60802 Dynamic Time Sync Error – Monte Carlo Analysis Results for Comparison with Time Series Simulations

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Updated 19th March
Full Monte Carlo Results
Latest RStudio Script
[Backup data still from v1]

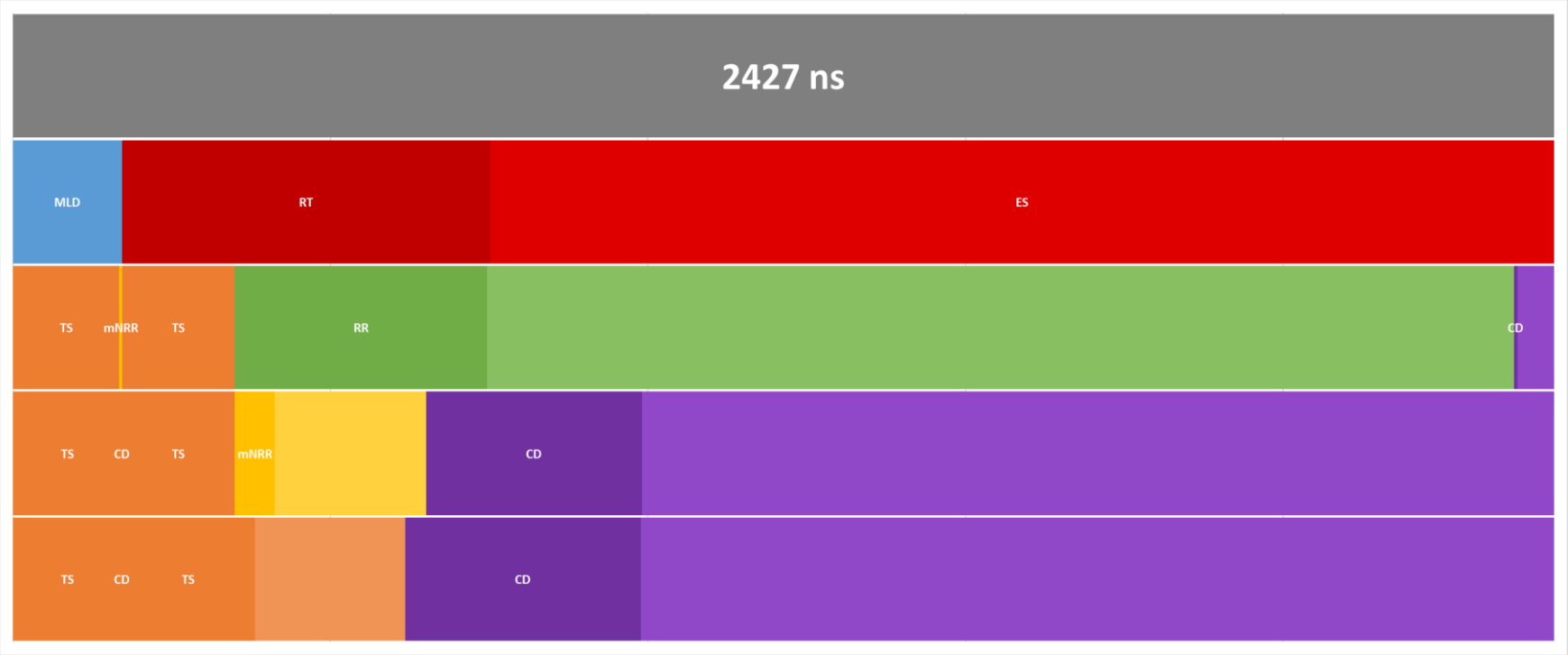
Abstract

- Industrial Automation Systems require microsecond-accurate time across long daisy-chains of devices using IEEE Std. 802.1AS™-2020 as specified by IEEE/IEC 60802.
- Simulated protocol and system parameters have thus far either been judged impractical or have failed to meet the time-accuracy requirement.
- An analysis of how errors accumulate suggested that a Monte Carlo method analysis could support fast iteration of potential scenarios and deliver insights into cause and effect. See...
  - 60802-McCall-et-al-Time-Sync-Error-Model-0921-v03.pdf
  - 60802-McCall-Stanton-Time-Sync-Error-Model-and-Analysis-2021-11-v02.pdf
  - 60802-McCall-Stanton-Time-Sync-Error-Model-and-Analysis-0222-v03.pdf
  - 60802-McCall-Stanton-Time-Sync-Error-Model-and-Analysis-0322-v01.pdf
- In this contribution:
  - Present Monte Carlo analysis results to compare with upcoming Time Series simulation results

Content

- Addition of Error due to Clock Drift during Sync Messaging to Error Breakdown Charts
- Summary of Cases
- Summary of Results
  - Including contribution from different error factors
- Backup – Detailed Results
  - Graphs from Monte Carlo Analysis

Error Breakdown Charts



Input Errors		
GM Clock Drift Max	+1.5	ppm/s
GM Clock Drift Min	-1.5	ppm/s
GM Nodes w/ Clock Drift	80%	
Clock Drift Max (non-GM)	+1.5	ppm/s
Clock Drift Min (non-GM)	-1.5	ppm/s
Non-GM Nodes w/ Clock Drift	80%	
Timestamp Granularity TX	4	±ns
Timestamp Granularity RX	4	±ns
Dynamic Time Stamp Error TX	8	±ns
Dynamic Time Stamp Error RX	8	±ns
Input Parameters		
pDelay Interval	31.25	ms
Sync Interval	125	ms
pDelay Turnaround Time	1	ms
residenceTime	1	ms
Input Correction Factors		
Mean Link Delay Averaging	0	%
NRR Drift Rate Correction	0	%
RR Drift Rate Error Correction	0	%
pDelayResponse → Sync	0	%
mNRR Smoothing N	1	
mNRR Smoothing M	1	
Configuration		
Hops	100	
Runs	100,000	

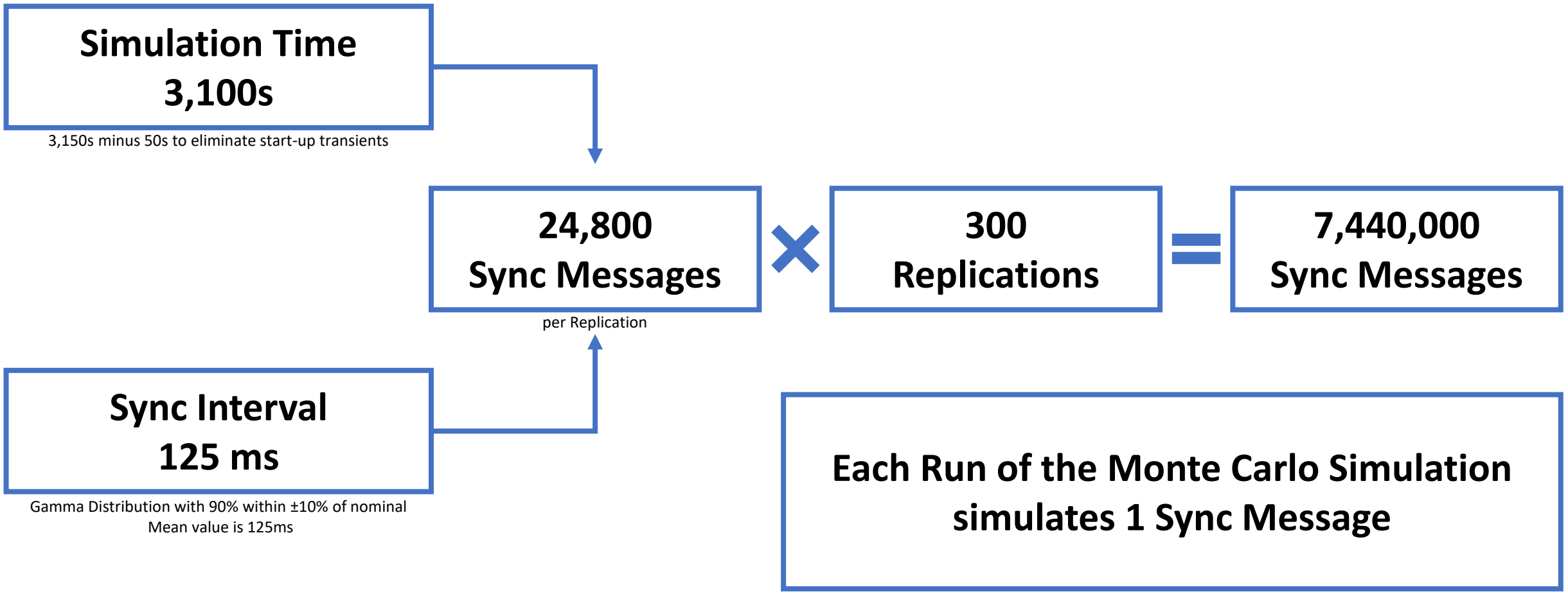
Summary of Cases

Proposed Time Series Simulations – Details

Experiment	Reason	Errors			Parameter			Correction Factors	
		Clock Drift Model – 40°C ↔ +85°C Hold for 1min at Each (Each node's position in cycle distributed at random across 100% of Cycle)	**Timestamp Granularity (ns)**	**Dynamic Timestamp Error (±ns)**	**pDelay Interval (ms)**	**Residence Time (ms)**	**pDelay Turnaround Time (ms)**	**Mean Link Delay Averaging**	**mNRR Smooting Factor N**
A	Baseline with previous assumptions	Ramp Rate 1°C / s (Cycle of 310 s)	8	8	31.25	1	1	Off	1
B	Verify optimised pDelayInterval		8	4	1000	10	10		
C					250	10	10		
D					31.25	10	10		
E	Verify effect of reduced Timestamp Error (reduced DTE when pDelay Interval is low, i.e. 31.25ms)		4	2	31.25	10	10		
F	Verify effect of reduced Clock Drift (reduced DTE when pDelay Interval is high, i.e. 1000ms)	Ramp Rate 0.5°C / s Cycle of 560s	8	4	1000	10	10		

Timestamp Granularity and Dynamic Timestamp Error are uniform distributions unless otherwise stated
Sync Interval: 125ms pDelay Interval variation is +0-30% with uniform distribution
Sync Interval variation is ±10% with 90% probability with gamma distribution
Note: 8ns Timestamp Granularity in Time Series Simulation is equivalent to ±4ns Timestamp Granularity Error in Monte Carlo Analysis
1°C / s temperature ramp rate is the equivalent of ±1.5 ppm/s clock drift rate in Monte Carlo Analysis
No difference between base (PHY related) propagation delay for pDelay and Sync messages

