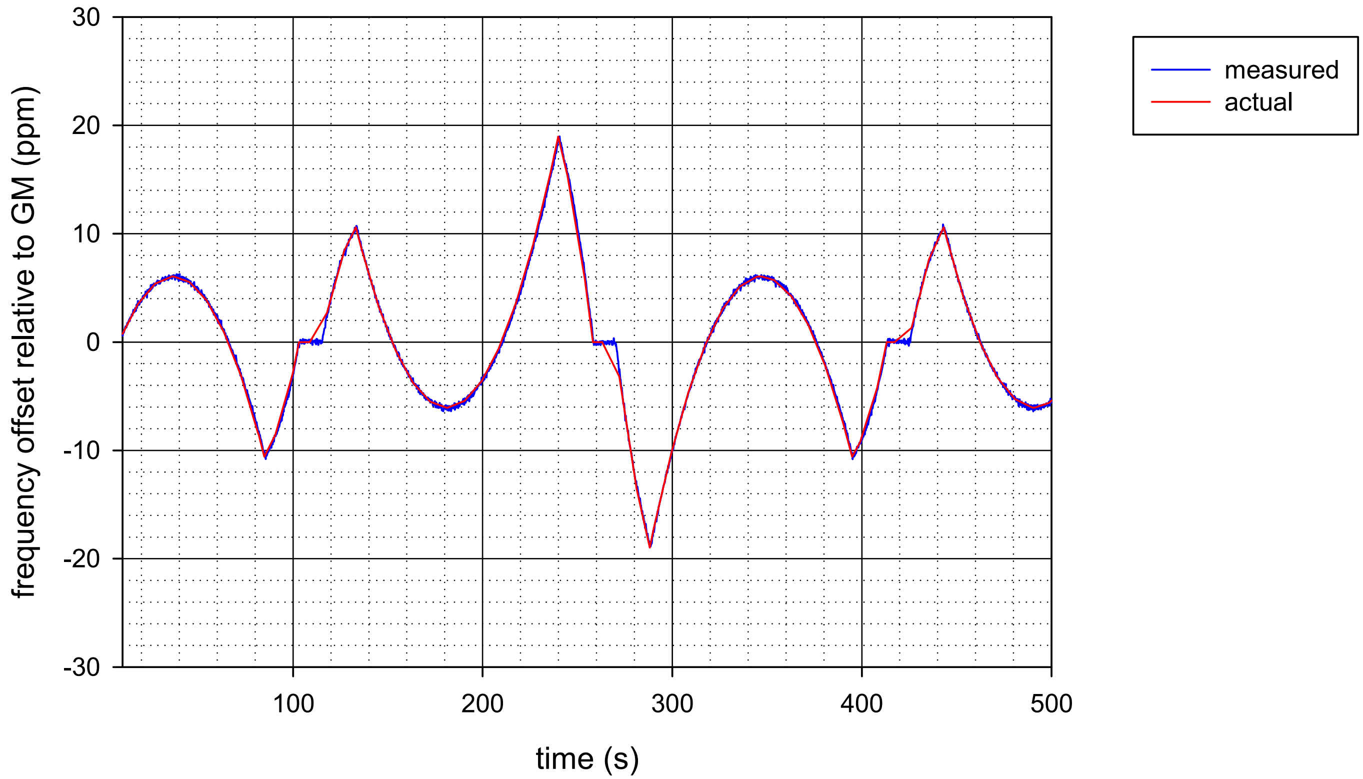
# Case16, Node 35 Detailed Results – 1

Simulation Case 16, Node 35
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



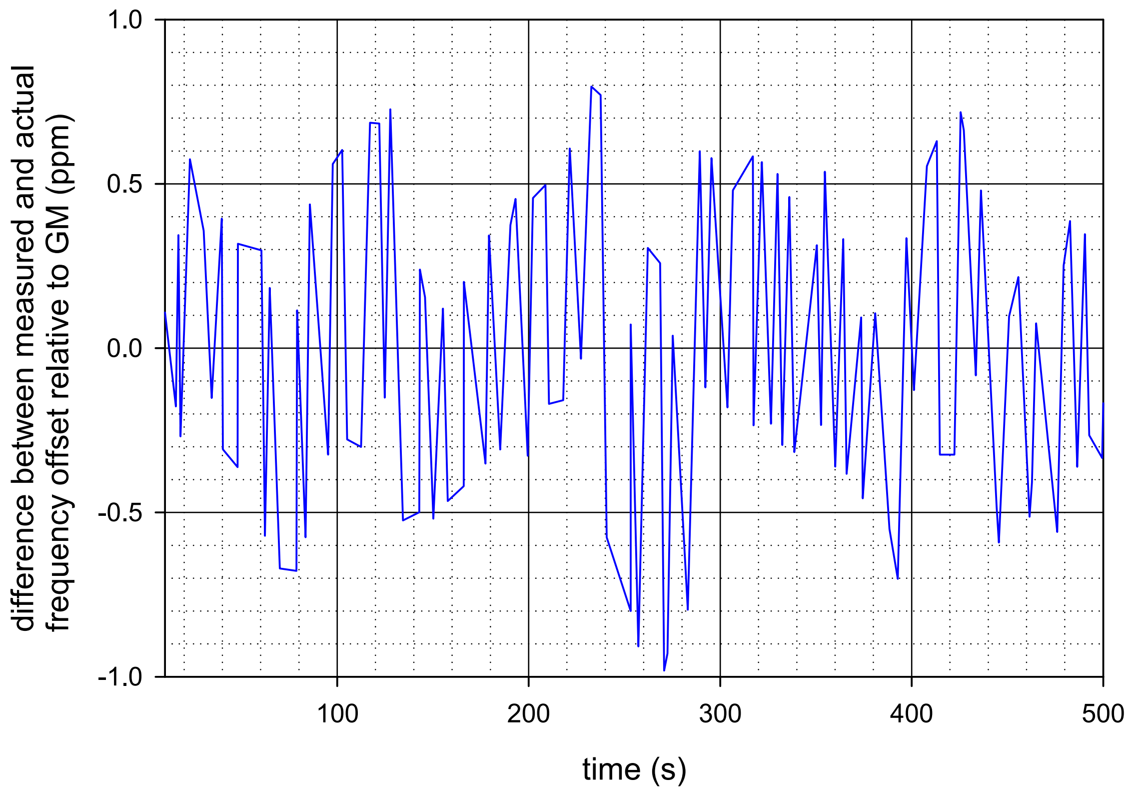
# Case16, Node 35 Detailed Results - 2

Simulation Case 16, Node 35
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



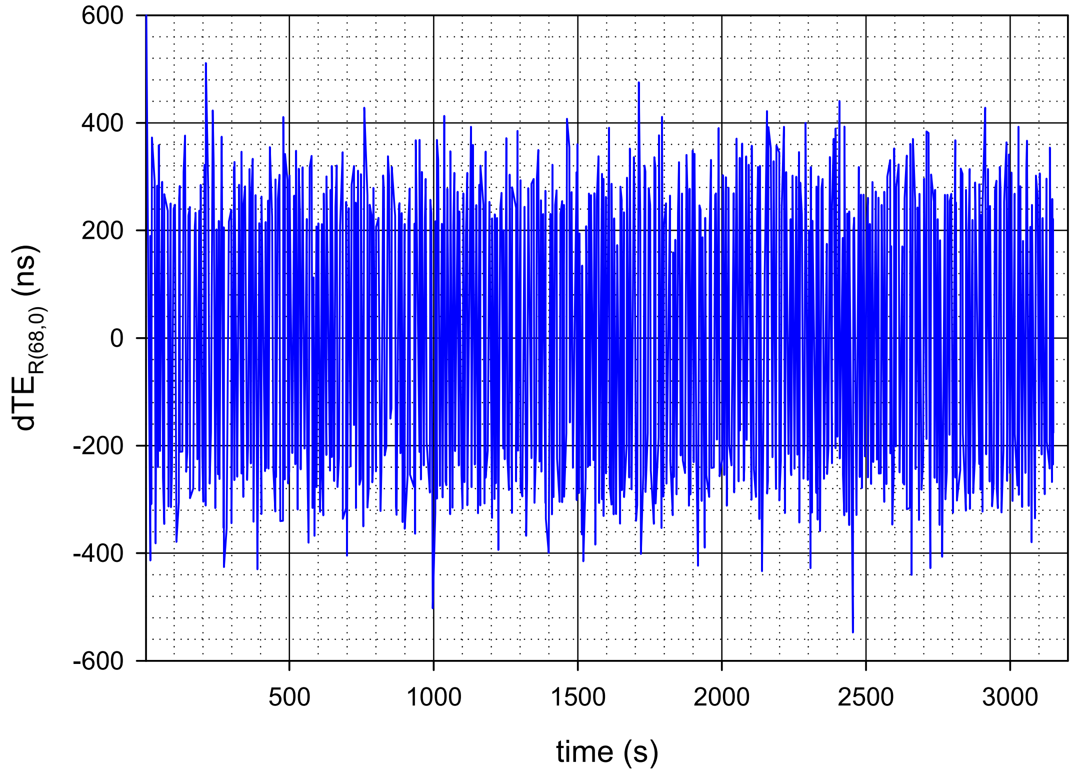
# Case16, Node 35 Detailed Results - 3

Simulation Case 16, Node 35
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



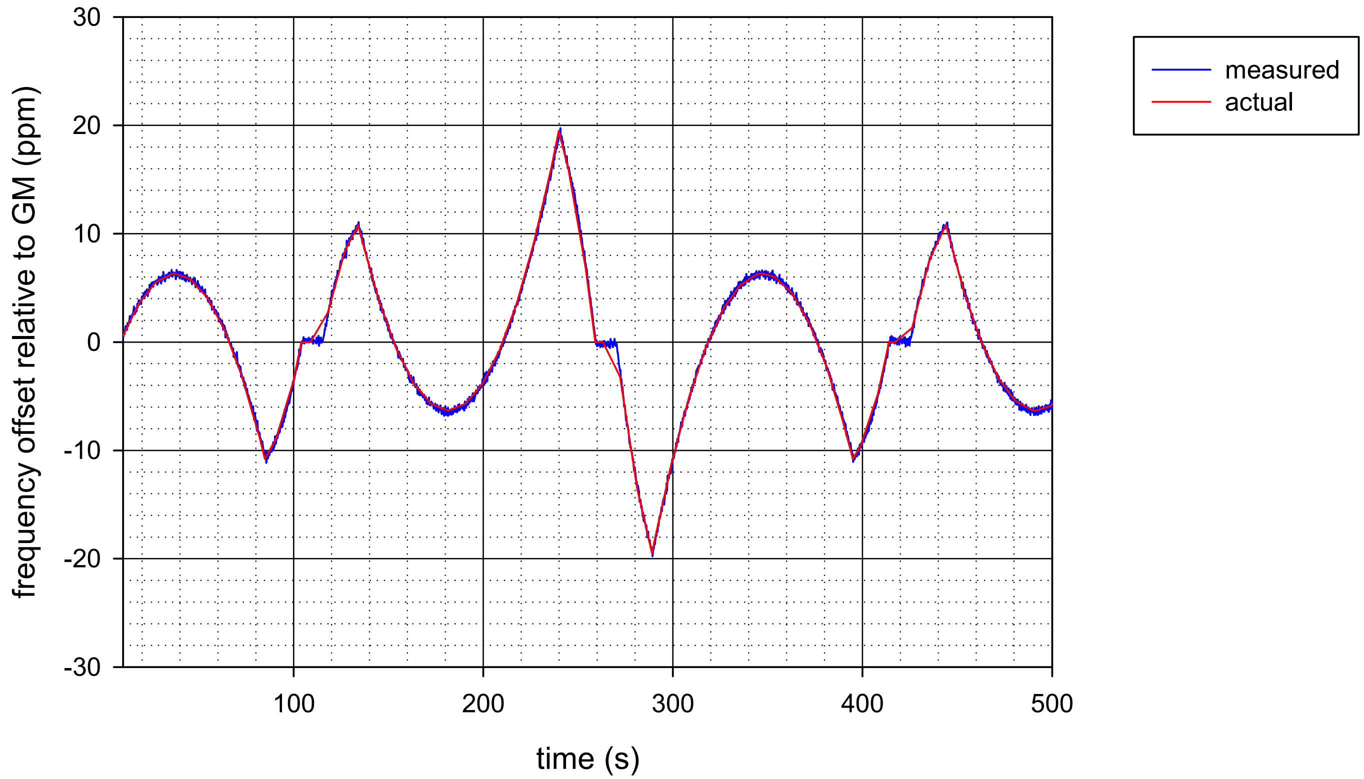
# Case16, Node 68 Detailed Results – 1

Simulation Case 16, Node 68
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



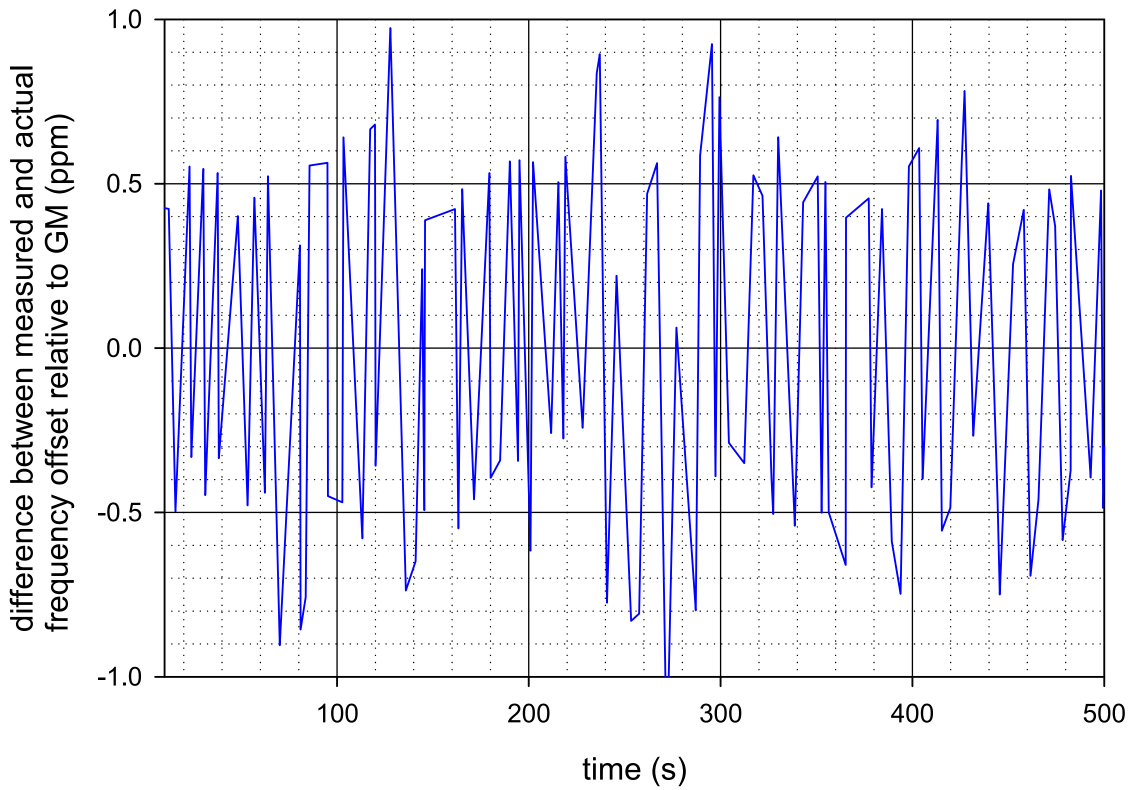
# Case16, Node 68 Detailed Results - 2

Simulation Case 16, Node 68
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



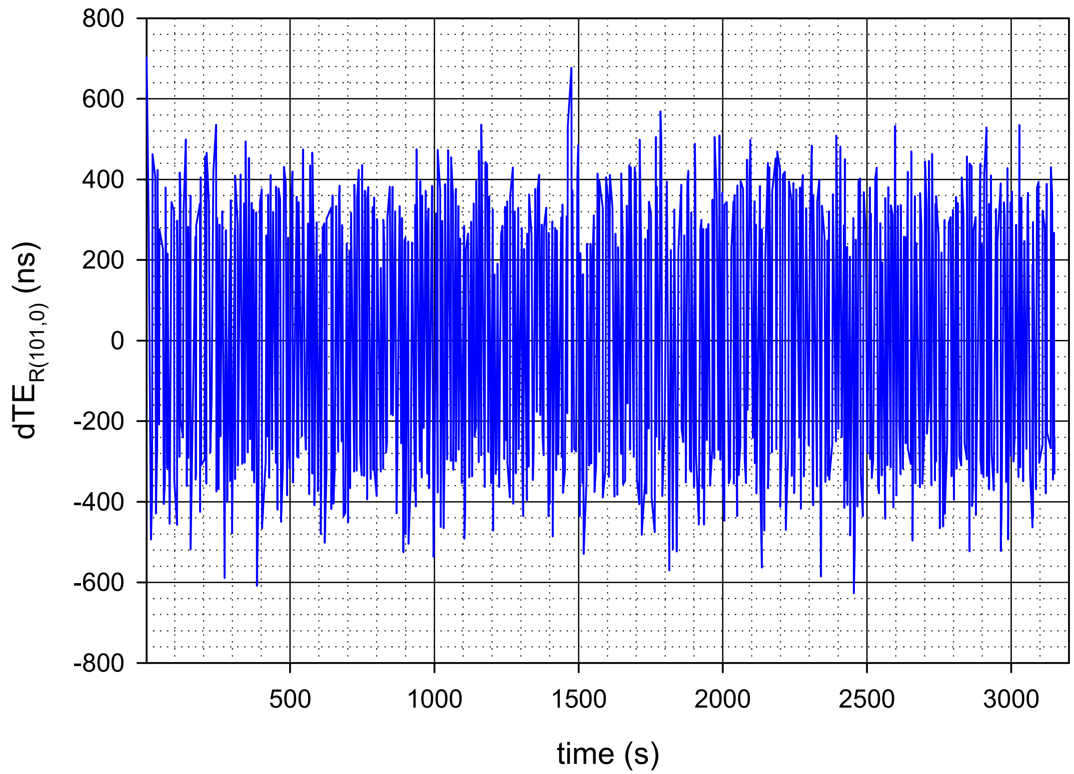
# Case16, Node 68 Detailed Results – 3

Simulation Case 16, Node 68
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