Number of Sync Messages



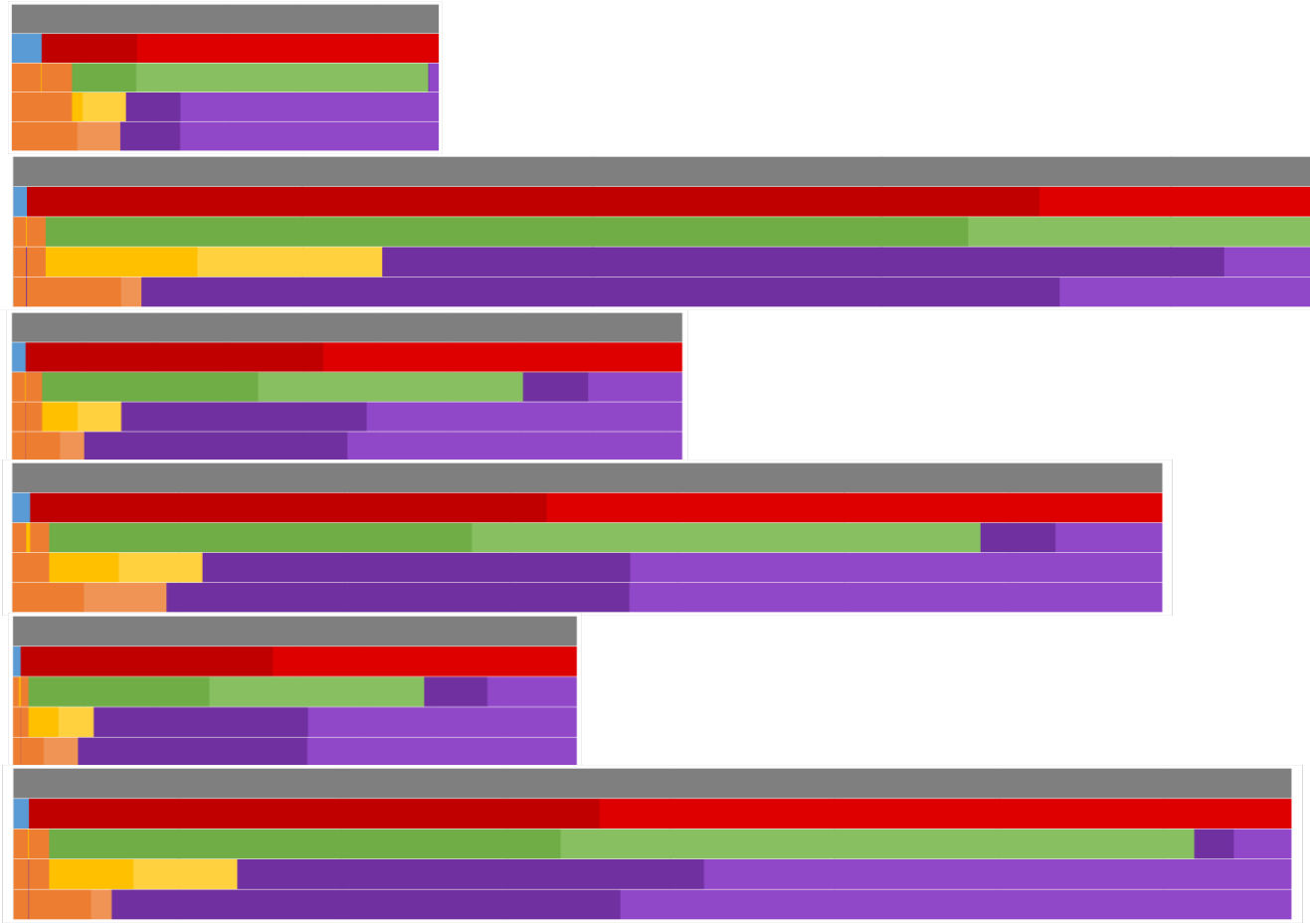
Summary of Results

Generating Results to Match Time Series

- For each Case: 7,440,000 Runs
  - Same number of Sync messages as 300 Time Series Replications
- Divide into 300 sections, each of 24,800 Runs
  - Same number of Sync messages as 1 Time Series Replication
  - Nothing special; just take 1st 24,800 runs, then 2nd, then 3rd, etc...
- Find max|DTE| for each section (i.e. 300 instances of max|DTE|)
- Find 99% confidence interval for the 0.95 quantile
  - Order the list of max|DTE| instances, lowest to highest, then...
  - Lower Confidence Limit: 275th Value
  - Point Estimate: 285th Value
  - Upper Confidence Interval: 294th Value

Summary of Results - MAXabs Charts

Case	Reason	Key Factor	max|DTE|
A	Baseline with previous assumptions	pDelayInterval 31.25ms; 1ms Residence Time & pDelay Turnaround; 8ns Dyn. Timestamp Error	2,941
B	Verify optimised pDelayInterval	pDelay Interval 1000ms	15,566
C		pDelay Interval 250ms	4,609
D		pDelay Interval 31.25ms	6,915
E	Verify effect of reduced Timestamp Error	Timestamp Errors halved pDelay Interval 31.25ms	3,996
F	Verify effect of reduced Clock Drift	Clock Drift halved pDelay Interval 1000ms	7,775



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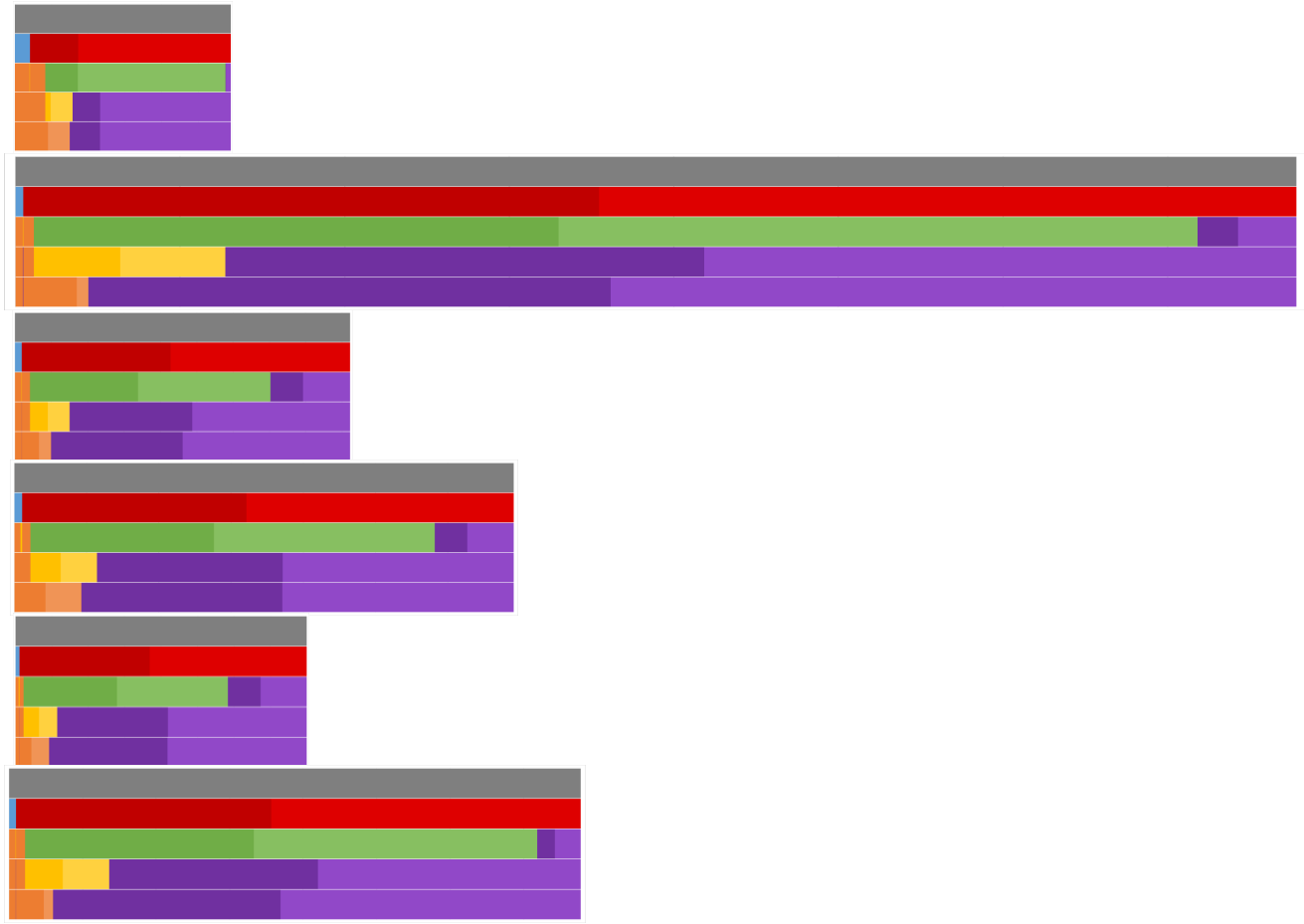


Comparison with Time Series Simulation

See 60802-garner-mult-replic-time-series-simul-resutls-for-comparison-with-monte-carlo-simuls-0322-v01.pdf

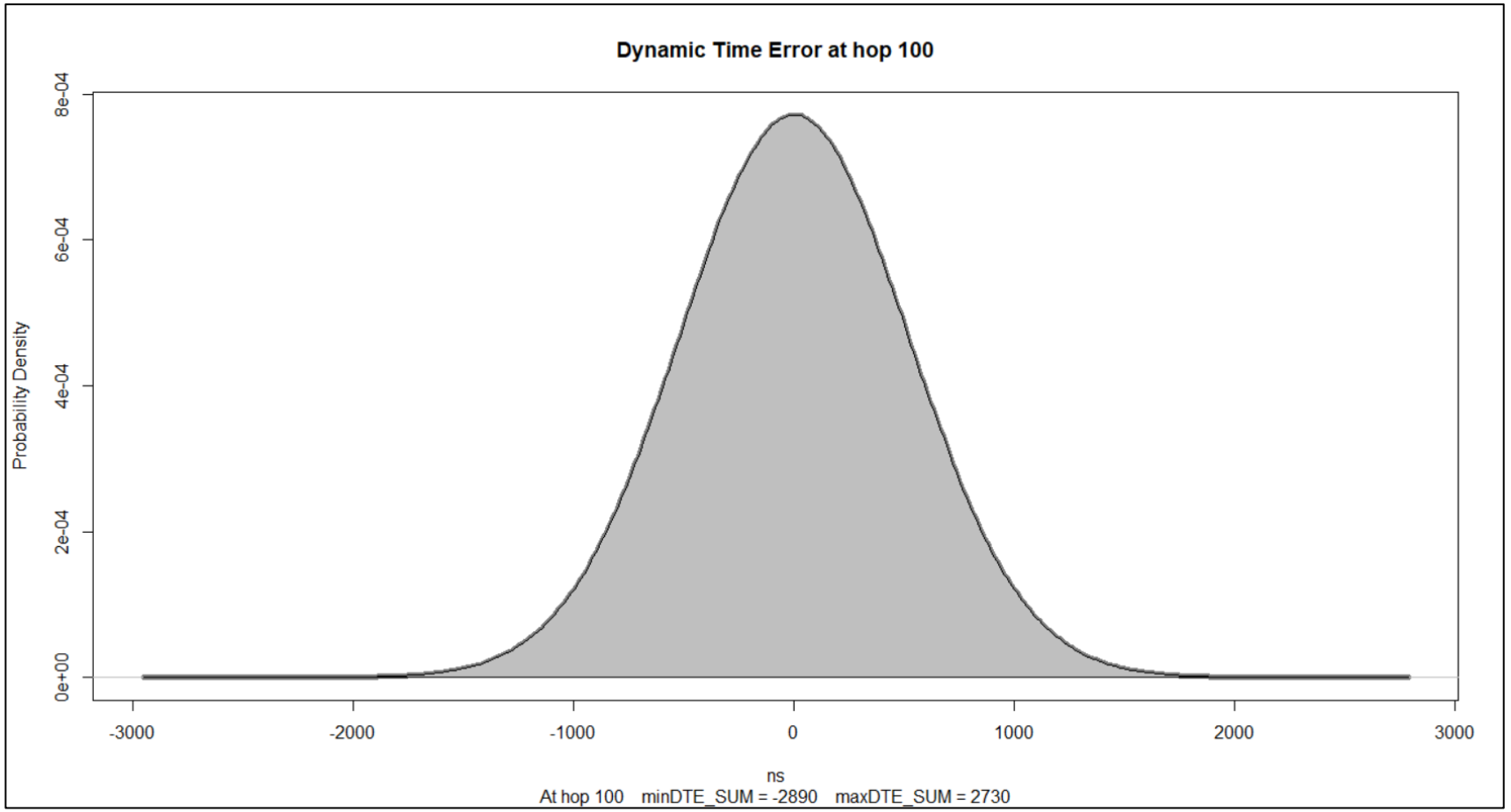
		Confidence Intervals & MAX →	Monte Carlo				Time Series – Unfiltered				Time Series – Filtered			
Case	Reason	Key Factor	Lower	Point	Upper	MAX	Lower	Point	Upper	MAX	Lower	Point	Upper	MAX
A	Baseline with previous assumptions	pDelayInterval 31.25ms; 1ms Residence Time & pDelay Turnaround; 8ns Dynamic Timestamp Error	2,543	2,657	2,774	2,941	2,265	2,315	2,375	2,515	1,624	1,688	1,772	1,887
							-10.9%	-12.9%	-14.4%	-14.5%				
B	Verify optimised pDelayInterval	pDelay Interval 1000ms	13,621	13,927	14,505	15,566	9,756	11,865	33,242	127,184	9,213	9,478	9,989	15,939
							-28.4%	-14.8%	129.2%	717.1%				
C		pDelay Interval 250ms	4,175	4,285	4,498	4,609	Not Run							
D		pDelay Interval 31.25ms	6,326	6,469	6,710	6,915	5,894	5,969	6,304	7,089	5,483	5,546	5,800	6,407
							-6.8%	-7.7%	-6.1%	2.5%				
E	Verify effect of reduced Timestamp Error	Timestamp Errors halved pDelay Interval 31.25ms	3,623	3,684	3,915	3,996	3,307	3,366	3,503	3,845	3,024	3,090	3,256	3,578
							-8.7%	-8.6%	-10.5%	-3.8%				
F	Verify effect of reduced Clock Drift	Clock Drift halved pDelay Interval 1000ms	6,816	6,961	7,224	7,775	7,096	11,108	24,077	4,090,674	4,808	4,989	5,240	13,087
							4.1%	59.6%	233.3%	52513.2%				

Thank you!

Backup Material

Detailed Results

Case A – Baseline



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GM Clock Drift Min	-1.5	ppm/s
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Timestamp Granularity TX	4	±ns
Timestamp Granularity RX	4	±ns
Dynamic Time Stamp Error TX	8	±ns
Dynamic Time Stamp Error RX	8	±ns
Input Parameters		
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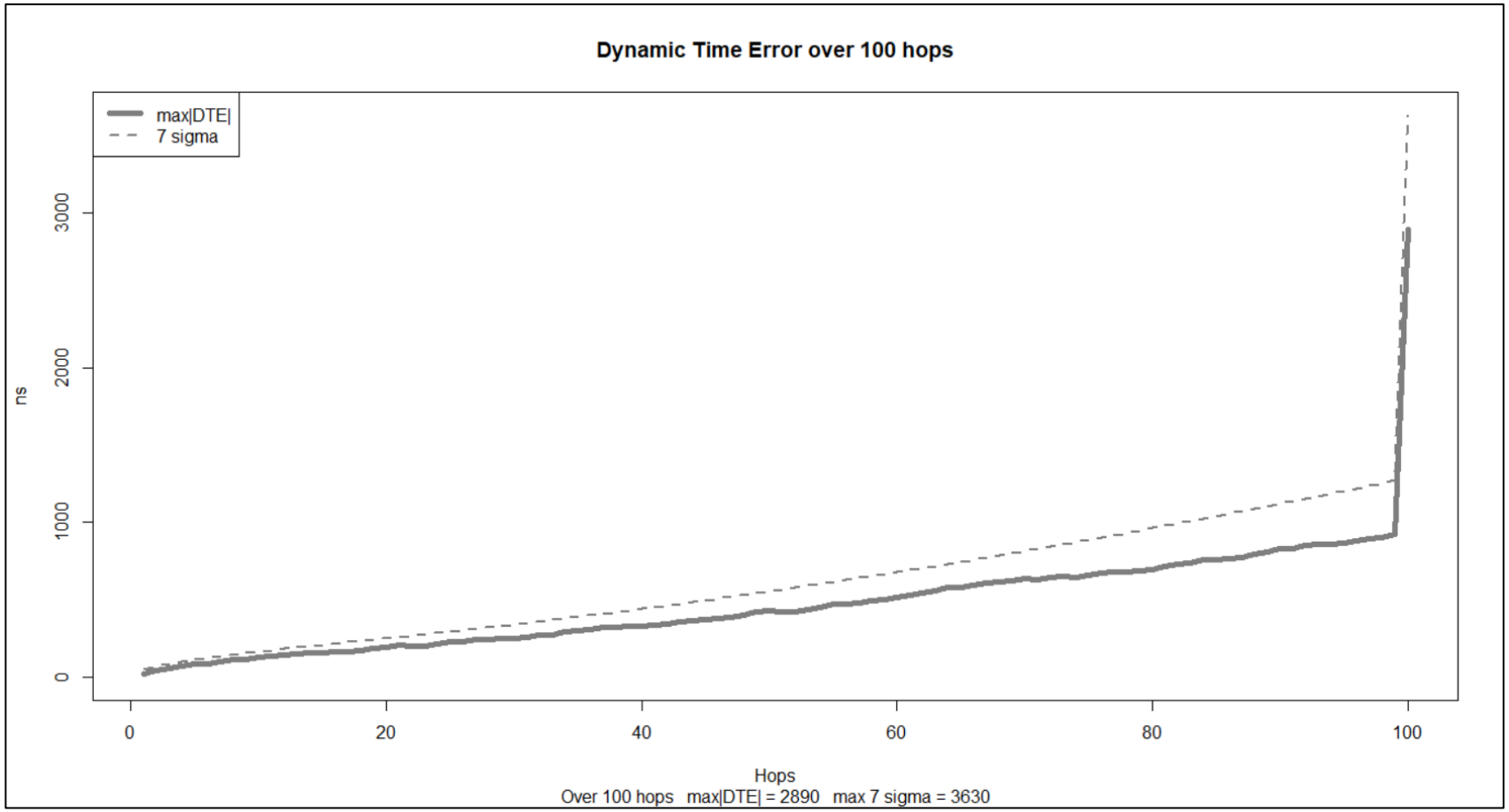
Sync Interval	125	ms
pDelay Response Time	1	ms
residenceTime	1	ms
Input Correction Factors		
Mean Link Delay Averaging	0	%
NRR Drift Rate Correction	0	%
RR Drift Rate Error Correction	0	%
pDelayResponse → Sync	0	%
mNRR Smoothing N	1	
mNRR Smoothing M	1	
Configuration		
Hops	100	
Runs	7,440,000	

Case A – Baseline



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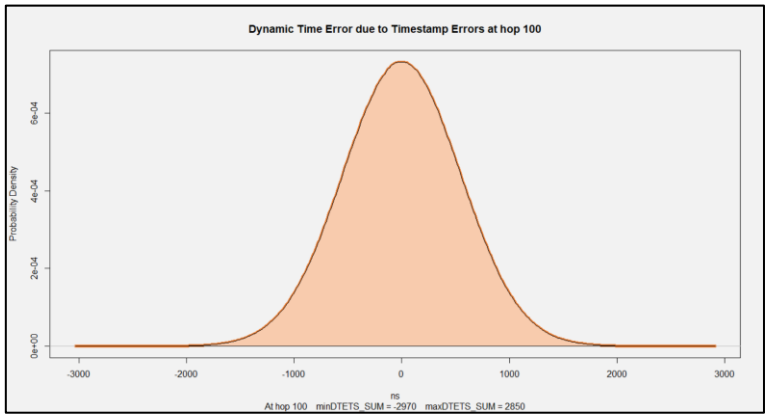