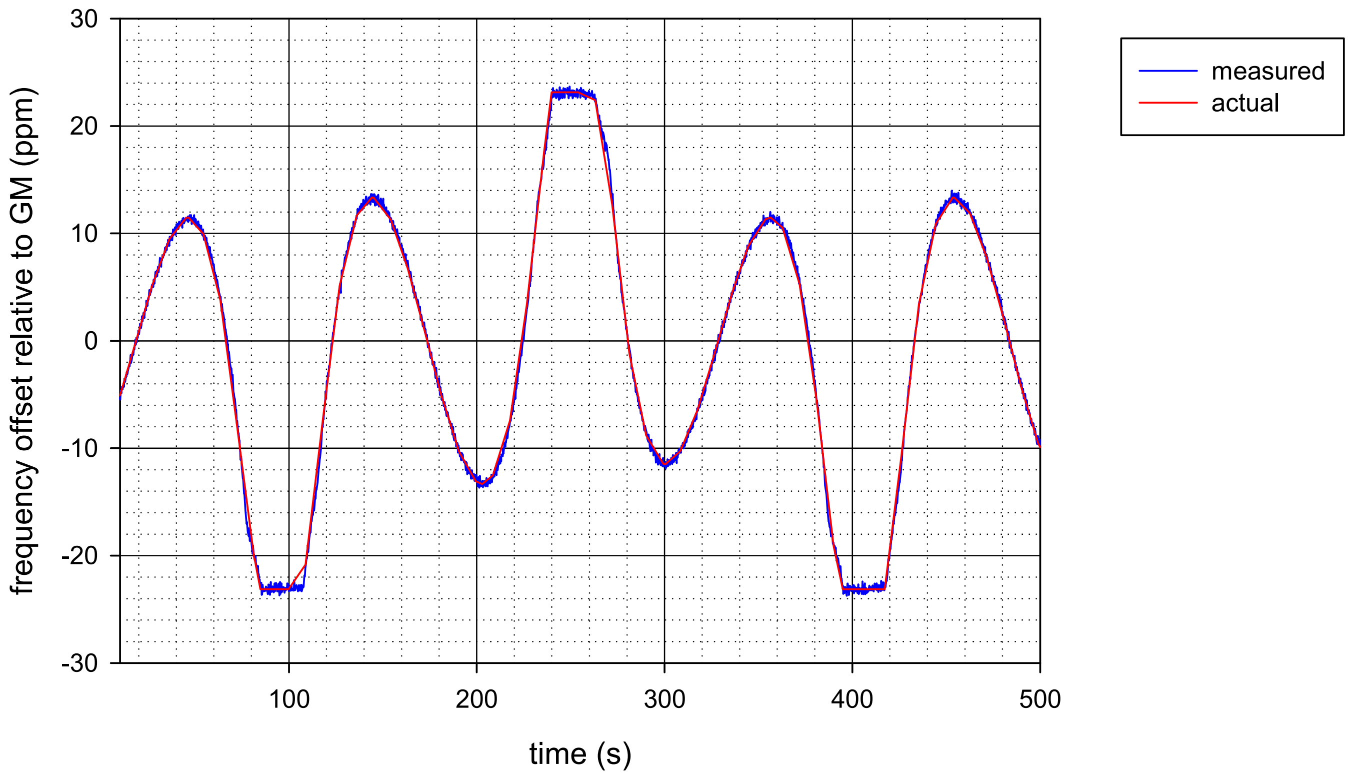
# Case16, Node 101 Detailed Results - 1

Simulation Case 16, Node 101
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



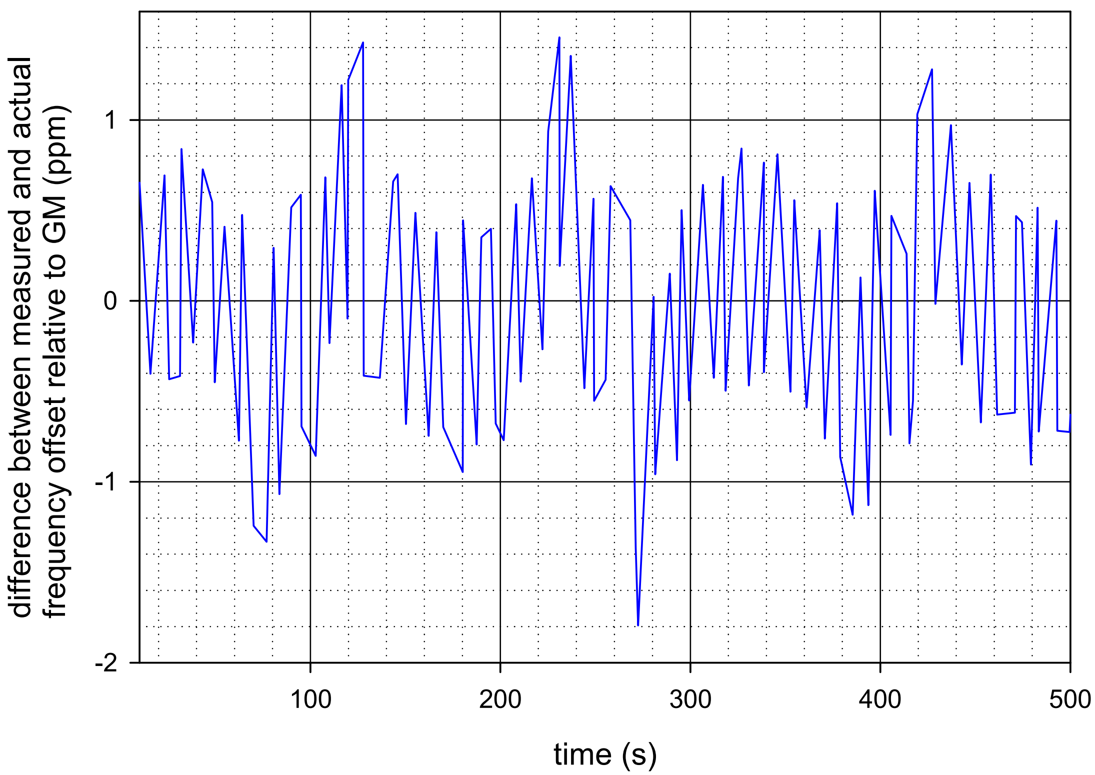
# Case16, Node 101 Detailed Results - 2

Simulation Case 16, Node 101
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



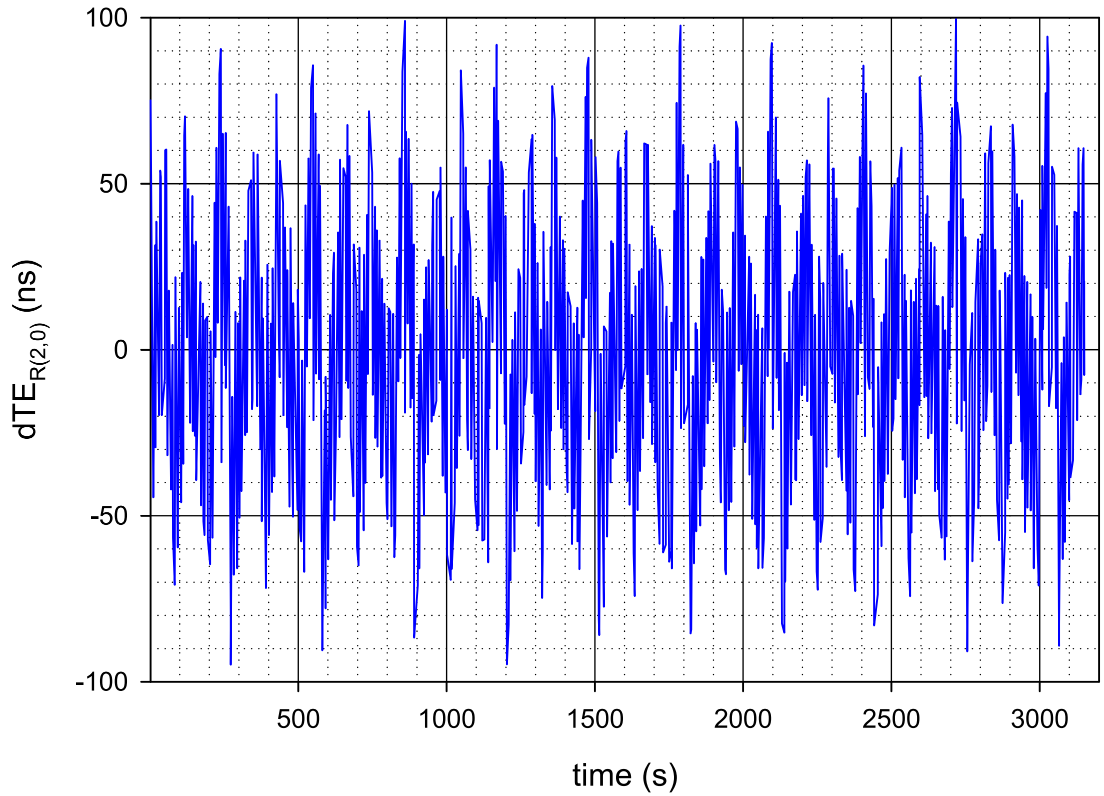
# Case16, Node 101 Detailed Results - 3

Simulation Case 16, Node 101
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



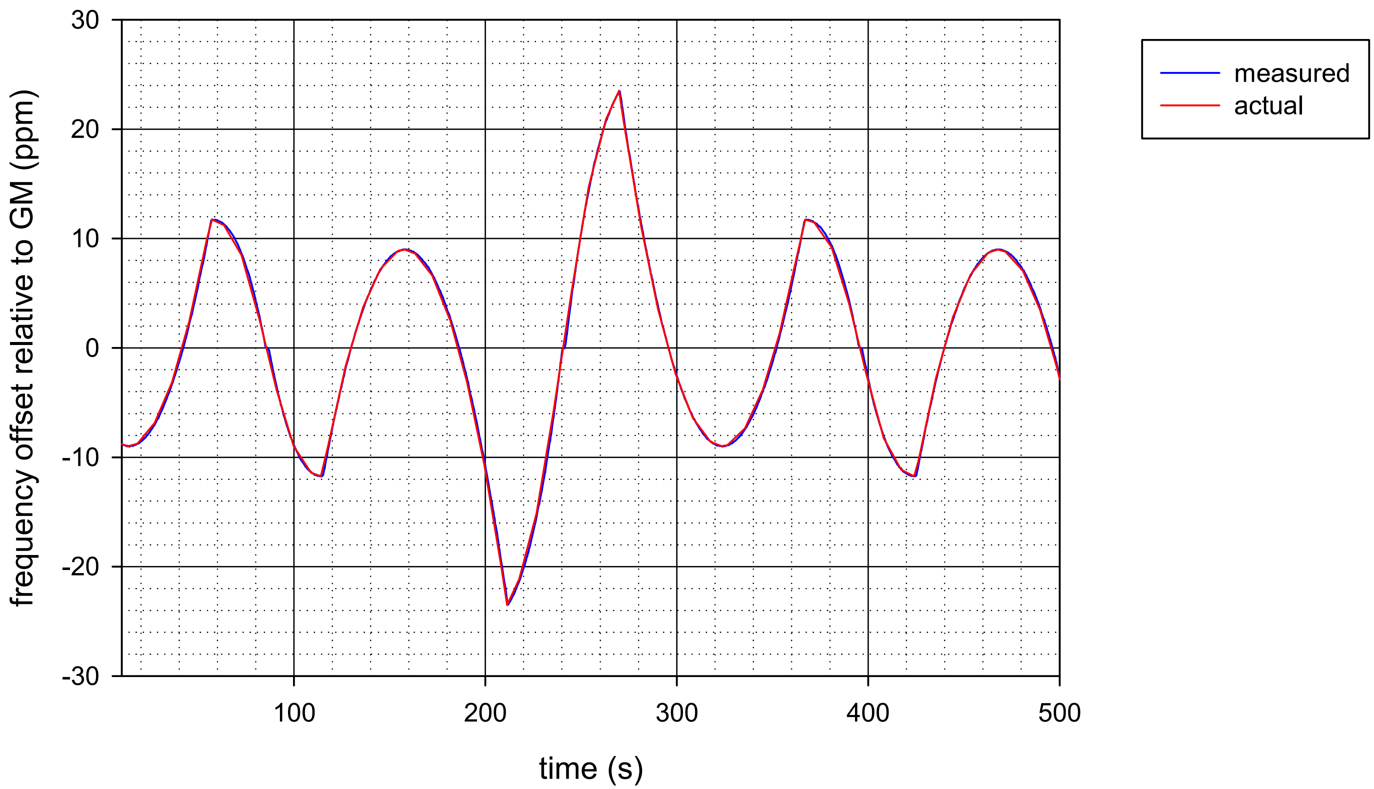
# Case 18, Node 2 Detailed Results - 1

Simulation Case 18, Node 2
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



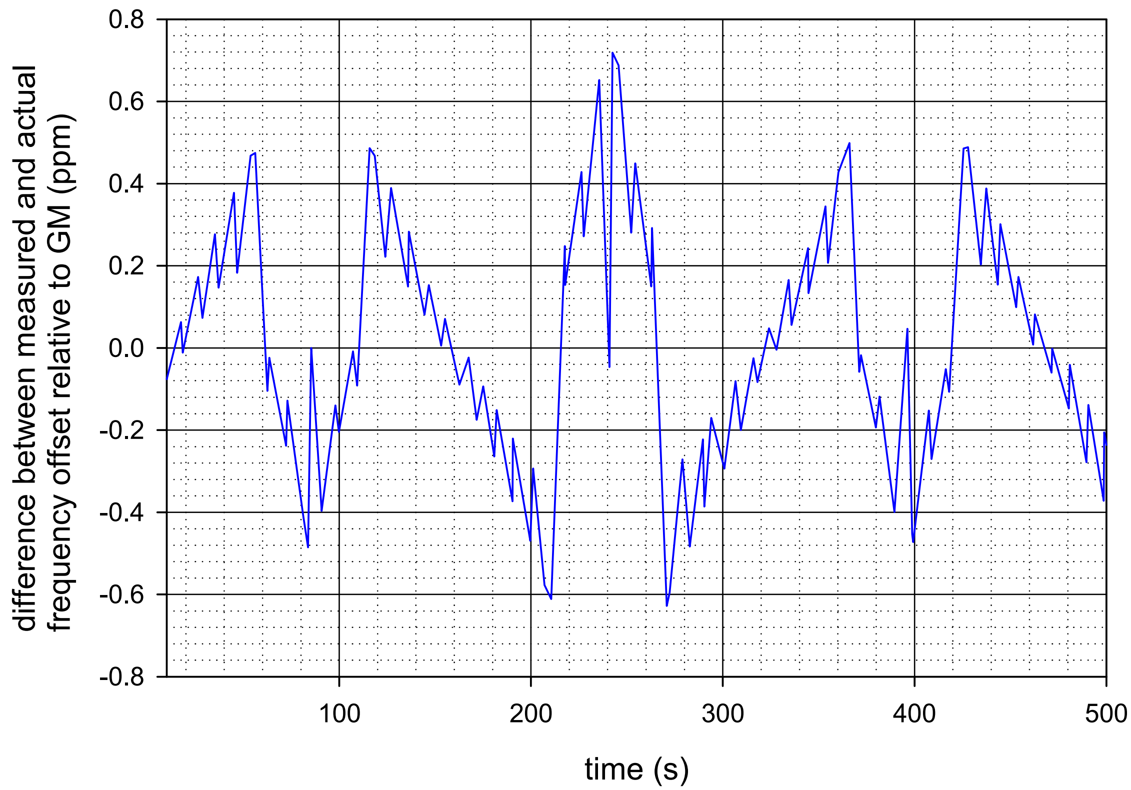
# Case 18, Node 2 Detailed Results - 2

Simulation Case 18, Node 2
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



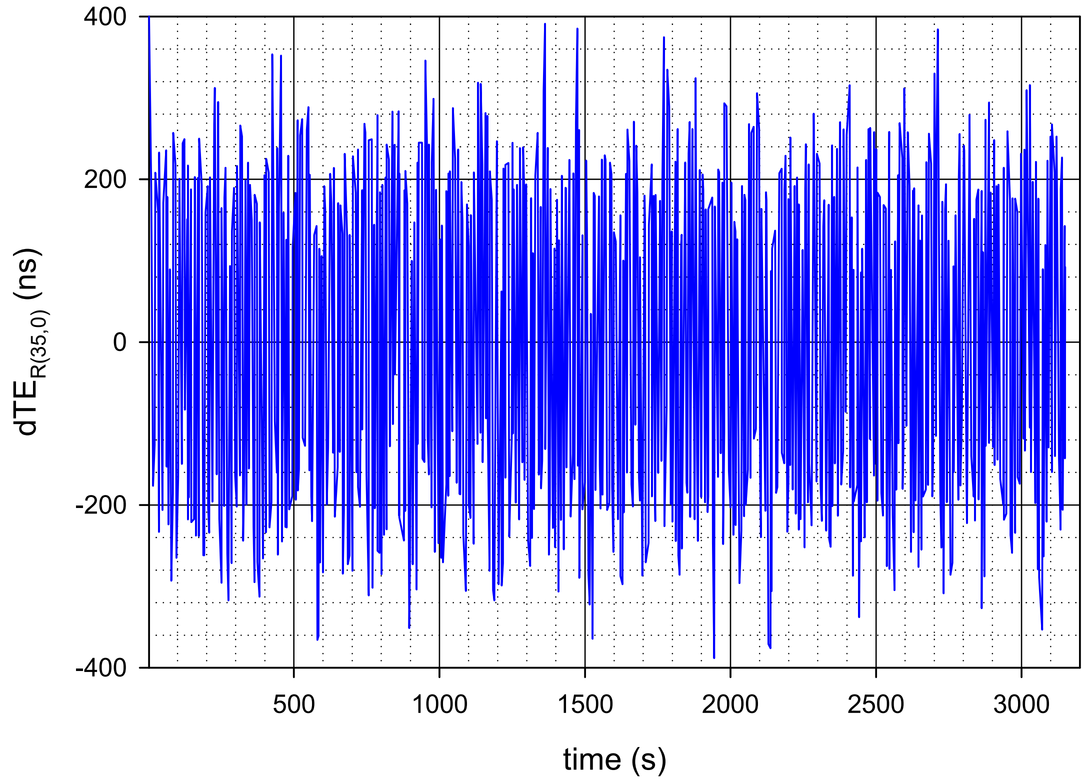
# Case 18, Node 2 Detailed Results - 3

Simulation Case 18, Node 2
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



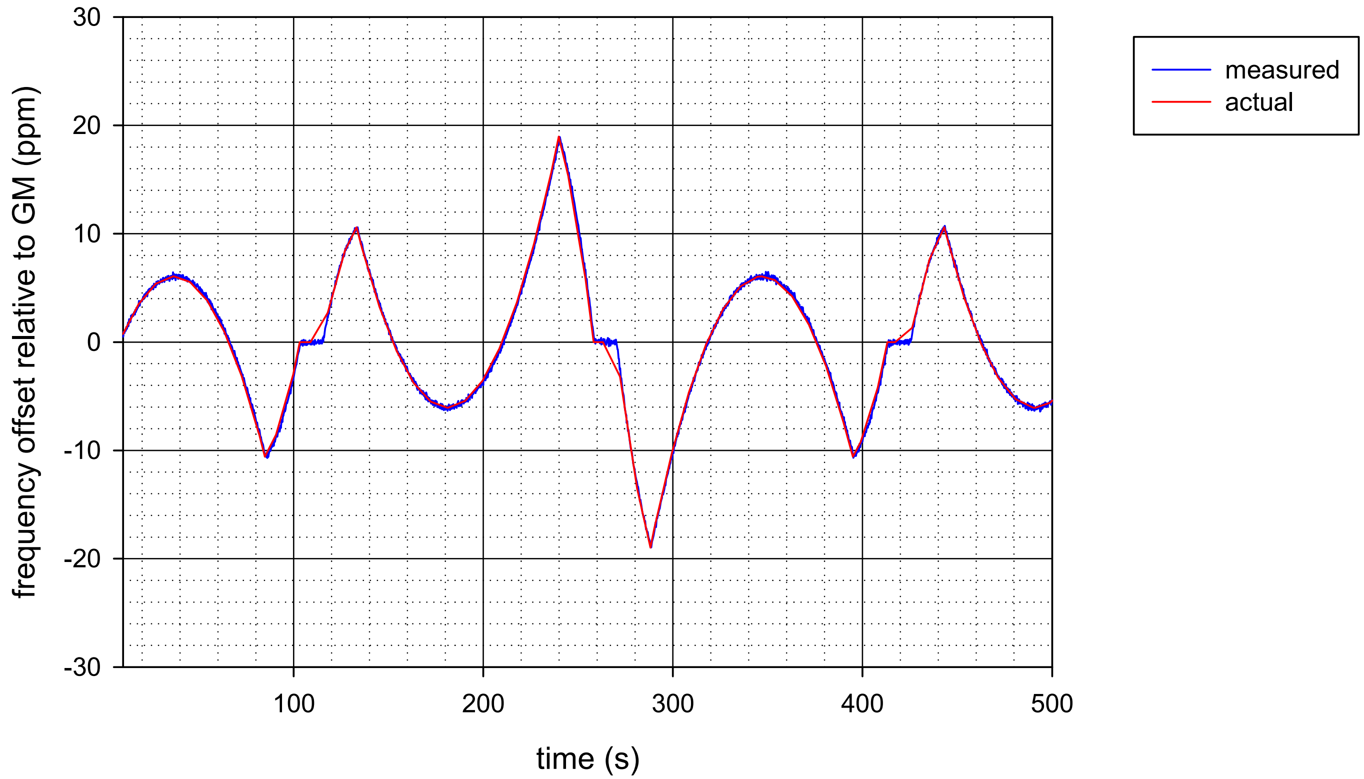
# Case 18, Node 35 Detailed Results - 1

Simulation Case 18, Node 35
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



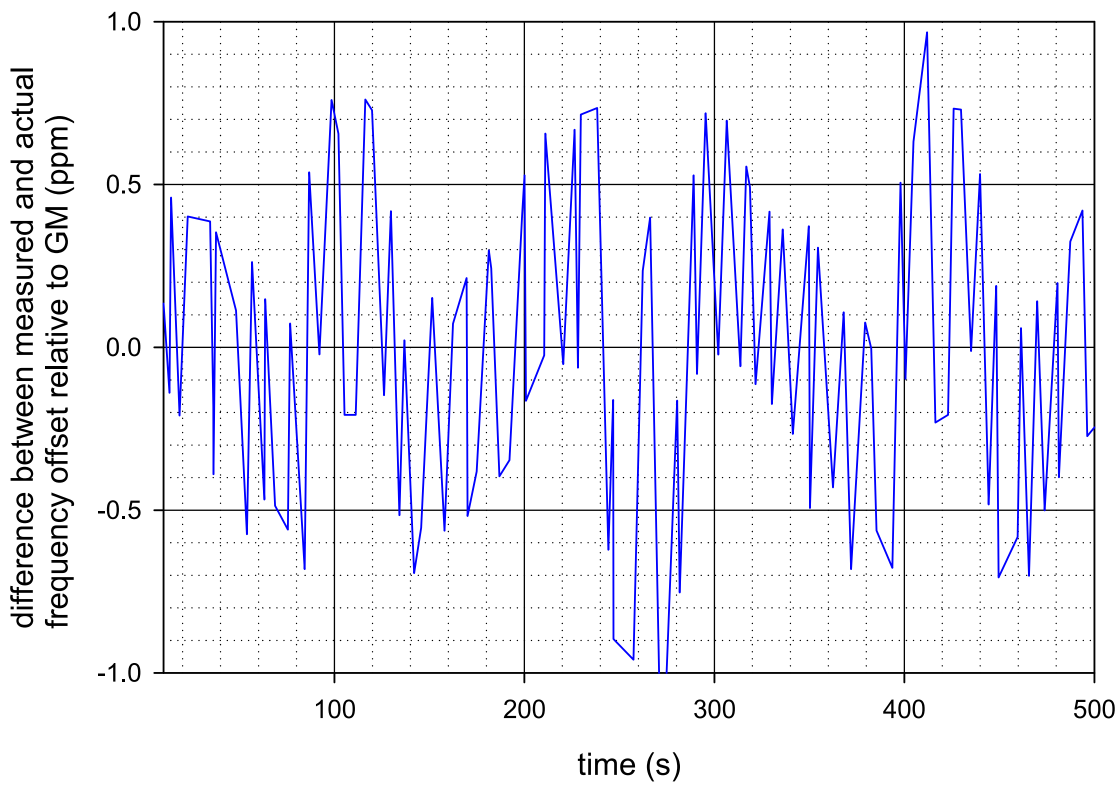
# Case 18, Node 35 Detailed Results - 2

Simulation Case 18, Node 35
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



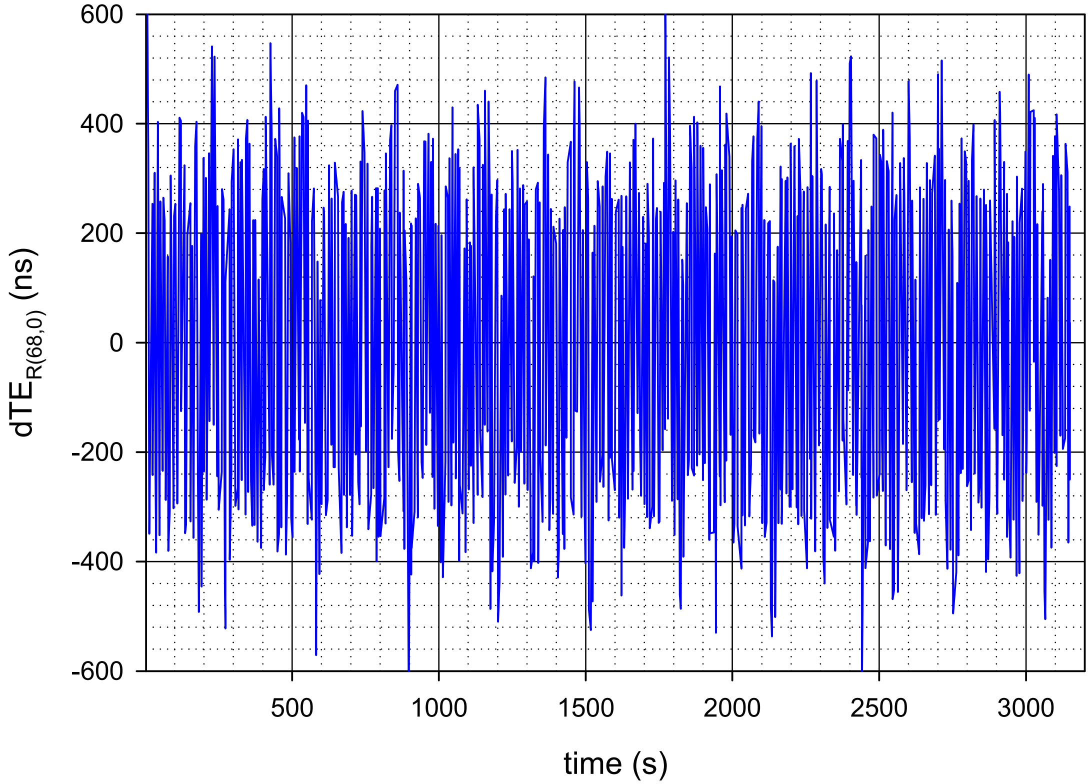
# Case 18, Node 35 Detailed Results - 3

Simulation Case 18, Node 35
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



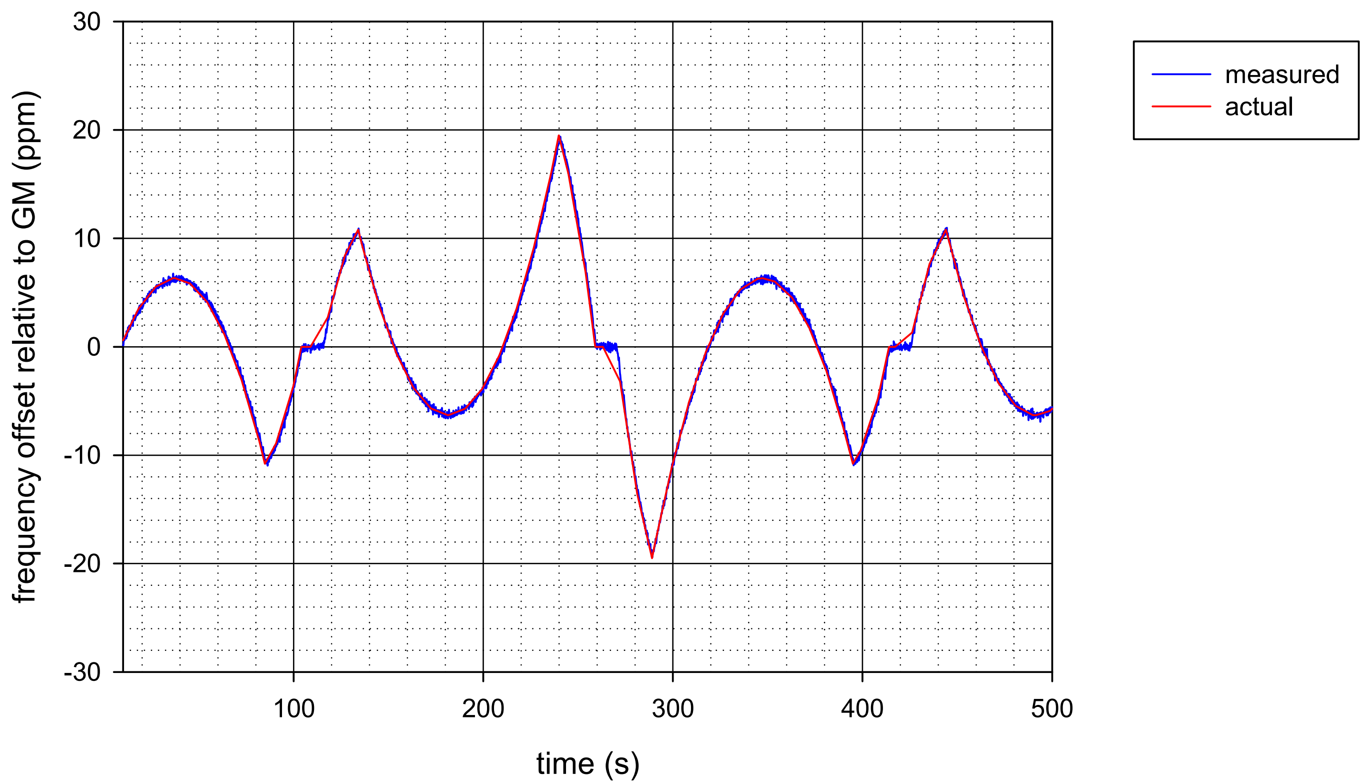
# Case 18, Node 68 Detailed Results - 1

Simulation Case 18, Node 68
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



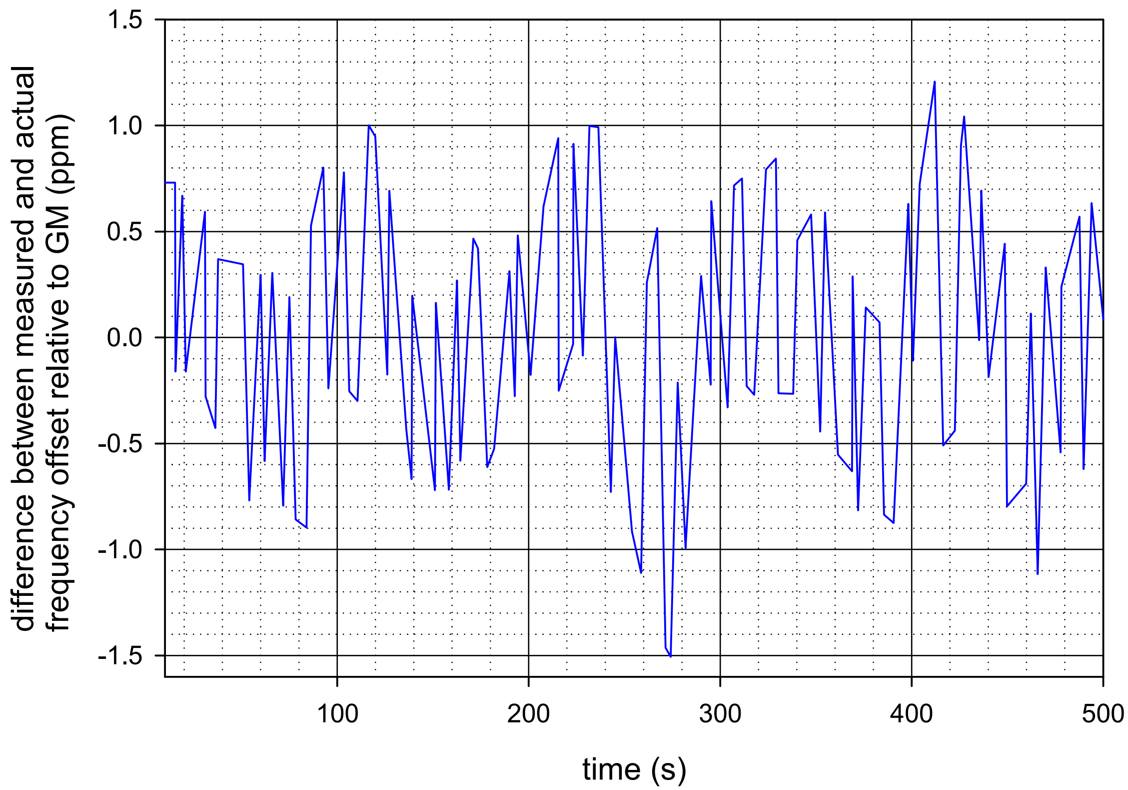
# Case 18, Node 68 Detailed Results - 2

Simulation Case 18, Node 68
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