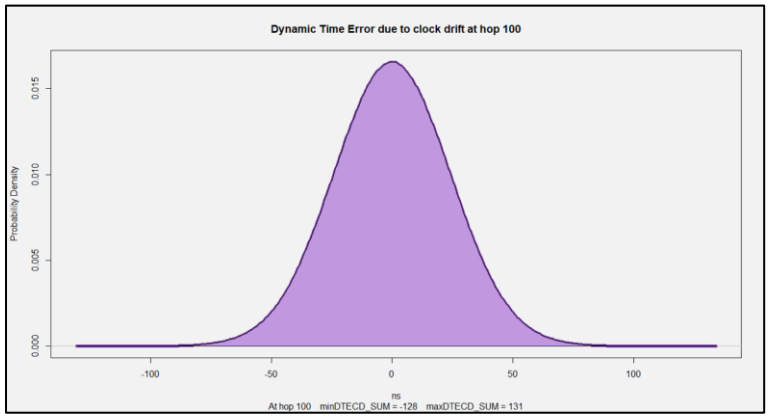

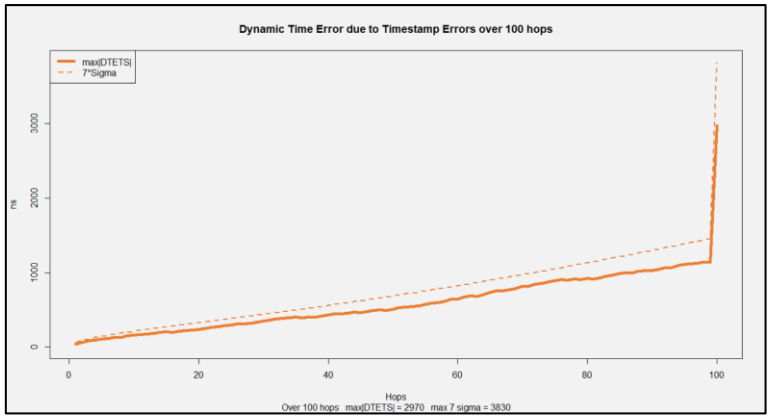

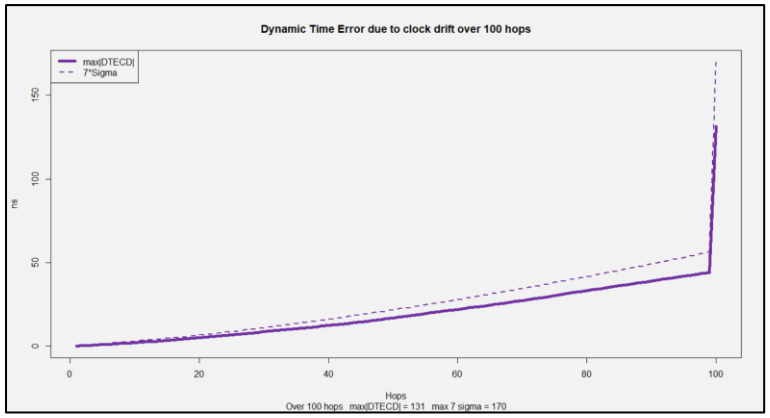

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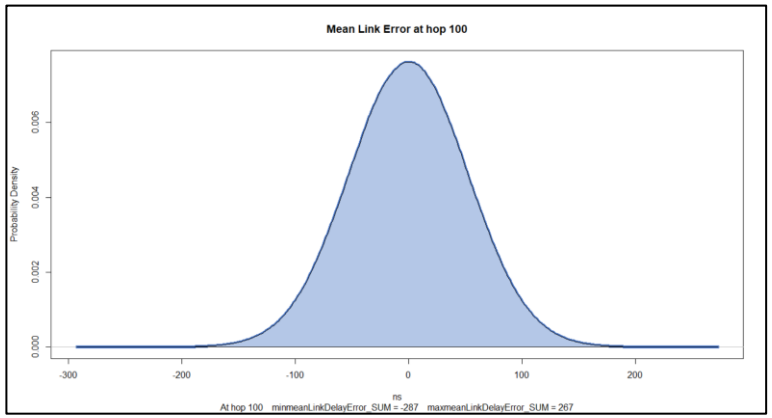
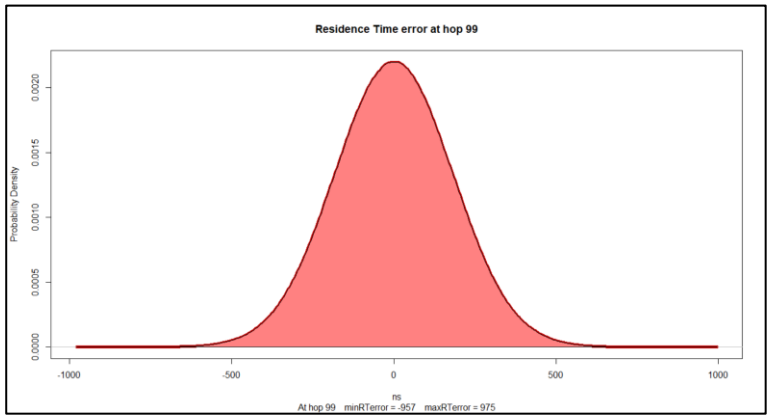
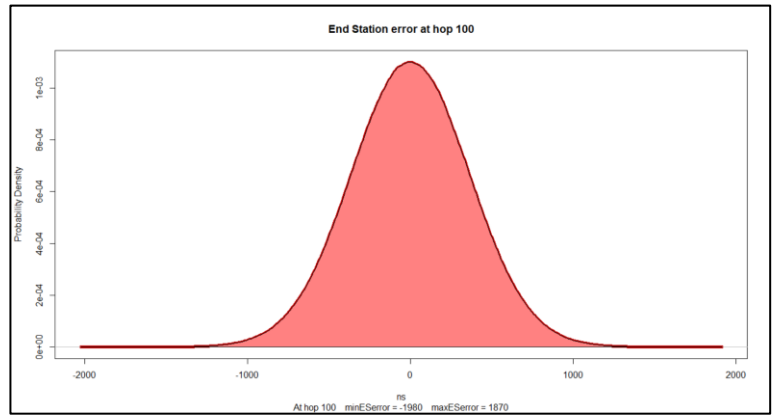
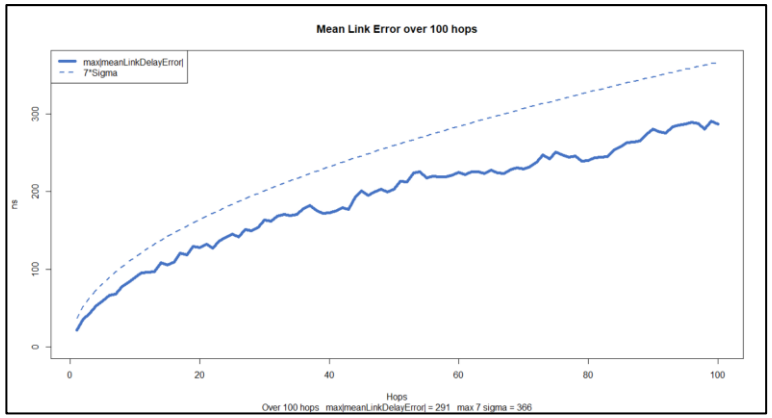
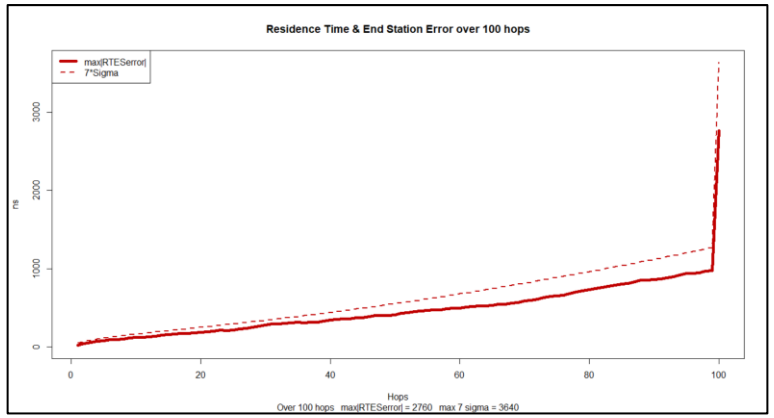


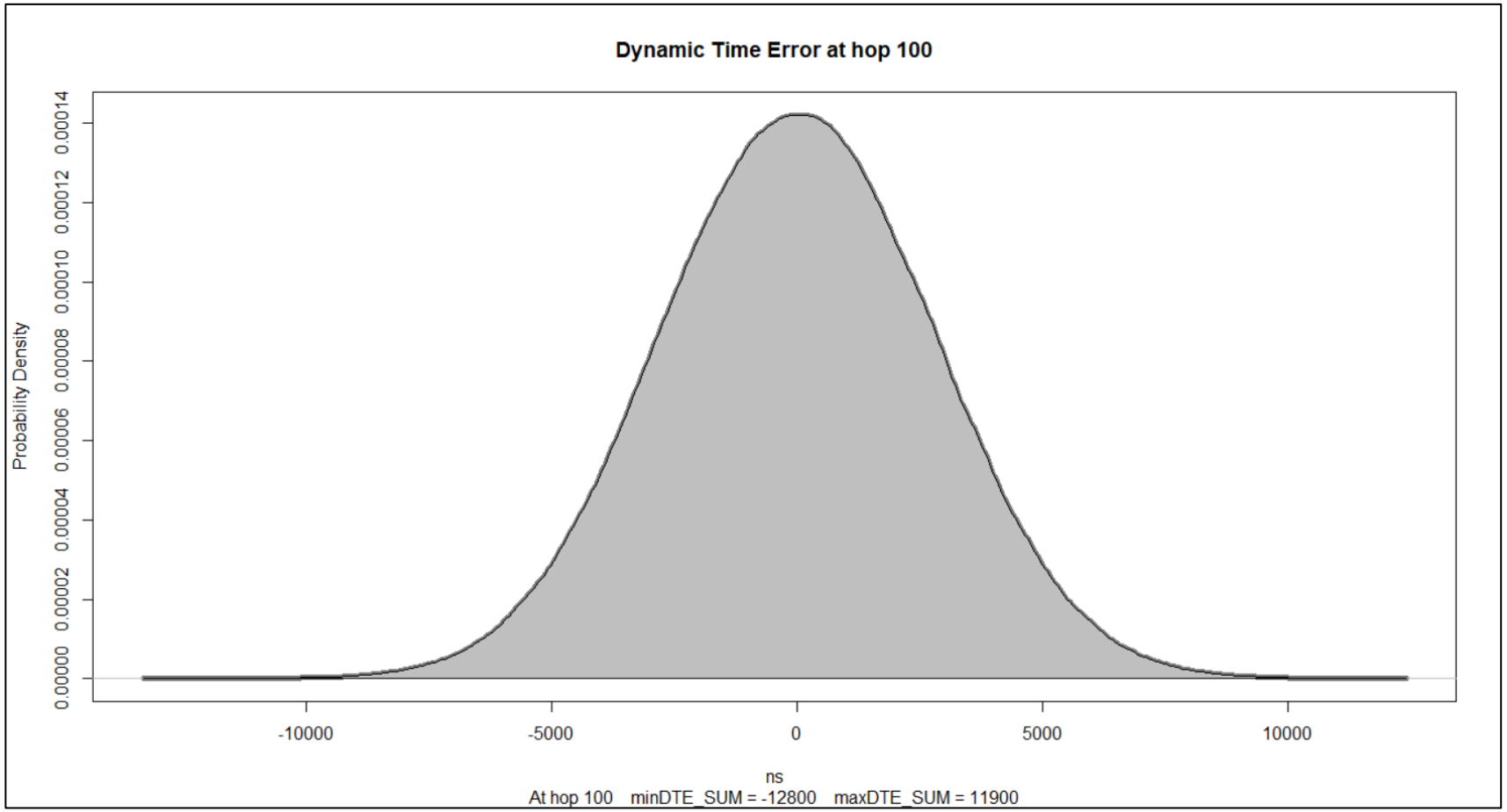








Case B – Optimise pDelay – 1000 ms



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GM Clock Drift Min	-1.5	ppm/s
Clock Drift Max (non-GM)	+1.5	ppm/s
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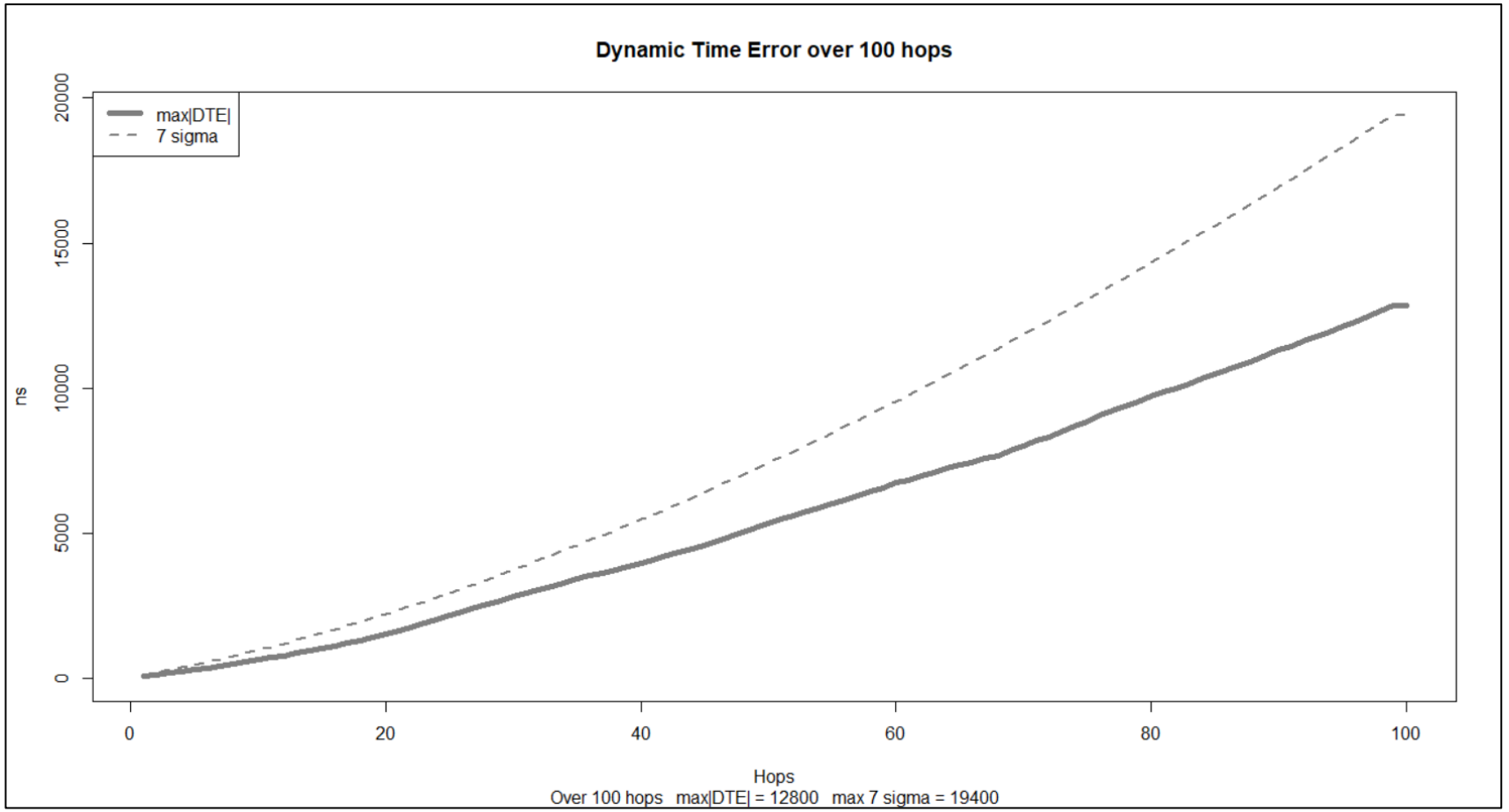
Timestamp Granularity TX	4	±ns
Timestamp Granularity RX	4	±ns
Dynamic Time Stamp Error TX	4	±ns
Dynamic Time Stamp Error RX	4	±ns
Input Parameters		
pDelay Interval	1000	ms
Sync Interval	125	ms
pDelay Response Time	10	ms
residenceTime	10	ms
Input Correction Factors		
Mean Link Delay Averaging	0	%
NRR Drift Rate Correction	0	%
RR Drift Rate Error Correction	0	%
pDelayResponse → Sync	0	%
mNRR Smoothing N	1	
mNRR Smoothing M	1	
Configuration		
Hops	100	
Runs	1,000,000	

Case B – Optimise pDelay – 1000 ms



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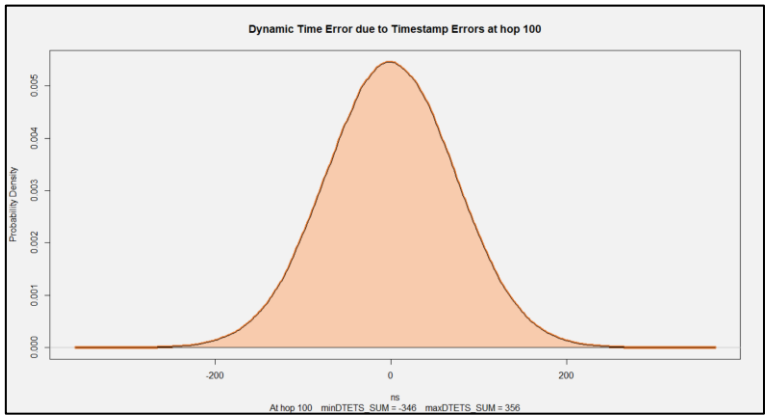