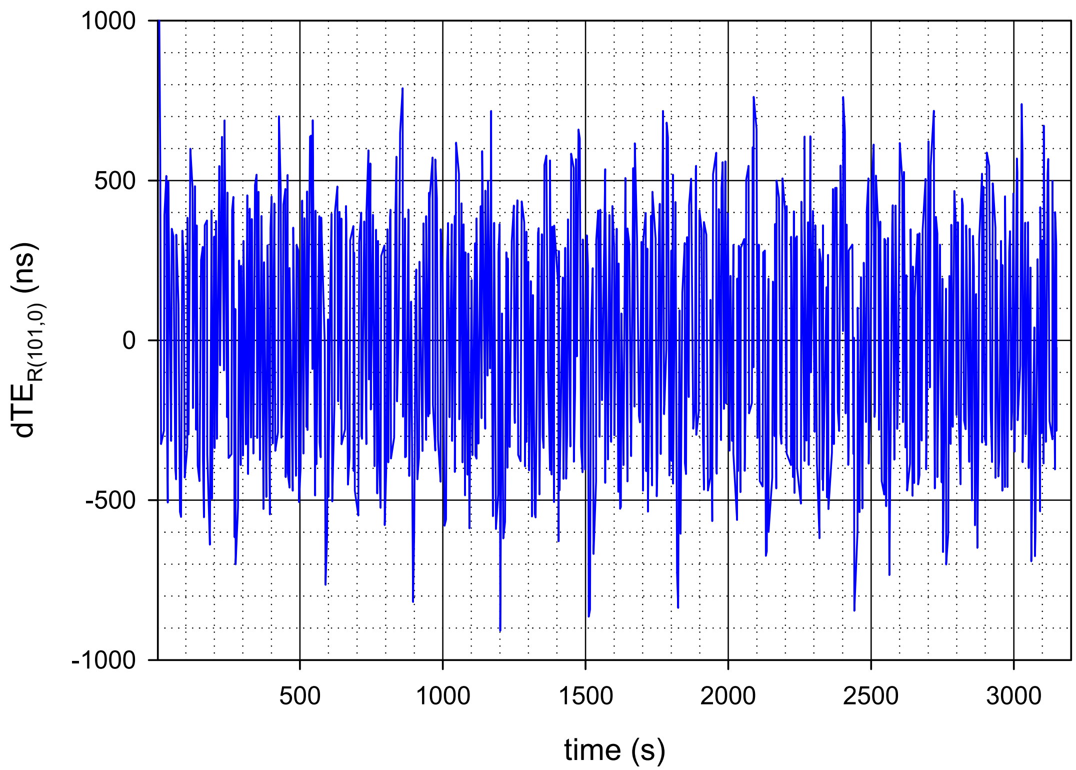
# Case 18, Node 68 Detailed Results - 3

Simulation Case 18, Node 68
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



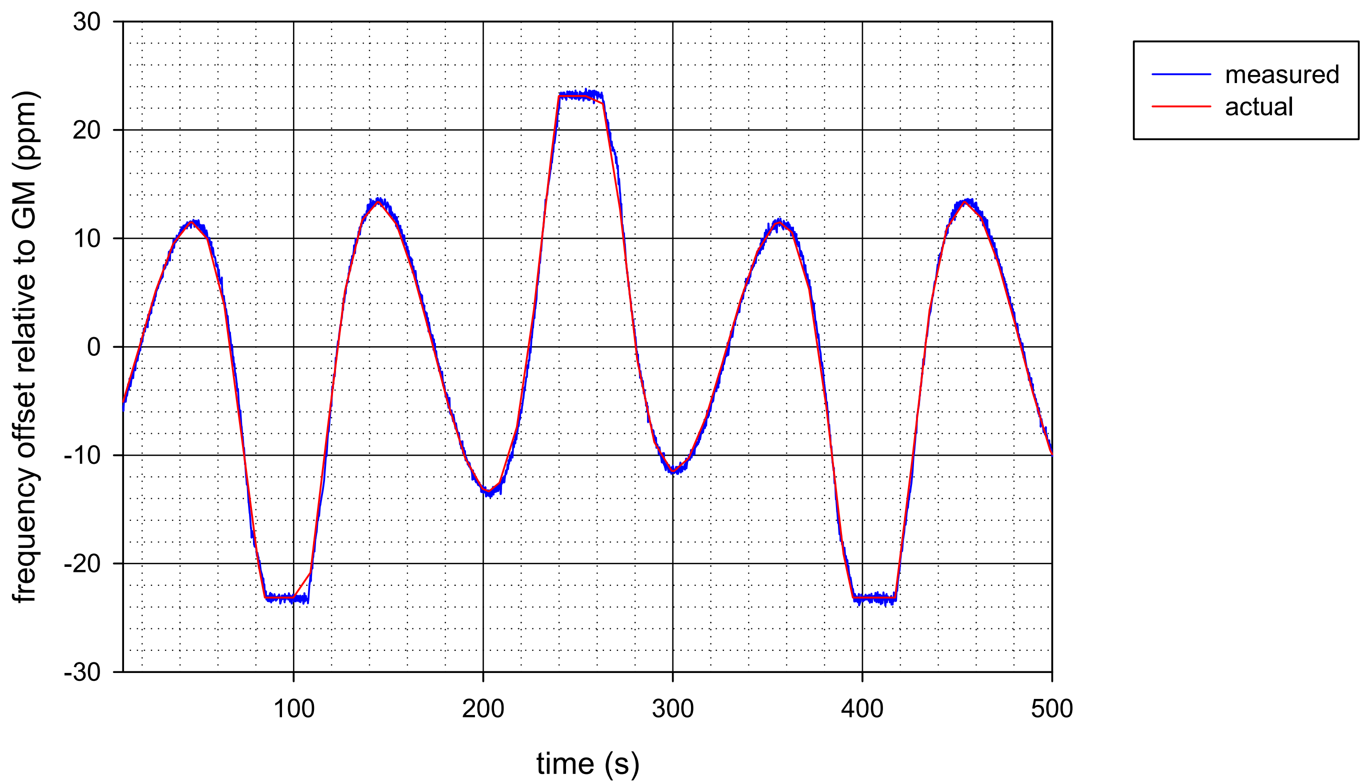
# Case 18, Node 101 Detailed Results - 1

Simulation Case 18, Node 101
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



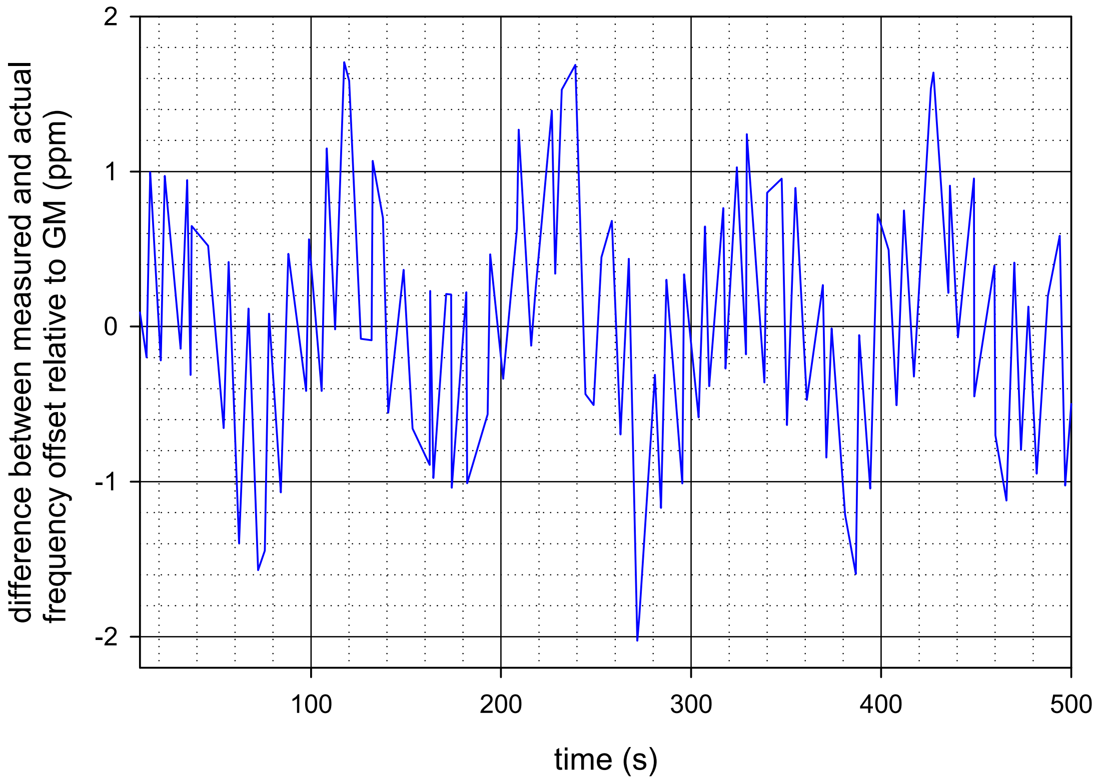
# Case 18, Node 101 Detailed Results - 2

Simulation Case 18, Node 101
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



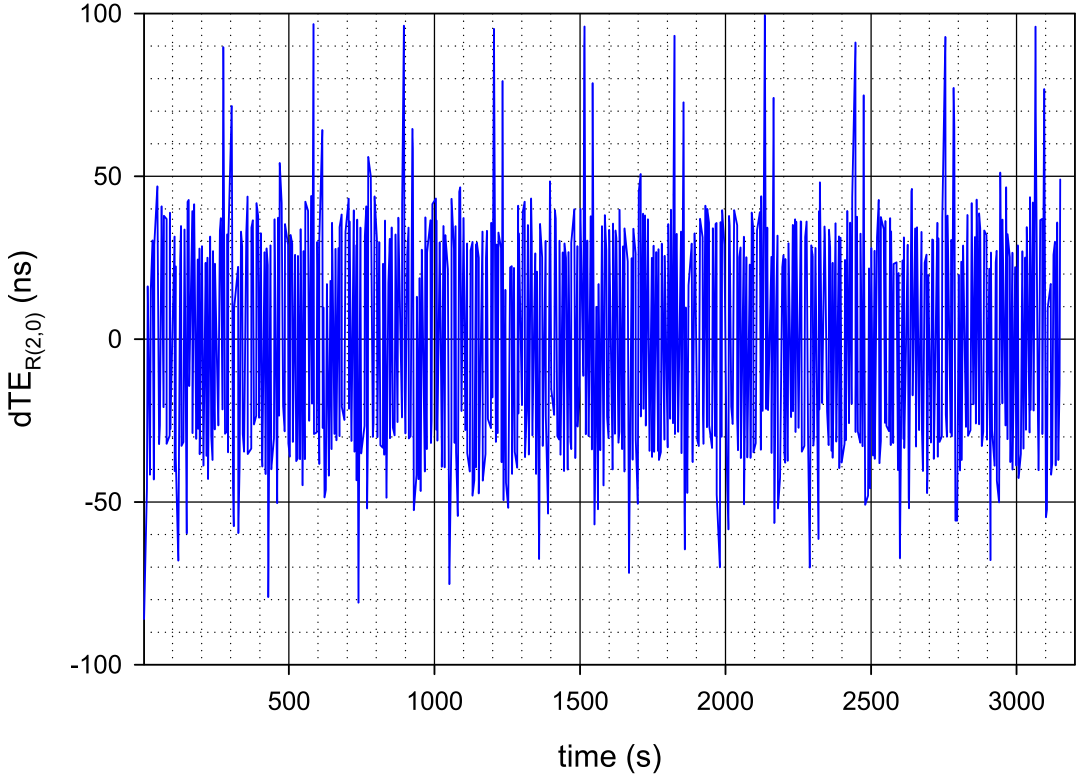
# Case 18, Node 101 Detailed Results - 3

Simulation Case 18, Node 101
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 100% of cycle
Residence time: 4 ms
Timestamp granularity: 8 ns