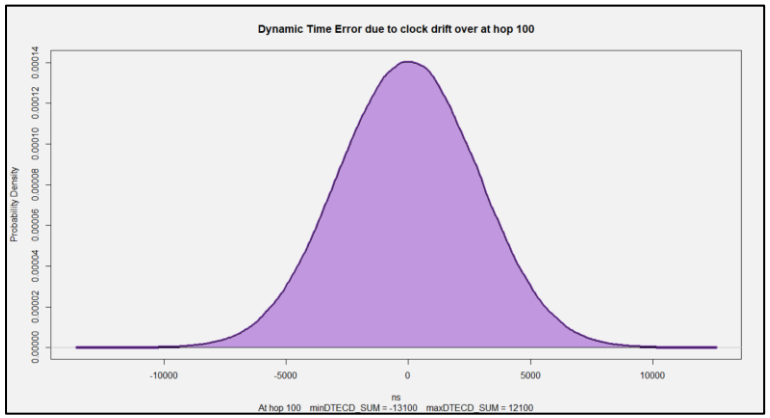

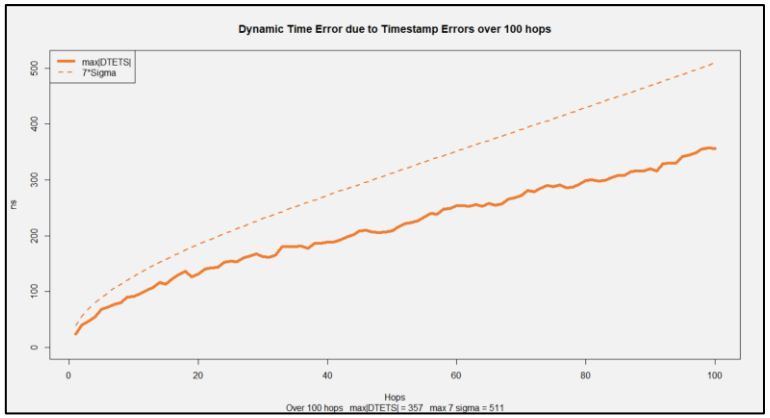

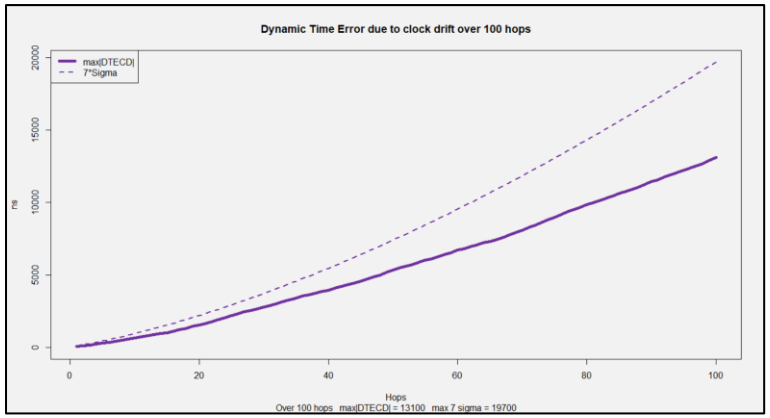

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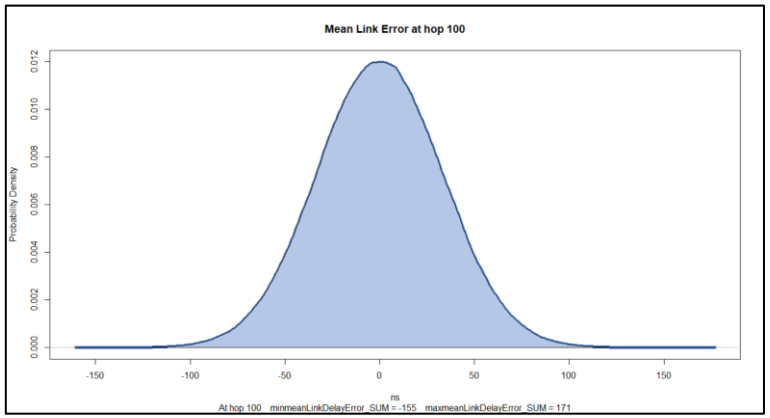
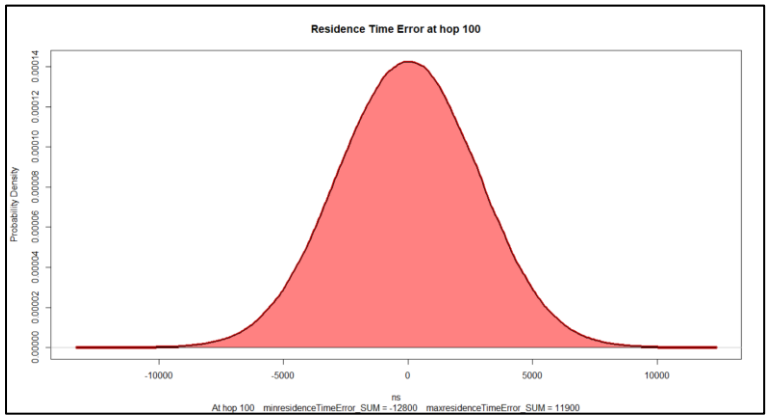
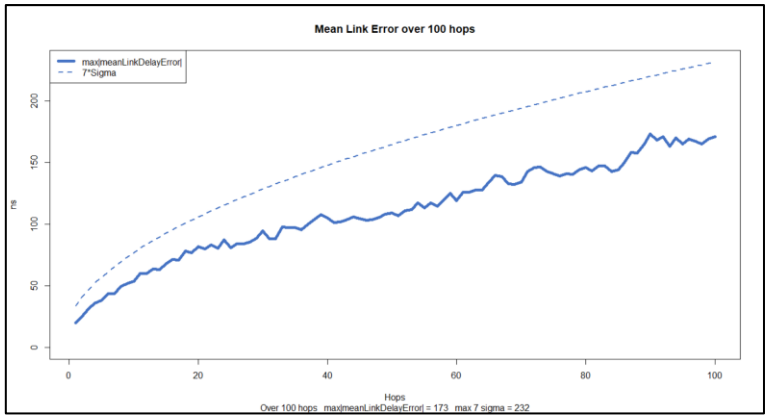
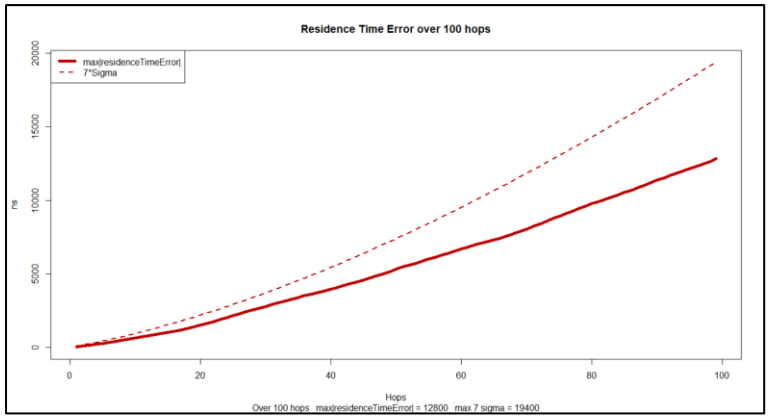
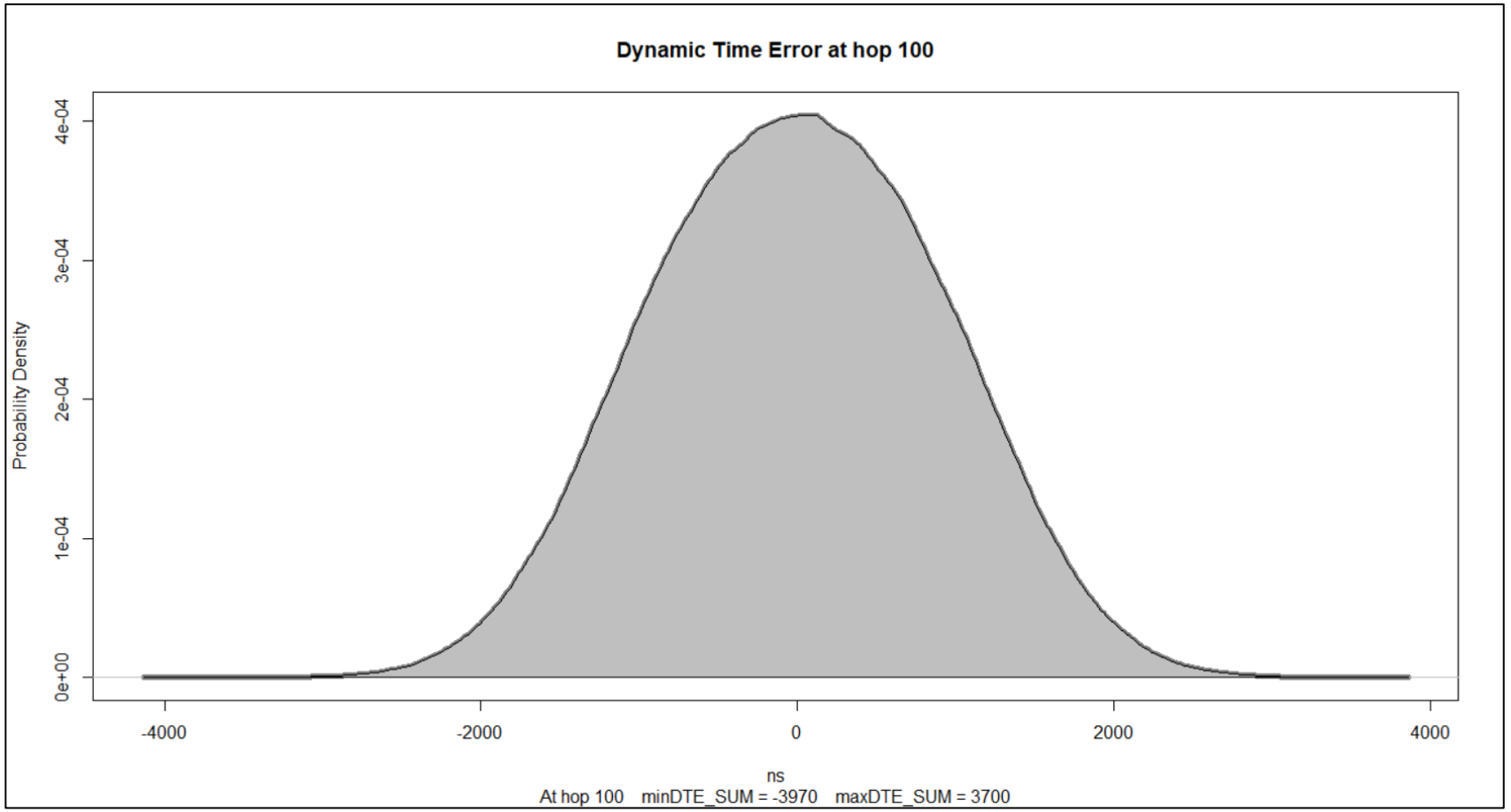








Case C – Optimise pDelay – 250 ms



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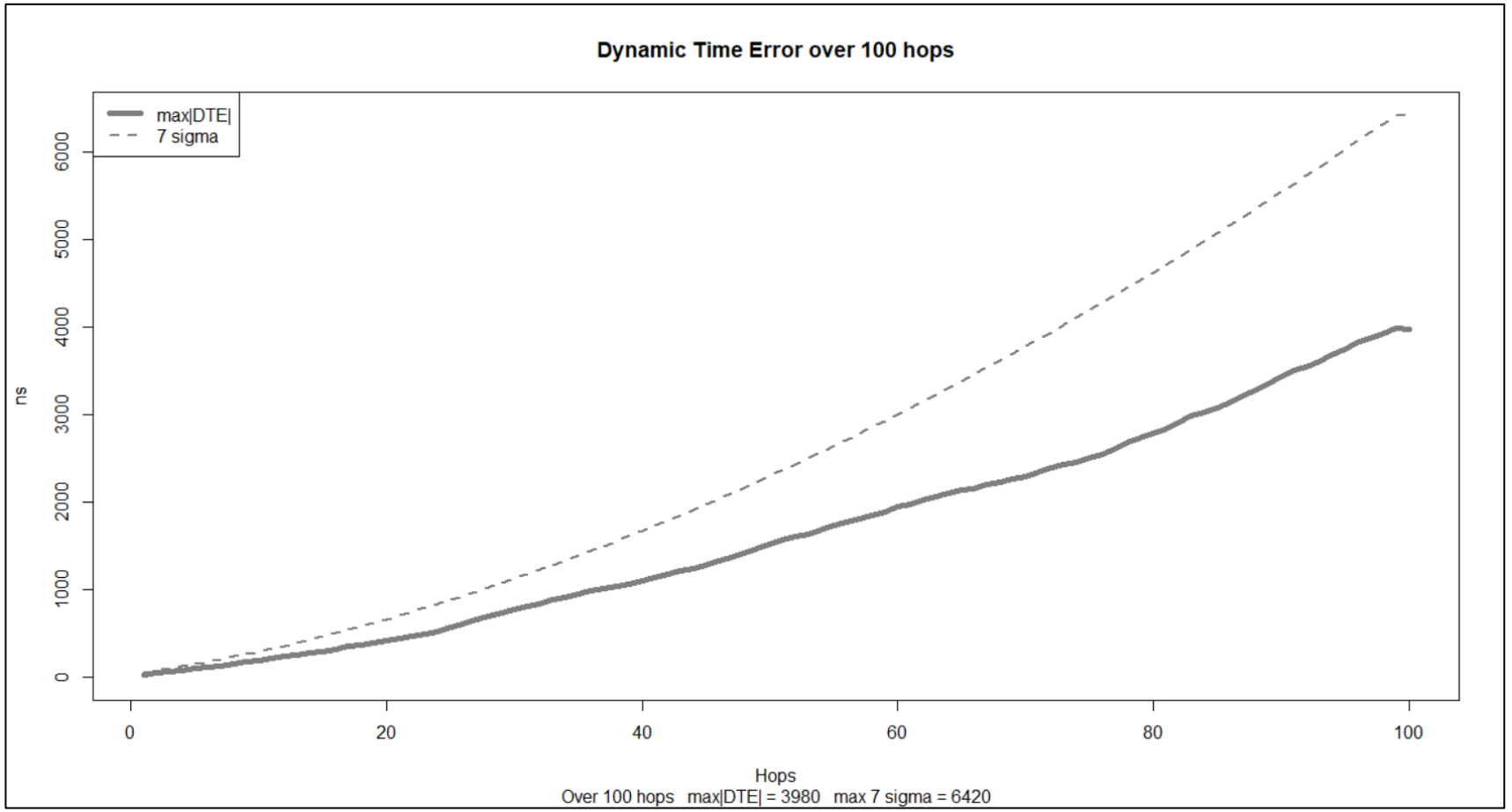
GM Clock Drift Min	-1.5	ppm/s
Clock Drift Max (non-GM)	+1.5	ppm/s
Clock Drift Min (non-GM)	-1.5	ppm/s
Timestamp Granularity TX	4	±ns
Timestamp Granularity RX	4	±ns
Dynamic Time Stamp Error TX	4	±ns
Dynamic Time Stamp Error RX	4	±ns
Input Parameters		
pDelay Interval	250	ms
Sync Interval	125	ms
pDelay Response Time	10	ms
residenceTime	10	ms
Input Correction Factors		
Mean Link Delay Averaging	0	%
NRR Drift Rate Correction	0	%
RR Drift Rate Error Correction	0	%
pDelayResponse → Sync	0	%
mNRR Smoothing N	1	
mNRR Smoothing M	1	
Configuration		
Hops	100	
Runs	1,000,000	

Case C – Optimise pDelay – 250 ms



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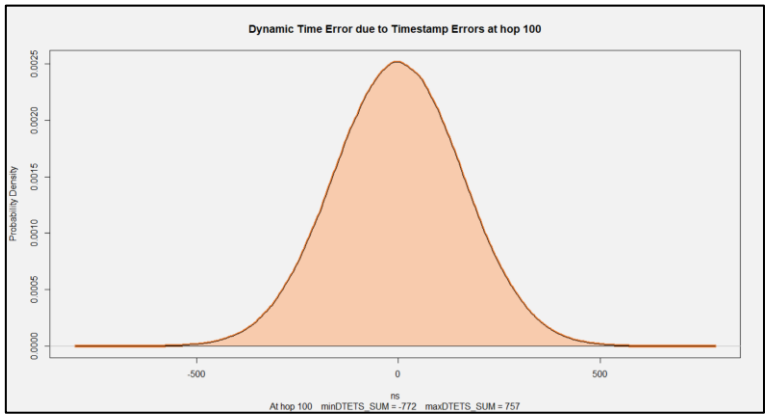

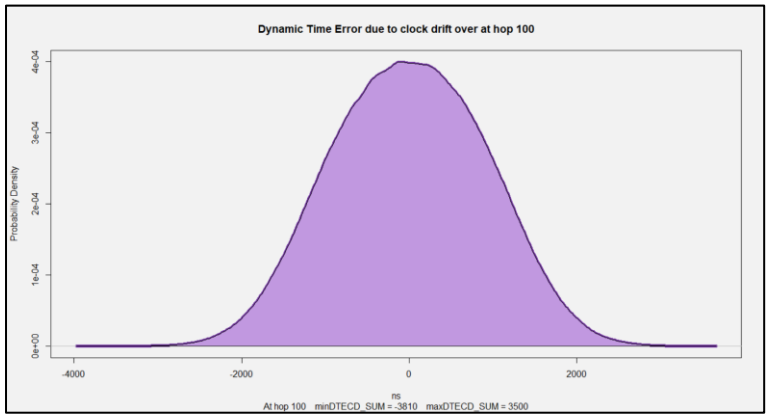

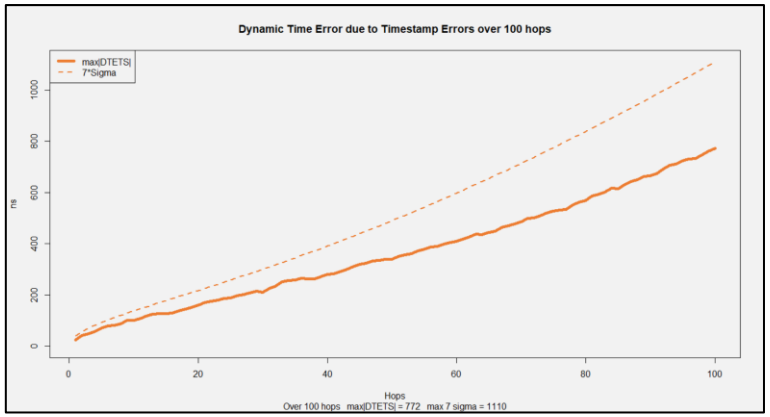

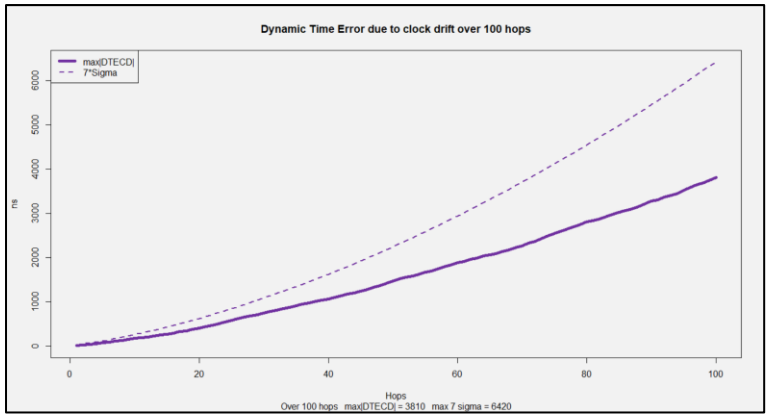

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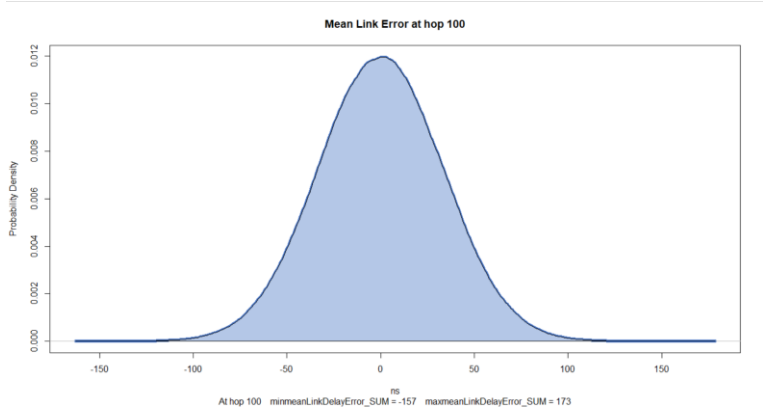
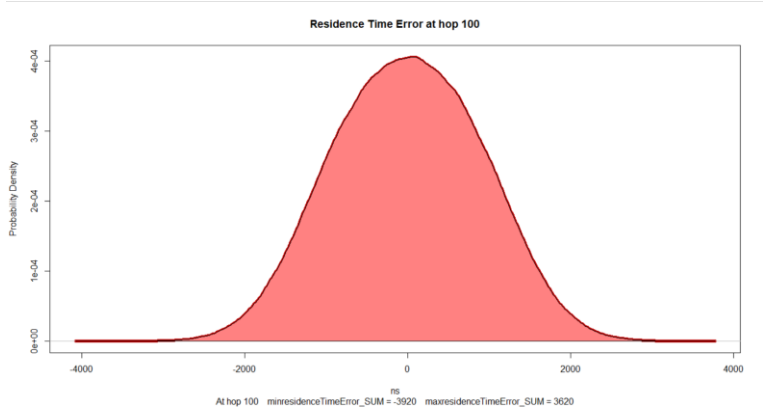
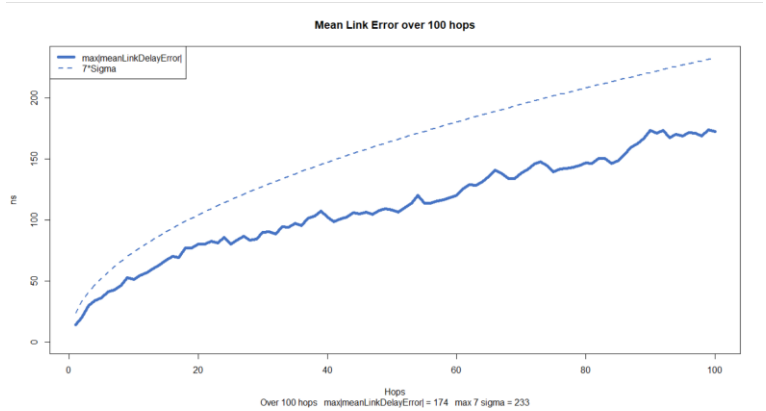
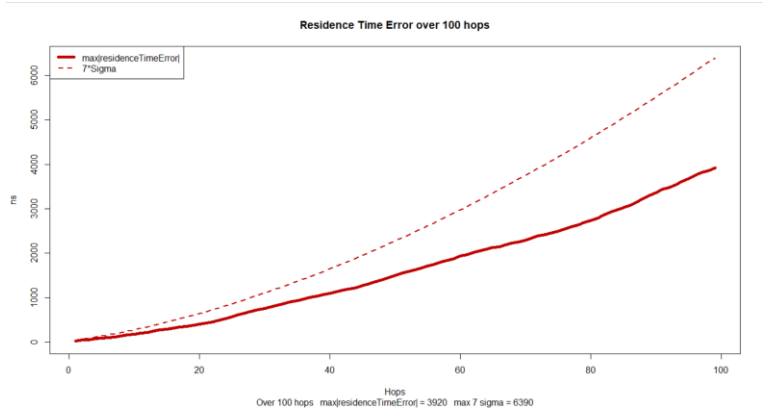
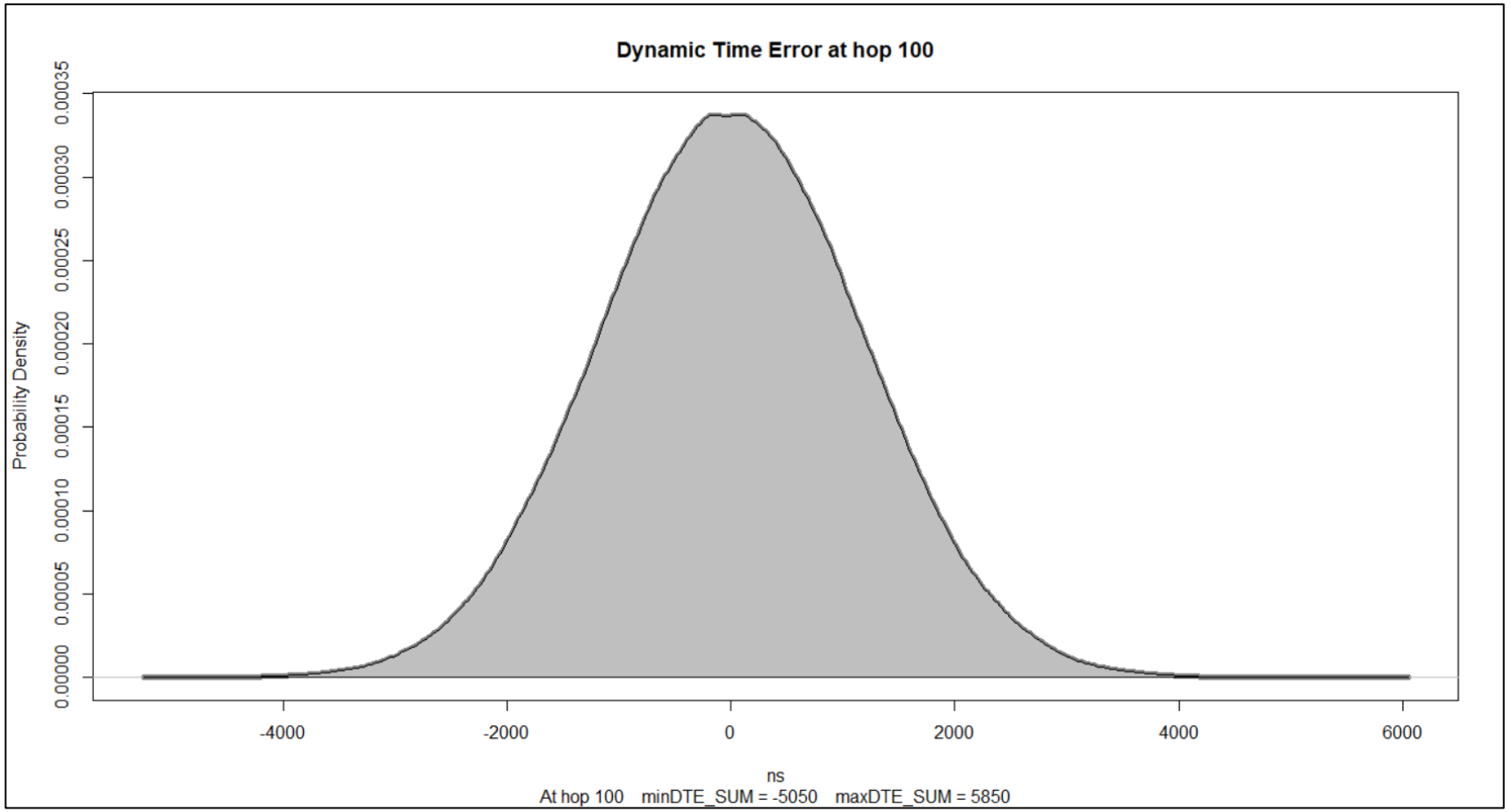