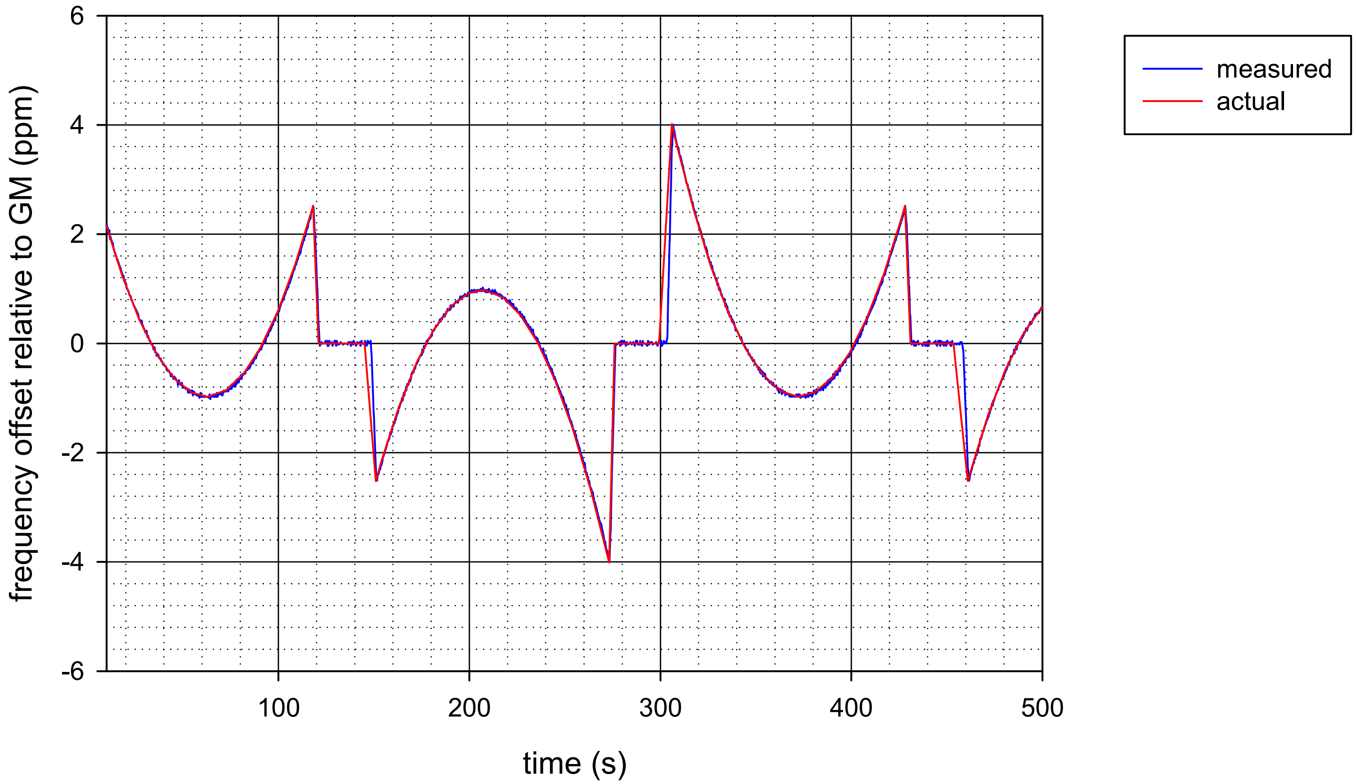
# Case22, Node 2 Detailed Results - 1

Simulation Case 22, Node 2
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



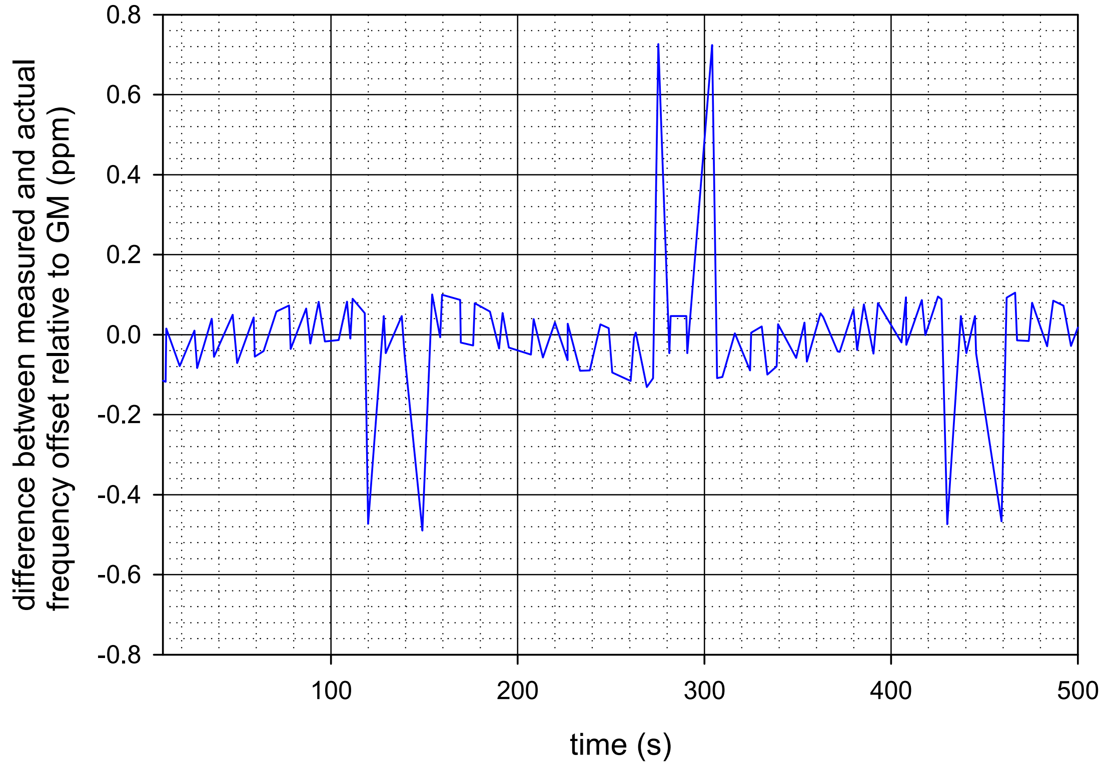
# Case22, Node 2 Detailed Results - 2

Simulation Case 22, Node 2
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



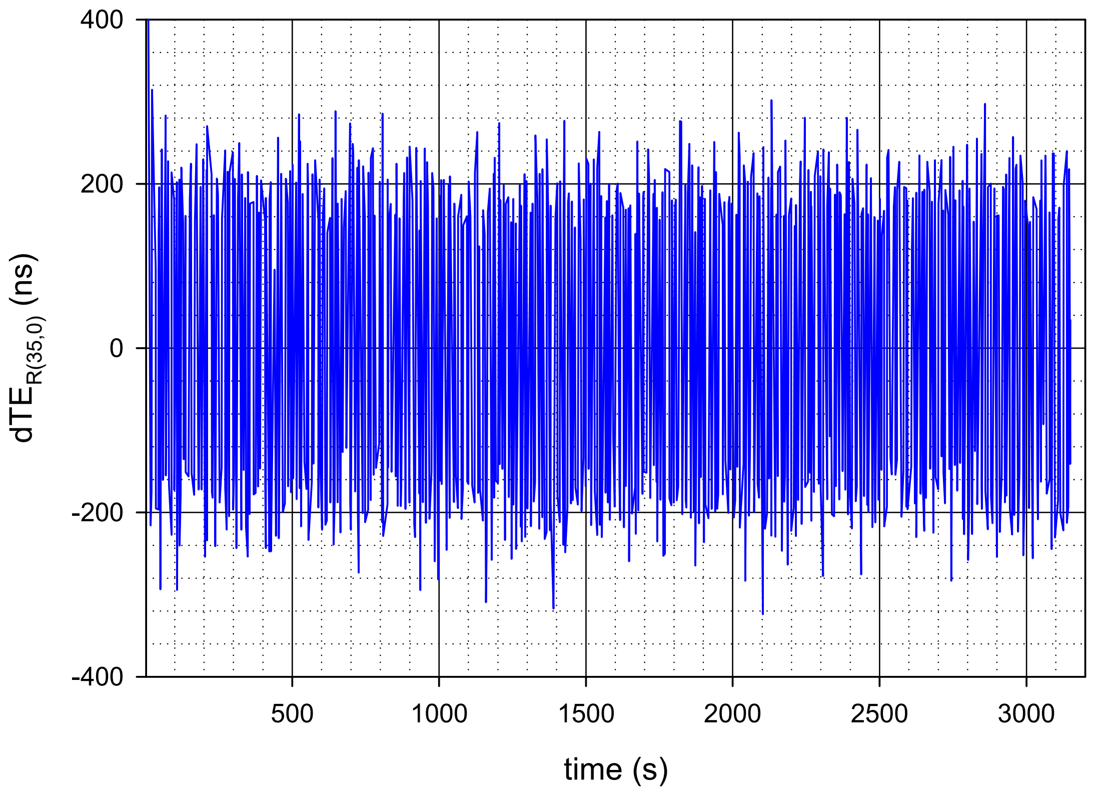
# Case22, Node 2 Detailed Results - 3

Simulation Case 22, Node 2
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



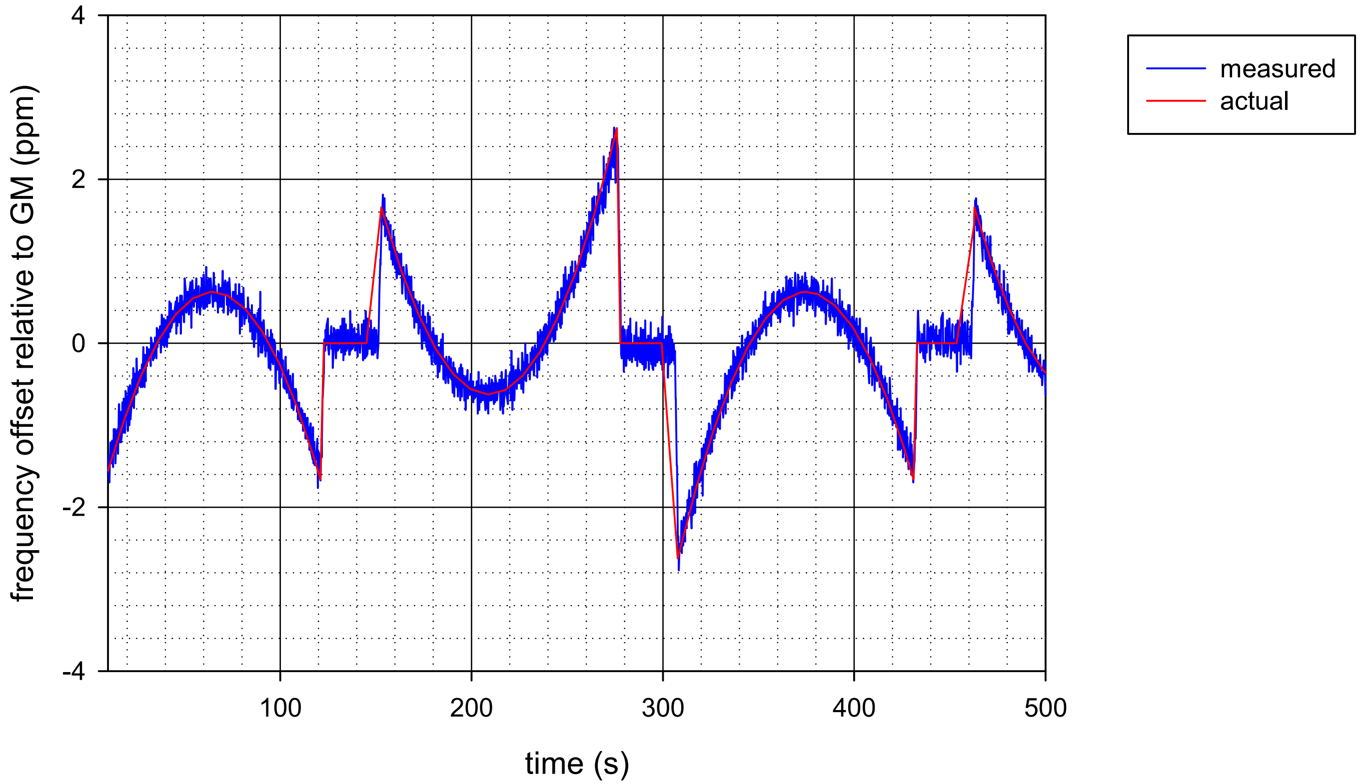
# Case22, Node 35 Detailed Results – 1

Simulation Case 22, Node 35
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



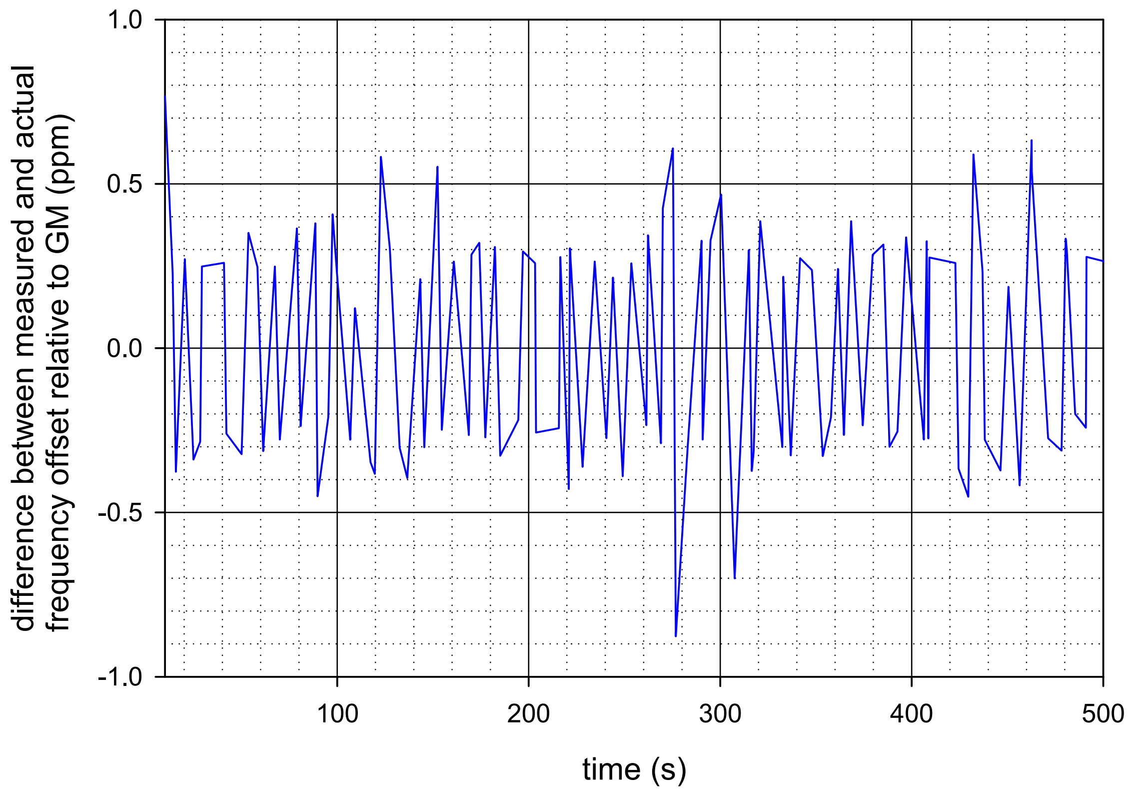
# Case22, Node 35 Detailed Results - 2

Simulation Case 22, Node 35
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



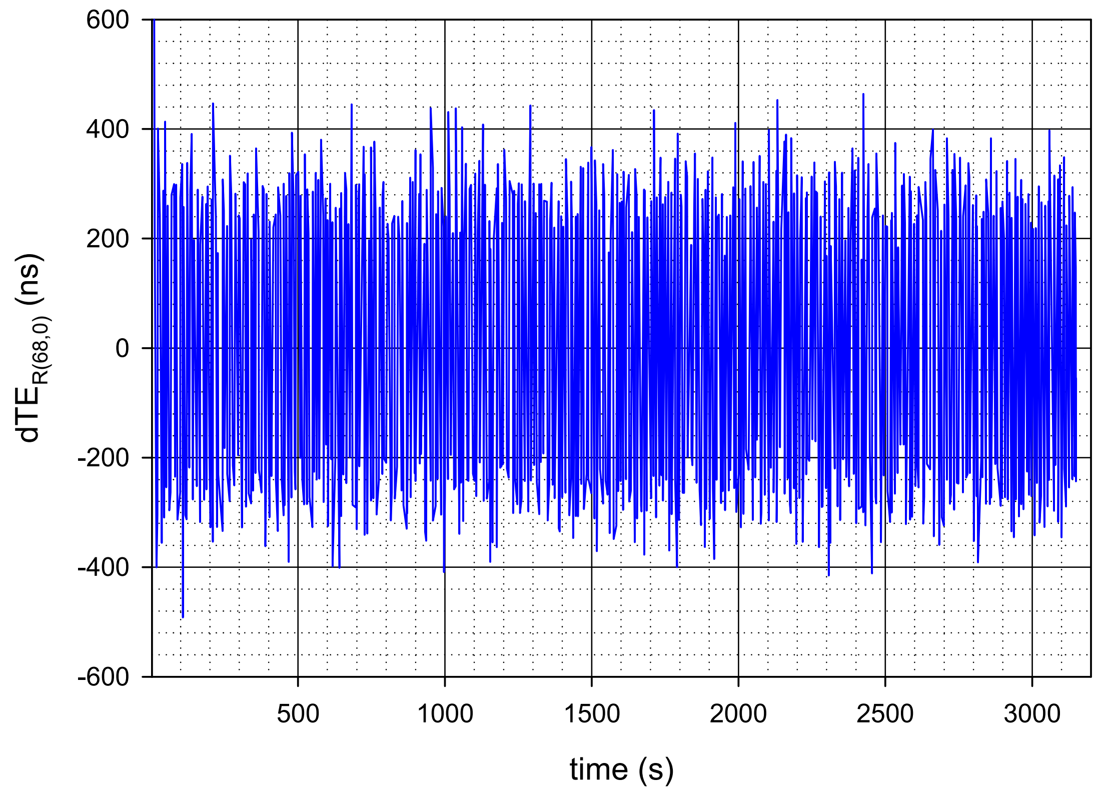
# Case22, Node 35 Detailed Results - 3

Simulation Case 22, Node 35
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



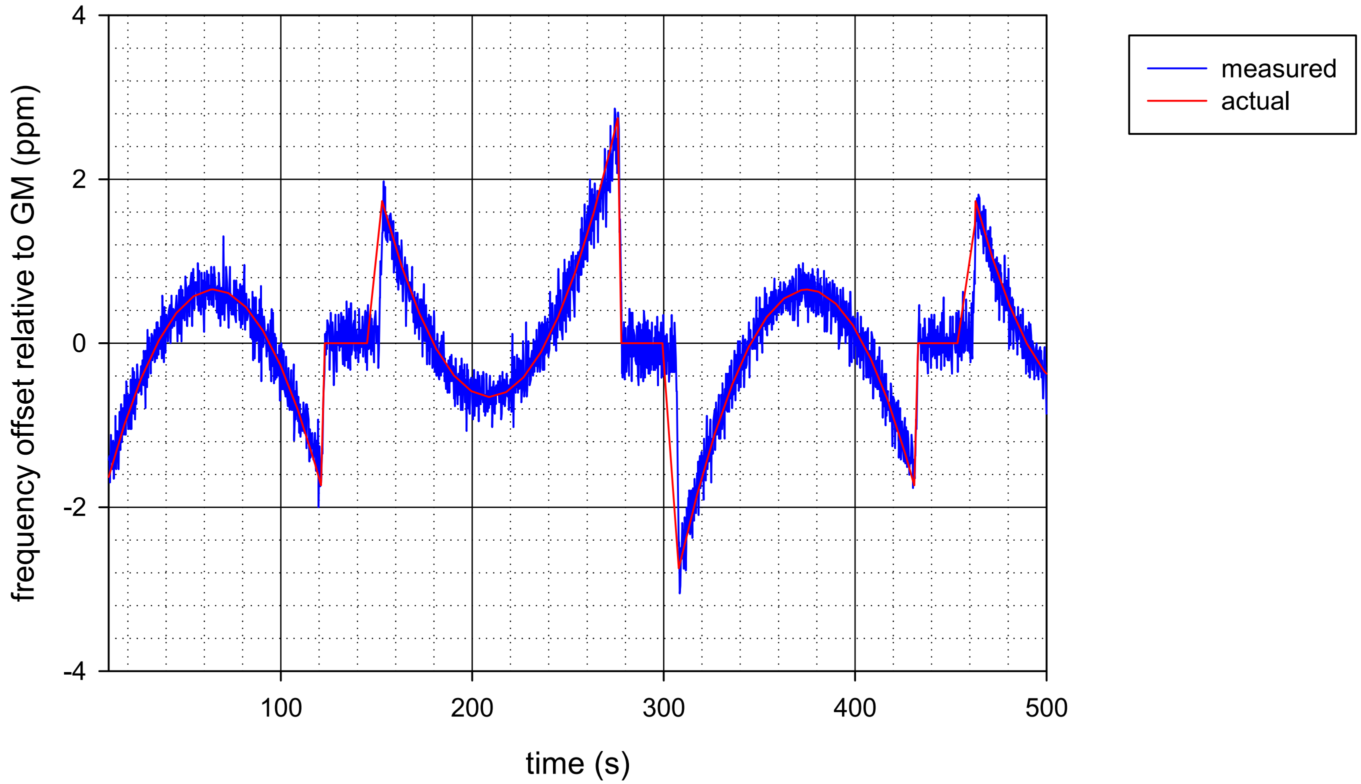
# Case22, Node 68 Detailed Results – 1

Simulation Case 22, Node 68
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



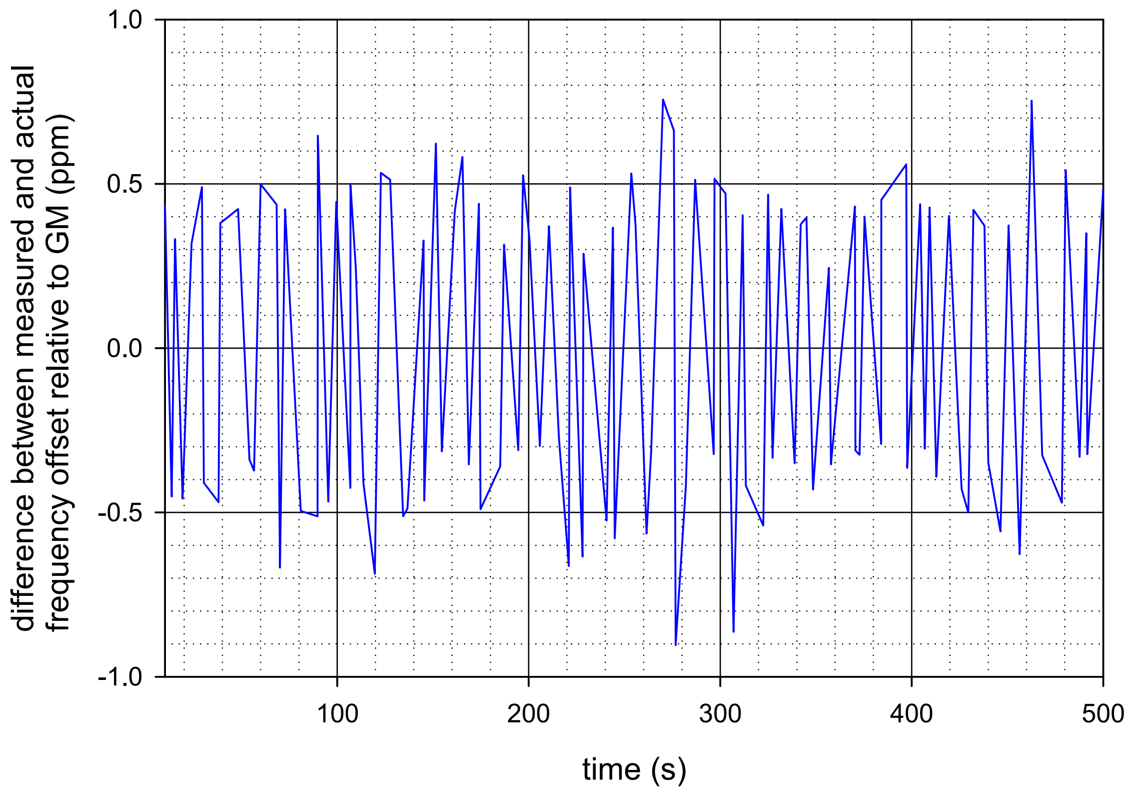
# Case22, Node 68 Detailed Results - 2

Simulation Case 22, Node 68
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