Case D – Optimise pDelay – 31.25 ms



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Timestamp Granularity RX	4	±ns
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Dynamic Time Stamp Error RX	4	±ns
Input Parameters		
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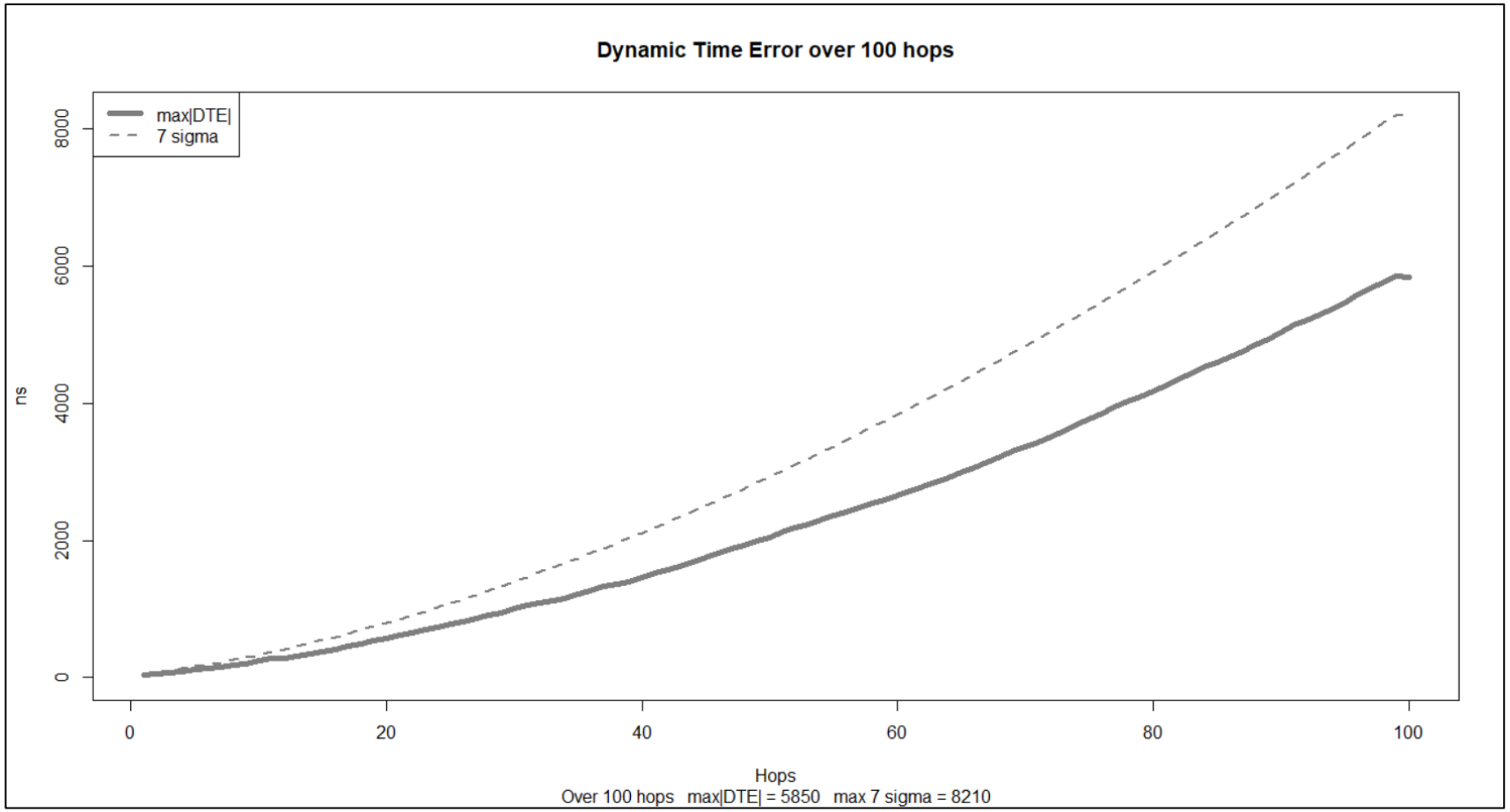
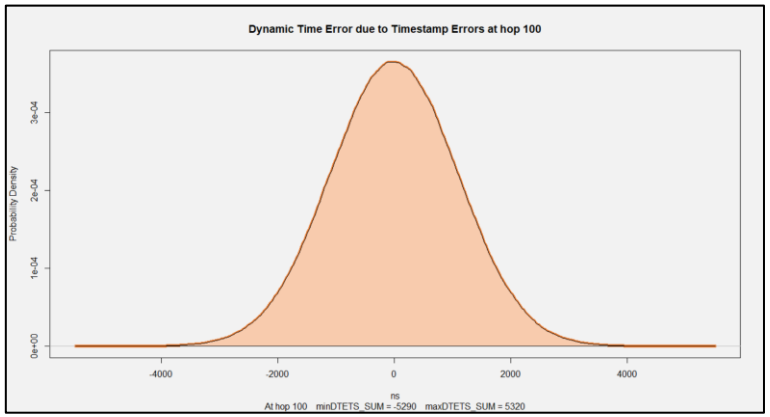
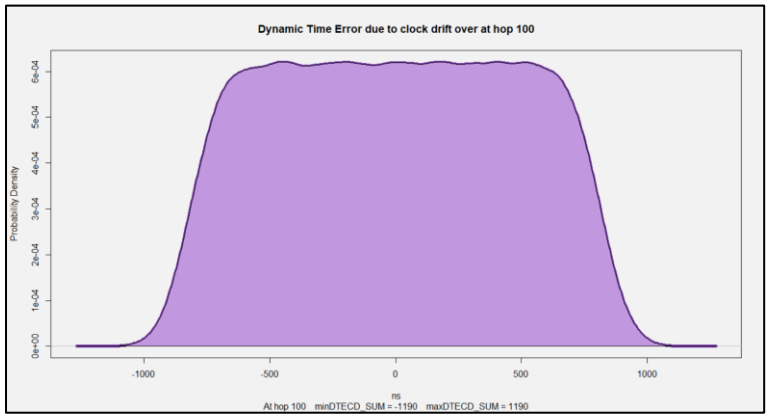
Sync Interval	125	ms
pDelay Response Time	10	ms
residenceTime	10	ms
Input Correction Factors		
Mean Link Delay Averaging	0	%
NRR Drift Rate Correction	0	%
RR Drift Rate Error Correction	0	%
pDelayResponse → Sync	0	%
mNRR Smoothing N	1	
mNRR Smoothing M	1	
Configuration		
Hops	100	
Runs	1,000,000	