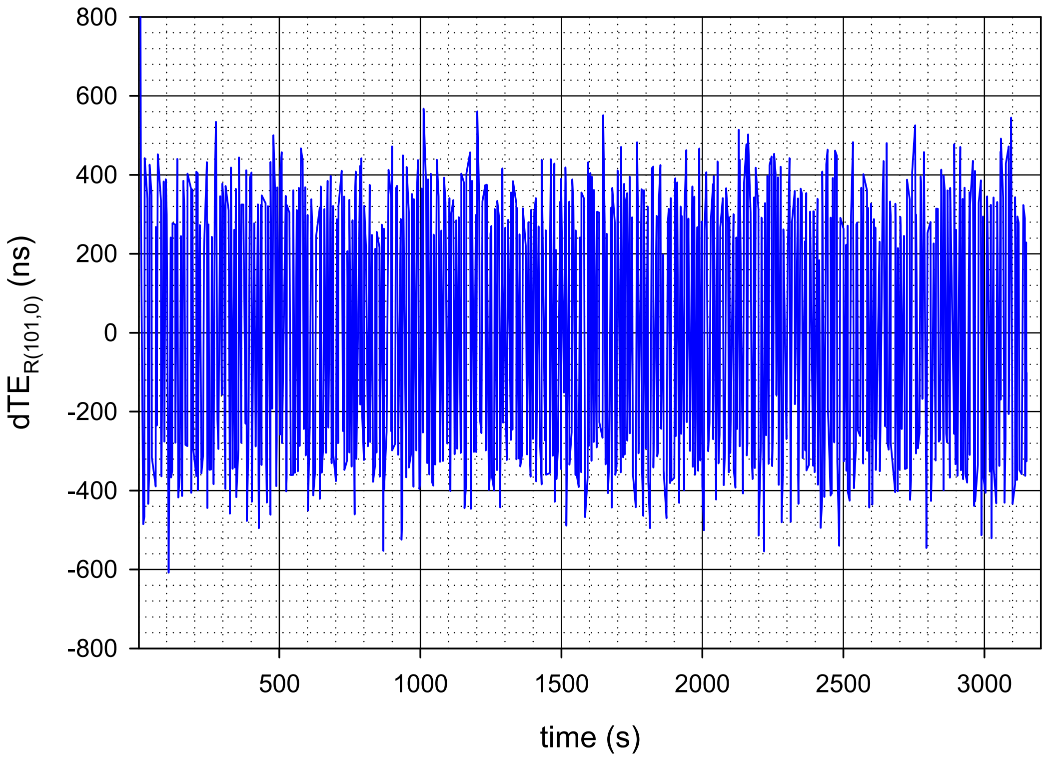
# Case22, Node 68 Detailed Results – 3

Simulation Case 22, Node 68
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



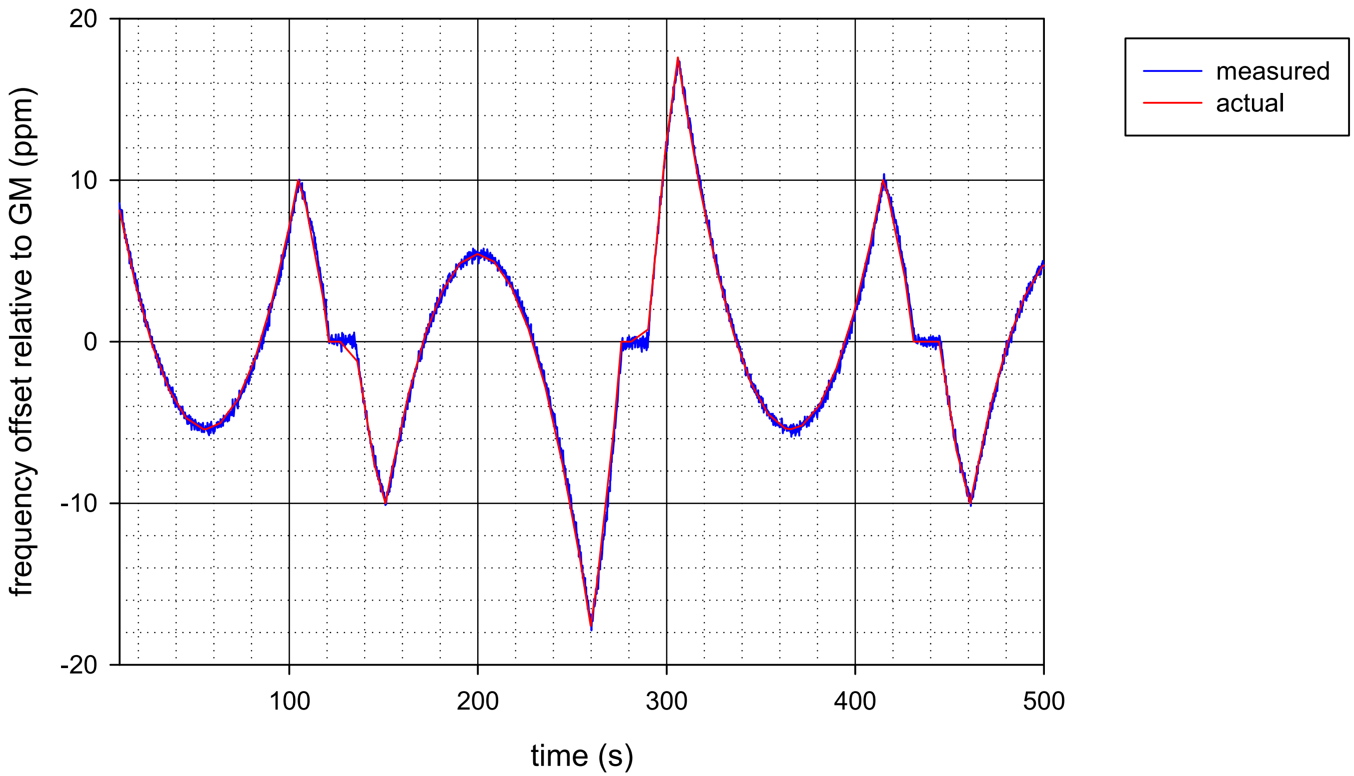
# Case22, Node 101 Detailed Results - 1

Simulation Case 22, Node 101
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



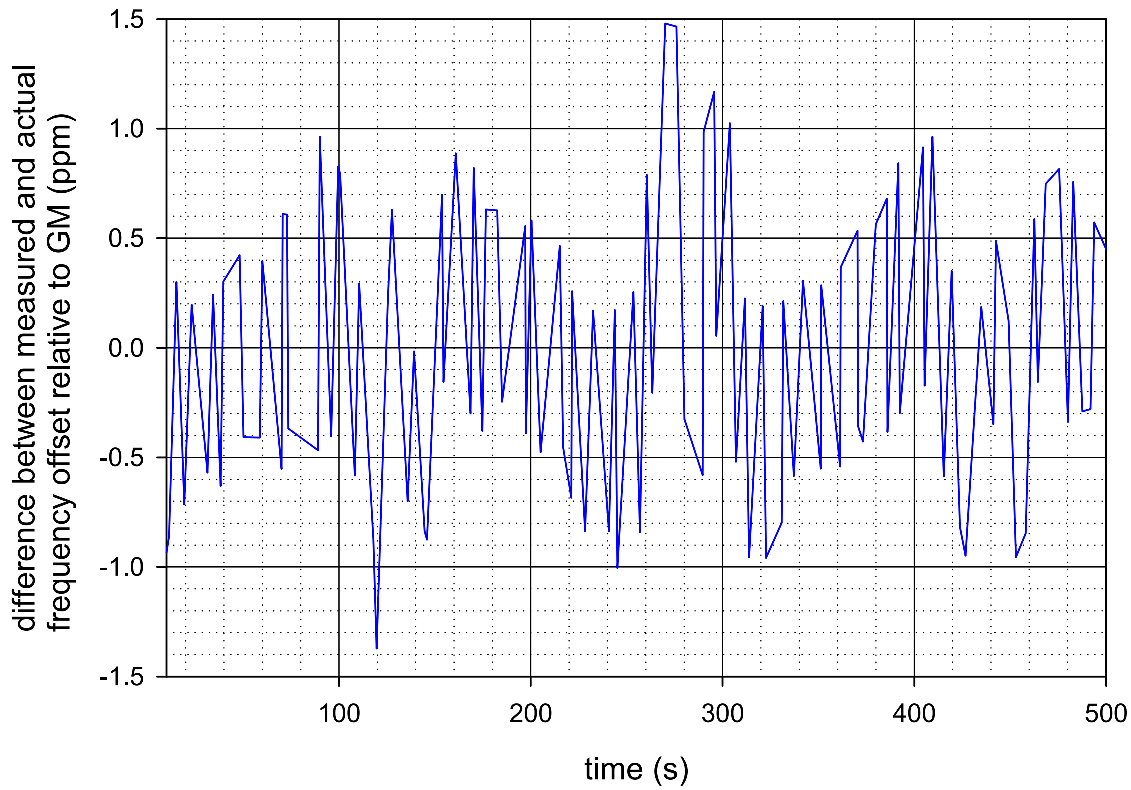
# Case22, Node 101 Detailed Results - 2

Simulation Case 22, Node 101
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



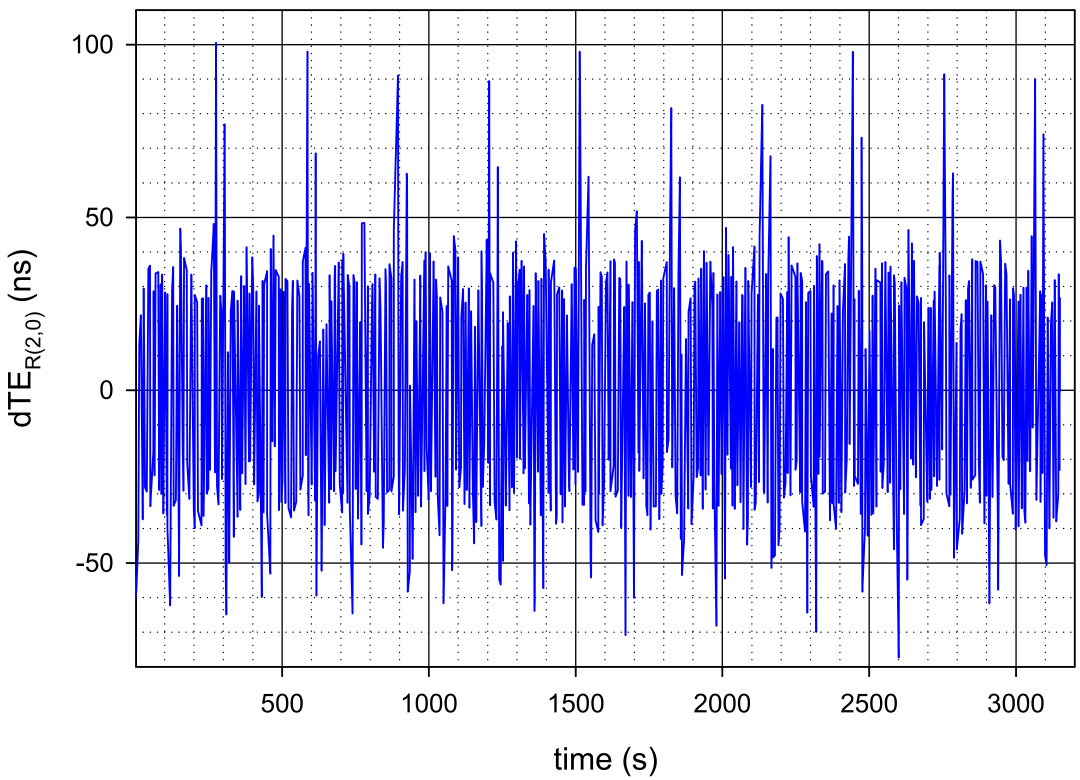
# Case22, Node 101 Detailed Results - 3

Simulation Case 22, Node 101
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 1 ms
Timestamp granularity: 8 ns



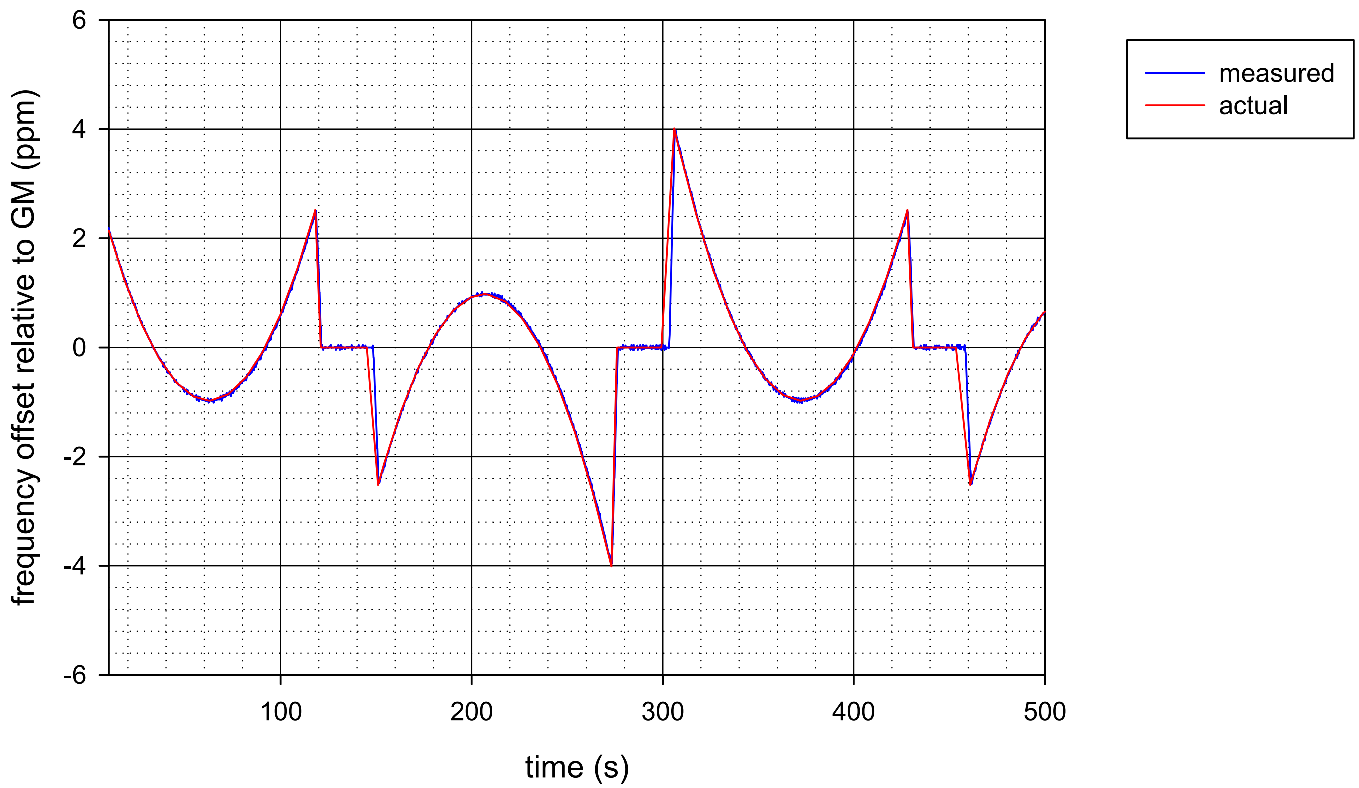
# Case27, Node 2 Detailed Results - 1

Simulation Case 27, Node 2
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



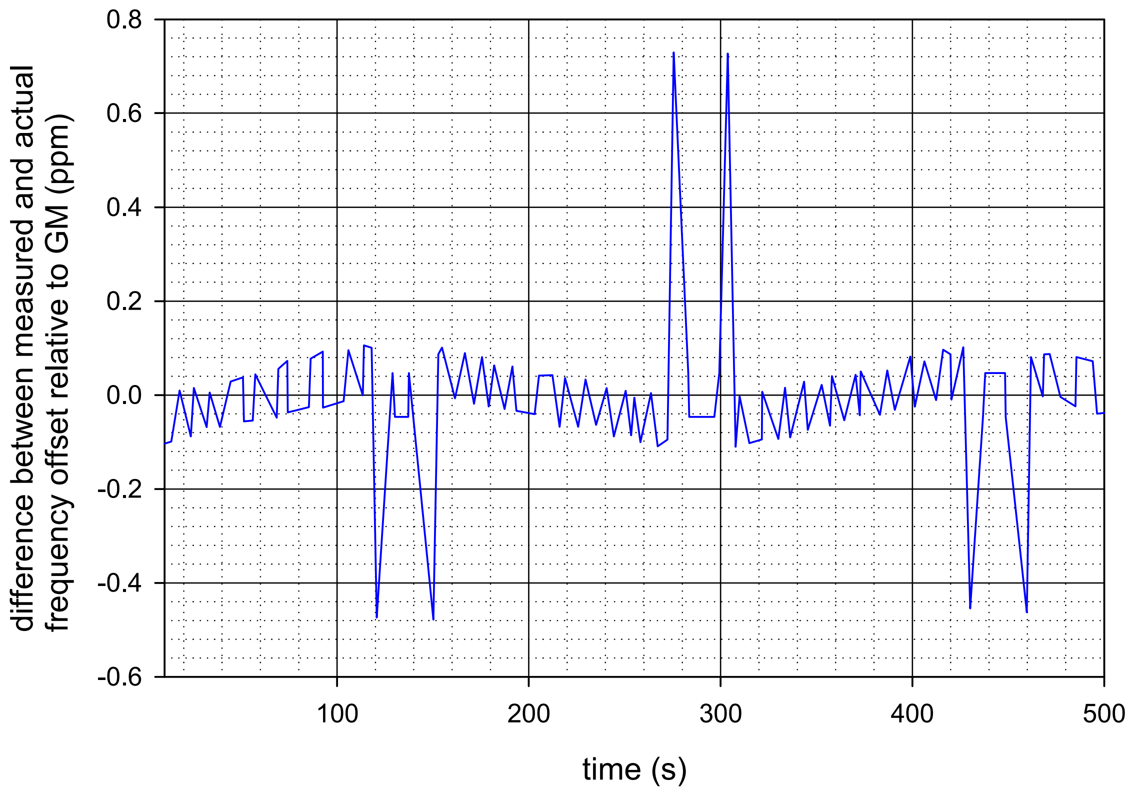
# Case27, Node 2 Detailed Results - 2

Simulation Case 27, Node 2
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



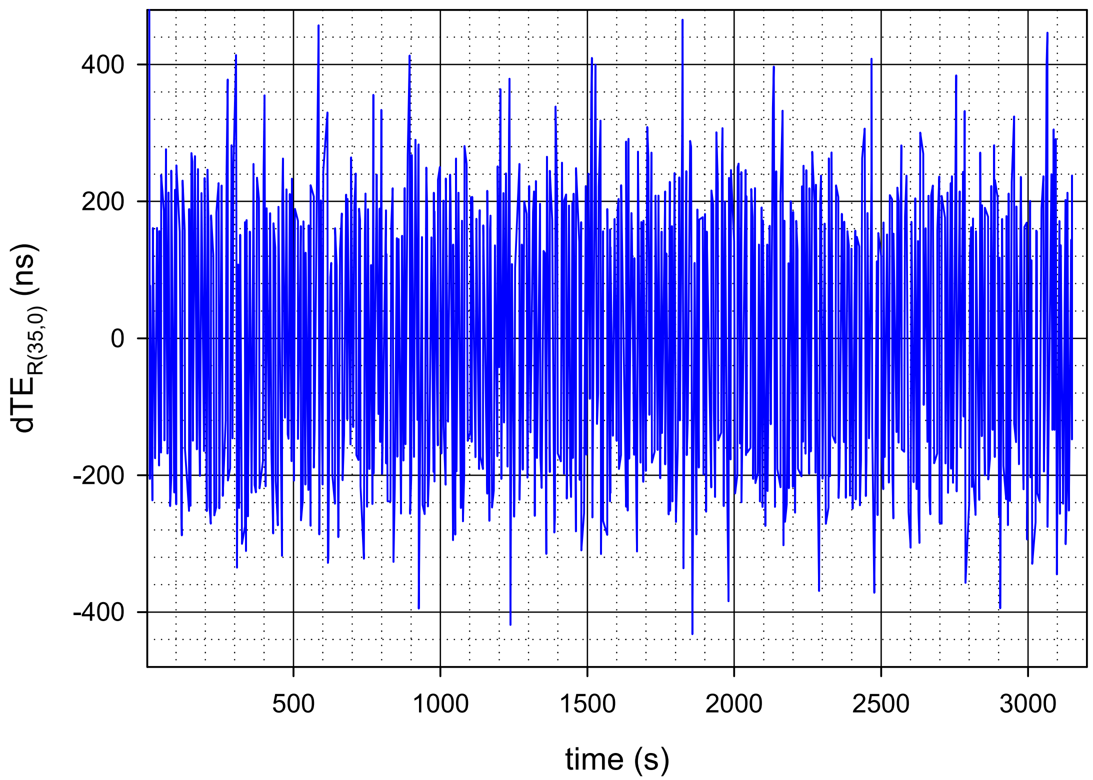
# Case27, Node 2 Detailed Results - 3

Simulation Case 27, Node 2
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



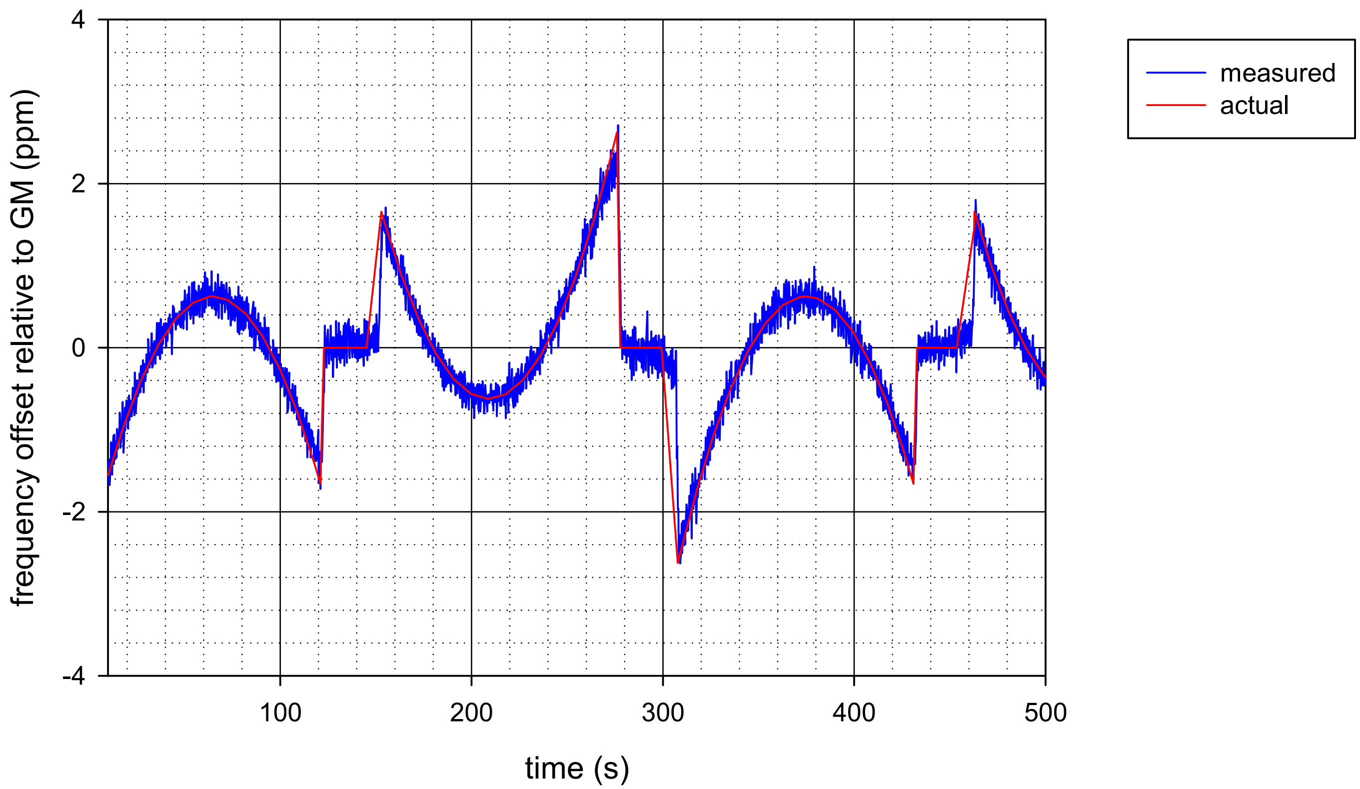
# Case27, Node 35 Detailed Results – 1

Simulation Case 27, Node 35
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



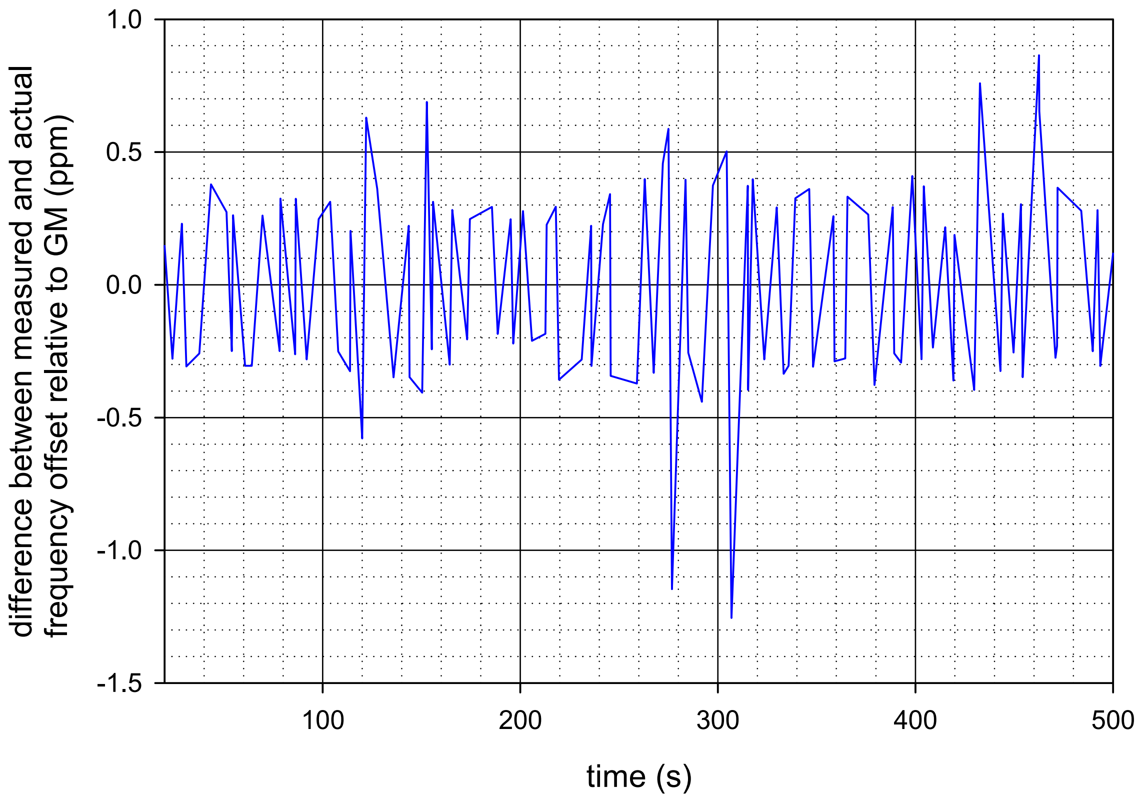
# Case27, Node 35 Detailed Results – 2

Simulation Case 27, Node 35
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4ns



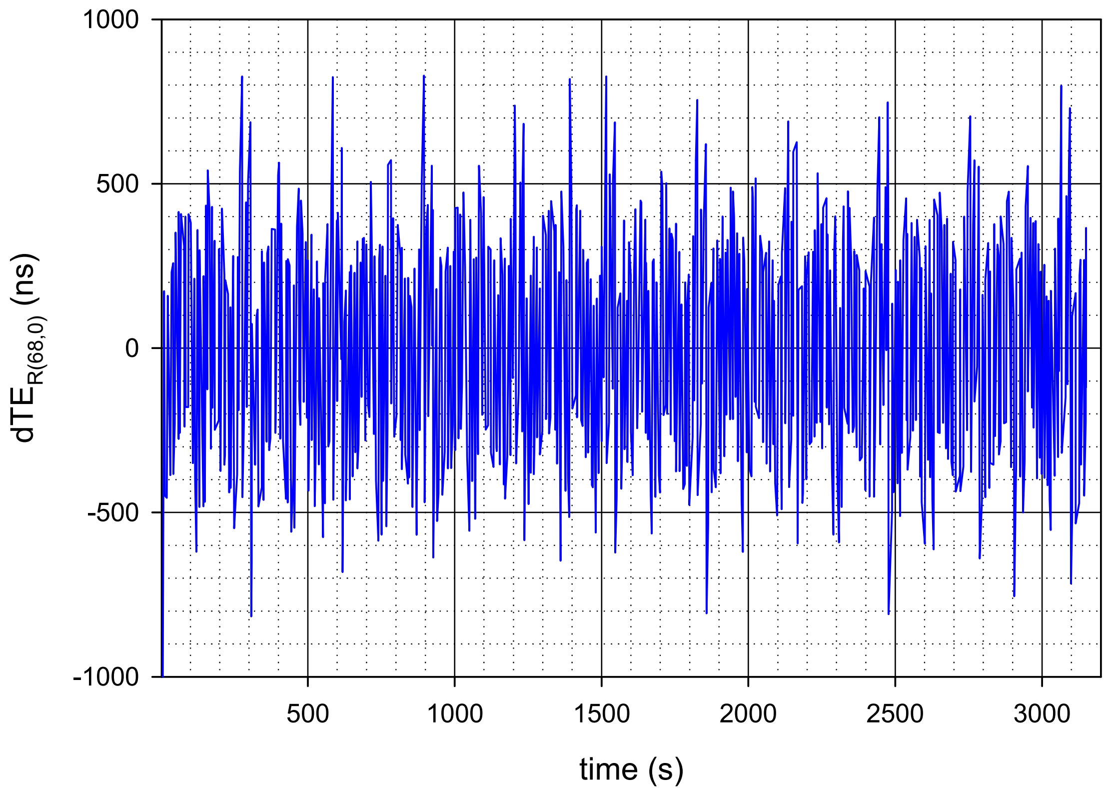
# Case27, Node 35 Detailed Results – 3

Simulation Case 27, Node 35
Replication 1: detail of 20 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



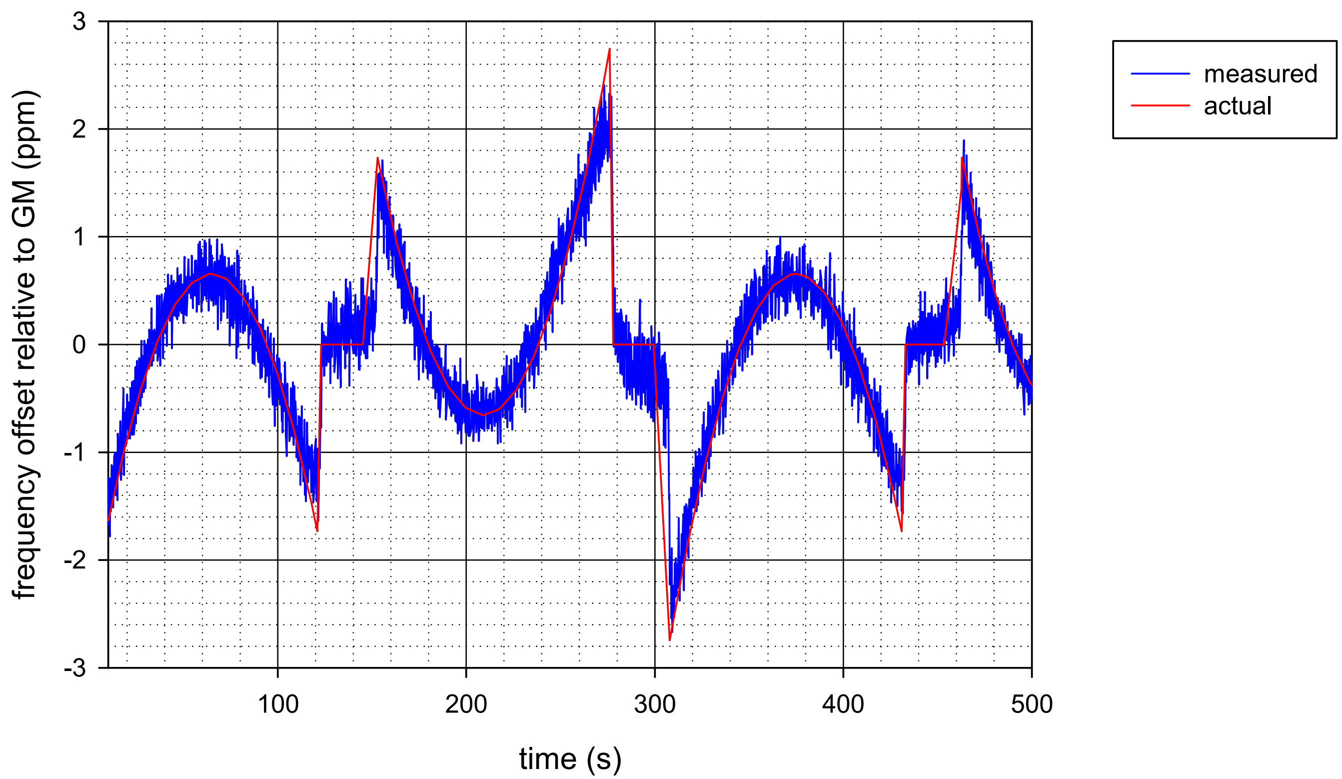
# Case27, Node 68 Detailed Results - 1

Simulation Case 27, Node 68
Replication 1: 2 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



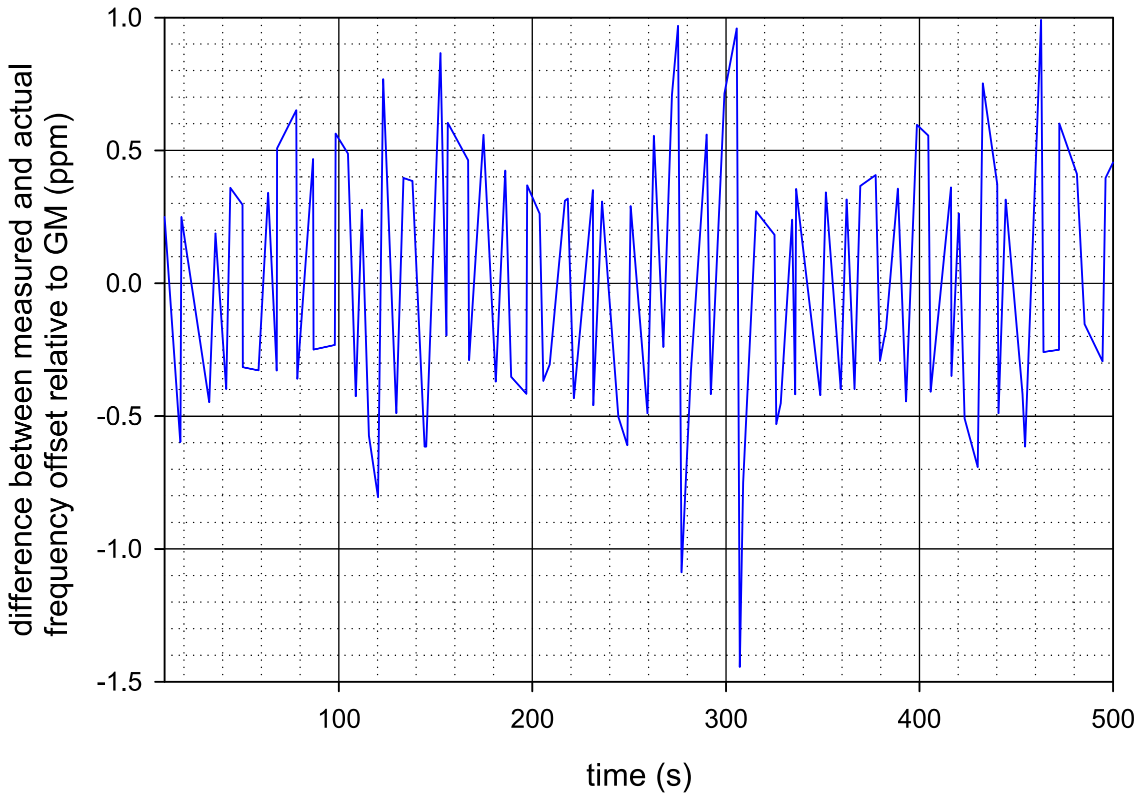
# Case27, Node 68 Detailed Results - 2

Simulation Case 27, Node 68
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



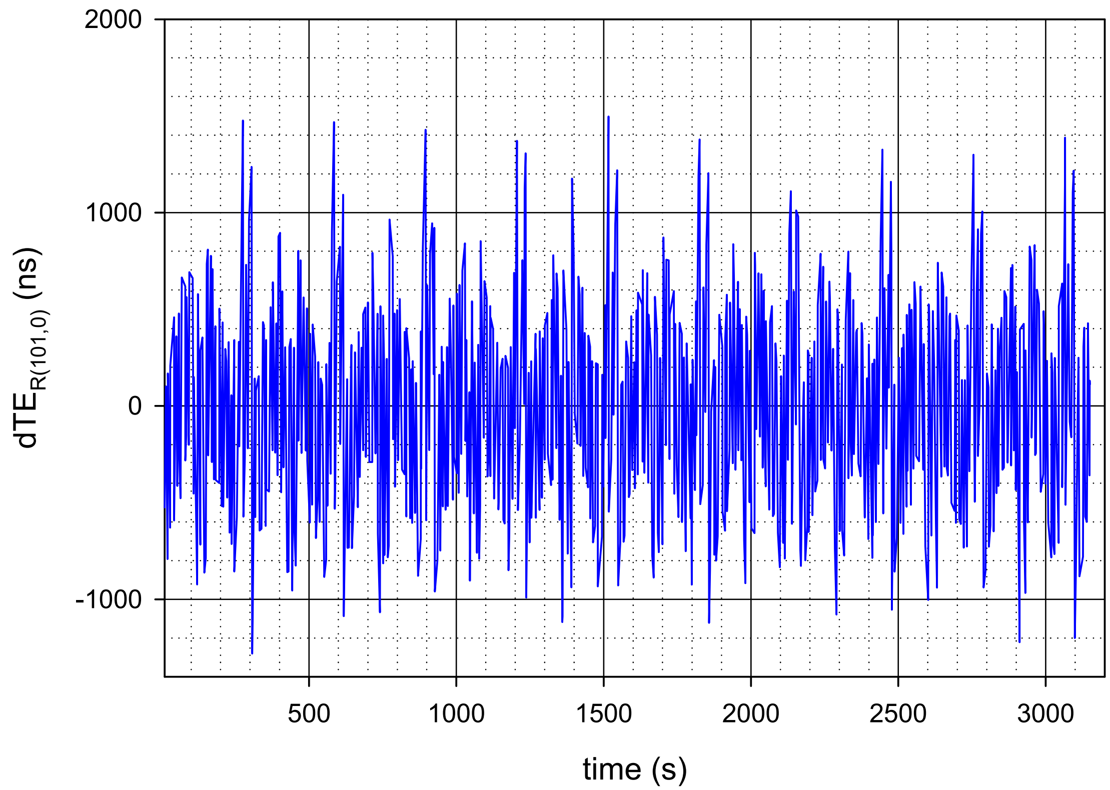
# Case27, Node 68 Detailed Results – 3

Simulation Case 27, Node 68
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



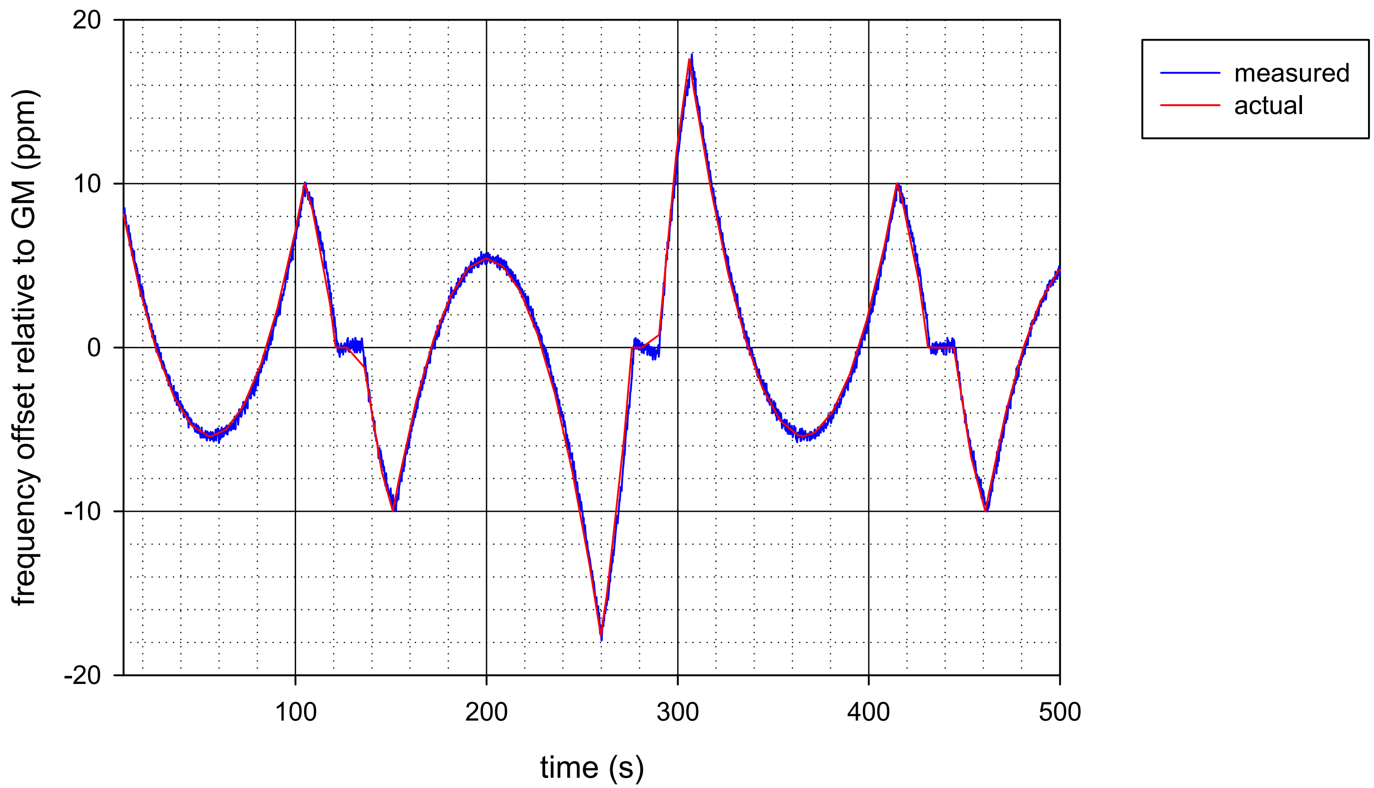
# Case27, Node 101 Detailed Results - 1

Simulation Case 22, Node 101
Replication 1: 10 - 3150 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



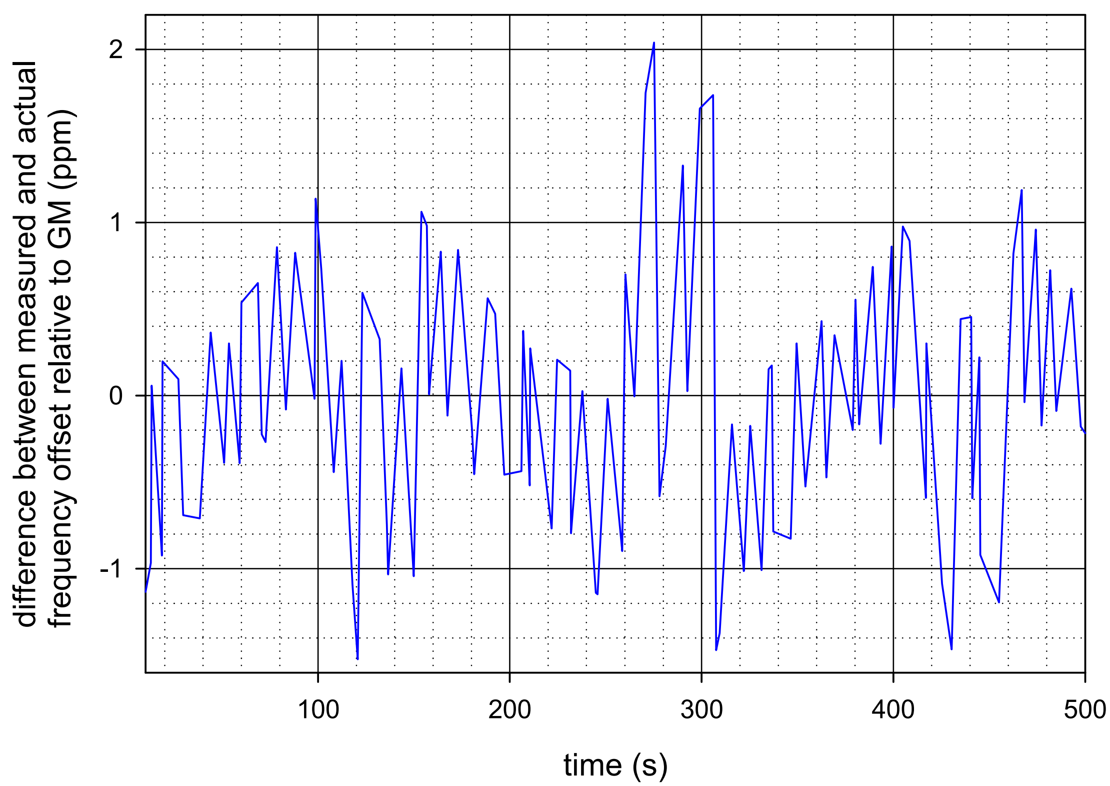
# Case27, Node 101 Detailed Results - 2

Simulation Case 27, Node 101
Replication 1, detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



# Case27, Node 101 Detailed Results - 3

Simulation Case 27, Node 101
Replication 1: detail of 10 - 500 s
GM time error modeled
Clock Model (all clocks): Frequency vs temperature stability and temperature vs time profile from [2]
Accumulate neighborRateRatio, which is measured with window of size 7 and median
KpKo = 11, KiKo = 65 (f3dB = 2.6 Hz, gain pk = 1.288 dB, zeta = 0.68219)
Initial LocalClock phase waveforms chosen randomly over 10% of cycle
Residence time: 10 ms
Timestamp granularity: 4 ns



# Cases 16, 22, 27, Detailed Results Summary

- All the results for measured and actual frequency offset show that the former follows the latter, with added noise that increases with node number (see slides 25, 28, 31, 34, 37, 40, 43, 46, 49, 52, 55, 58, 61, 64, 67, and 70)
  - The maximum frequency offset error at node 2 (1st node after the GM) is approximately 0.72 ppm, in all four cases
    - This is larger than the 0.56 ppm obtained in [1], and is due to the GM time error variation
    - The maximum frequency offset measurement error at node 2 is much greater than the requirement of 802.1AS-2020, B.2.4, of ±0.1 ppm
      - B2.4 should likely be clarified to indicate that the requirement is for neighborRateRatio
  - The maximum frequency offset error at node 35 is approximately 1 ppm, 1 ppm, 0.9 ppm, and 1.25 ppm, for cases 16, 18, 22, and 27, respectively
  - The maximum frequency offset error at node 68 is approximately 1 ppm, 1.5 ppm, 0.9 ppm, and 1.45 ppm, for cases 16, 18, 22, and 27, respectively
  - The maximum frequency offset error at node 101 is approximately 1.8 ppm, 2 ppm,1.5ppm, and 2 ppm, for cases 16, 22, and 27, respectively

# Conclusions - 1

- It appears that it is possible to meet the max|TE| objective of 1 μs over 64 hops, and over 100 hops if possible, if neighborRateRatio is measured over a window of size 7, with the median of the 7 values taken as the measurement, and residence time is 1 ms
  - If residence time is 4 ms, it might be possible to meet the max|TE| objective of 1 μs over 64 hops, but it is exceeded over 100 hops
  - Timestamp granularity is assumed to be 8 ns
    - Reducing timestamp granularity to 4 ns has small impact
  - Dynamic timestamp error is assumed to be ±8 ns, each with 0.5 probability
  - max|$dTE_R$| result for 100 hops ranges from 784 – 815 ns for 1 ms residence time, and is 1121 ns for 4 ms residence time and 2202 ns for 10 ms residence time
  - Max|$dTE_R$| result for 64 hops ranges from 625 – 710 ns for 1 ms residence time, and is 774 ns for 4 ms residence time and 1270 ns for 10 ms residence time

# Conclusions

- The results for 1 ms residence time appear to have sufficient margin for cTE for 64 hops; they might have sufficient margin for cTE for 100 hops, but this must be analyzed further
- The results for 4 ms residence time might have sufficient margin for cTE for 64 hops, but this must be analyzed further

# Possible Next Steps – Consideration of cTE

- Whether there is sufficient margin for cTE depends on how much cTE is allocated per gPTP link (including the effect of both the node and medium), and the model for accumulating cTE
  - See [8] for an initial analysis
- One next step is to consider cTE and any other impairments (e.g., effect of network reconfiguration), and develop an error budget
- A future presentation can consider this

## Possible Next Steps - Consideration of Requirements and Compliance - 1

- This slide and the next contain some initial ideas on what can be specified and how compliance can be tested
- The model for measurement of neighborRateRatio based on a window of size 7 and computation of the median is one of many ways that neighborRateRatio can be measured
- The particular way in which it is measured is implementation specific
- The IEC/IEEE 60802 profile should allow any measurement scheme, as long as respective requirements are met
    - In the case here, the requirement is that the error in the measurement of neighbor frequency offset (i.e., neighborRateRatio – 1) not exceed a specified limit
    - The results here 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 had maximum neighbor frequency offset error of 0.56 ppm with no GM time error variation (obtained in [1]) and 0.72 ppm with the GM time error variation considered here
    - Therefore, the limit could be larger than 0.1 ppm, but will depend on how compliance is tested (e.g., with or without GM time error variation)

## Possible Next Steps - Consideration of Requirements and Compliance - 1

- Since the Follow_Up Information TLV carries accumulated rateRatio, it should be possible to test a single PTP Instance with a test set both serving as the GM and measuring the result
- Limits on timestamp granularity and dynamic timestamp error also are relevant
  - These are tolerance requirements when the accuracy of the neighborRateRatio measurement is tested
  - In such a test, the test set would need to add both the specified timestamp granularity and dynamic timestamp error to the PTP event messages sent to the equipment under test, because the scheme used in the neighborRateRatio measurement would need to tolerate these errors
  - However, there would be no explicit requirement on timestamp granularity or dynamic timestamp error for the equipment under test itself
    - Rather, any timestamp granularity, dynamic timestamp error, and method for measuring neighborRateRatio would be allowed as long as the error in measured neighborRateRatio did not exceed the specified limit
- A more detailed description of these considerations can be given in a future presentation

Thank you

# References - 1


[1] Geoffrey M. Garner, New Simulation Results for dTE for an IEC/IEEE 60802 , Based on New Frequency Stability Model, Revision 1, IEC/IEEE 60802 presentation, April 9, 2021 (available at https://www.ieee802.org/1/files/public/docs2021/60802-garner-new-simulation-results-new-freq-stab-model-0421-v01.pdf)

[2] Geoffrey M. Garner, *Summary of Assumptions for Next Simulations, based on Presentation and Subsequent Discussion of [1], Revision 1*, IEC/IEEE 60802 presentation, March 11, 2021 (available at https://www.ieee802.org/1/files/public/docs2021/60802-garner-summary-of-assumptions-next-simulations-0321-v01.pdf)

[3] Chris McCormick, *Crystal Fundamentals & State of the Industry*, IEC/IEEE 60802 presentation, February 22, 2021 call (available at https://www.ieee802.org/1/files/public/docs2021/60802-McCormick-Osc-Stability-0221-v01.pdf)

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[4] Geoffrey M. Garner, *Phase and Frequency Offset, and Frequency Drift Rate Time History Plots Based on New Frequency Stability Data*, IEC/IEEE 60802 presentation, March 8, 2021 call (available at https://www.ieee802.org/1/files/public/docs2021/60802-garner-temp-freqoffset-plots-based-on-new-freq-stabil-data-0321-v00.pdf)

[5] Jordan Woods, *Concerns regarding the clock model used in 60802 time synchronization simulations*, Revision 1, IEC/IEEE 60802 presentation, December 21, 2020 call (available at https://www.ieee802.org/1/files/public/docs2020/60802-woods-ClockModel-1220-v02.pdf)

[6] 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 14, 2020 call (available at https://www.ieee802.org/1/files/public/docs2020/60802-garner-further-simulation-results-time-sync-transport-1120-v02.pdf)

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

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[8] Geoffrey M. Garner, *Analysis of the Accumulation of Constant Time Error in an IEC/IEEE 60802 Network*, IEC/IEEE 60802 presentation, March 16, 2020 (available at https://www.ieee802.org/1/files/public/docs2020/60802-garner-analysis-of-accum-of-cTE-in-60802-network-0320-v00.pdf)