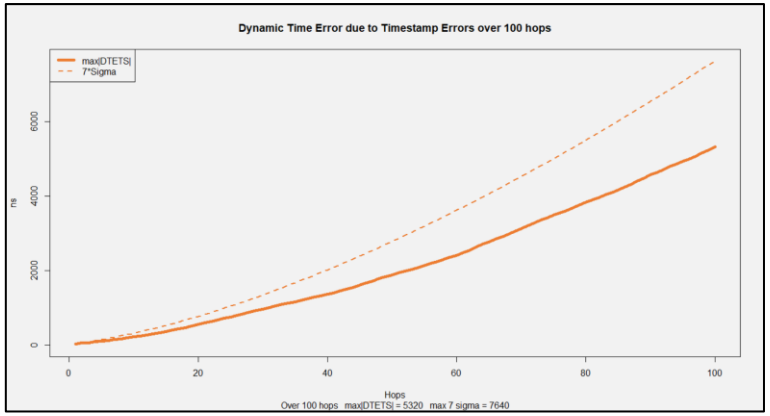
Case D – Optimise pDelay – 31.25 ms

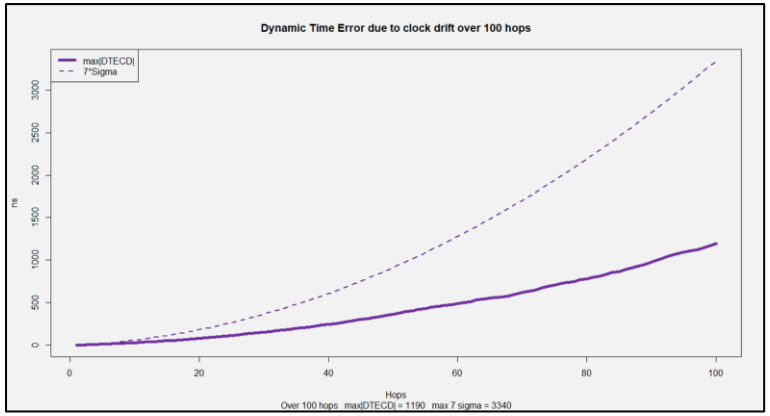


Case D – Optimise pDelay – 31.25 ms

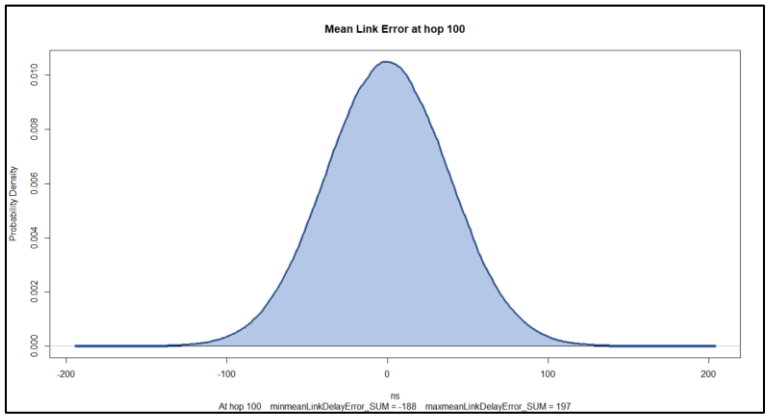


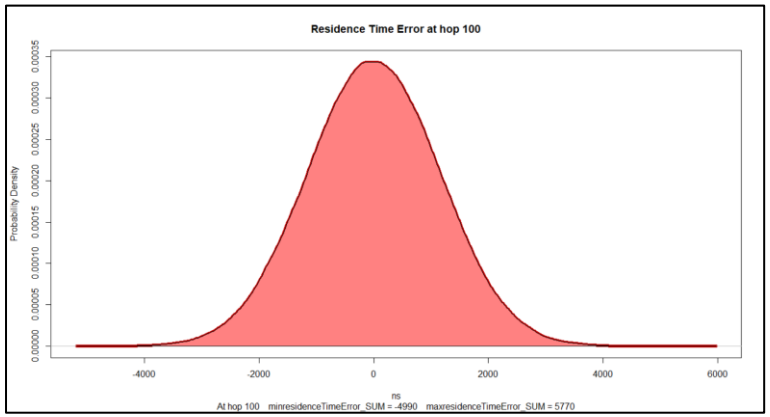


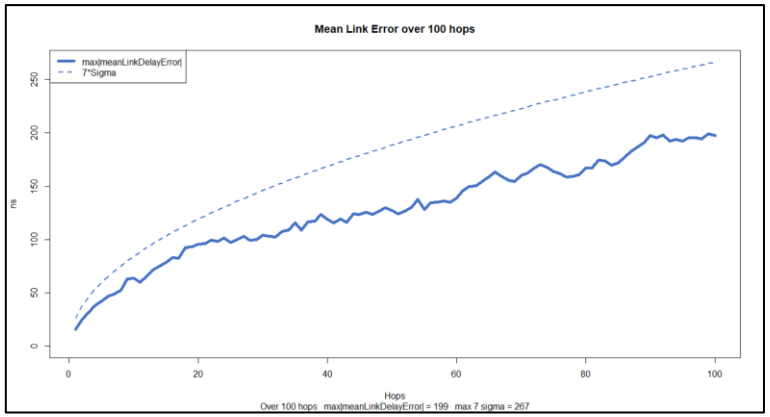


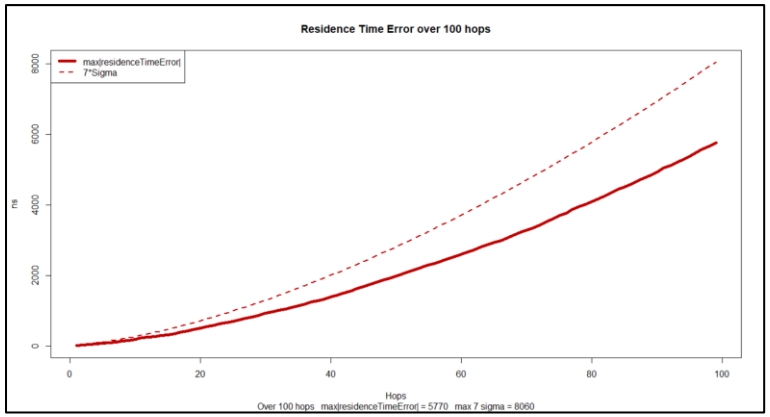


Case D – Optimise pDelay – 31.25 ms



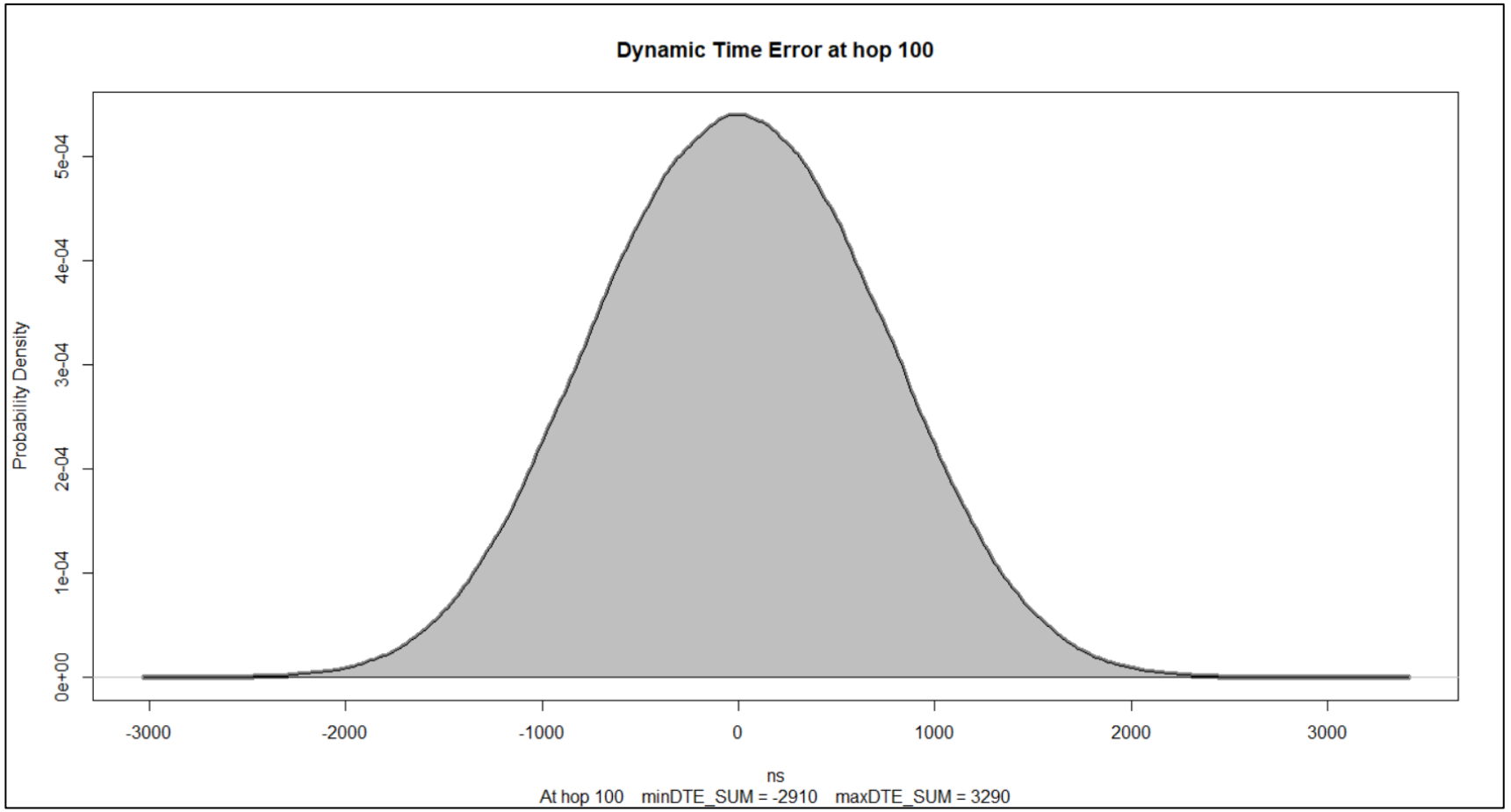






Case E – Timestamp Errors Halved

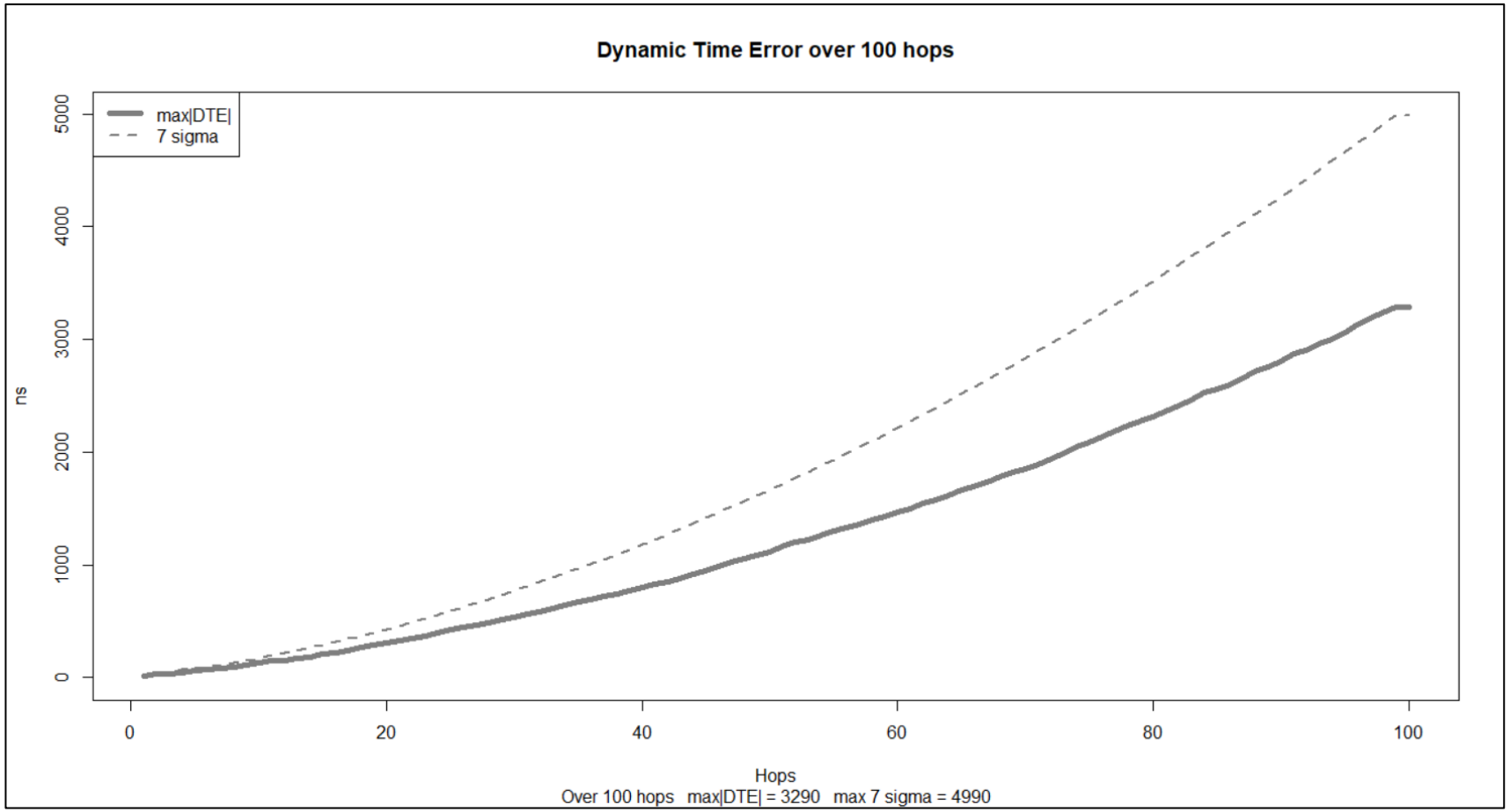
pDelay Interval 31.25ms



Input Errors		
GM Clock Drift Max	+1.5	ppm/s
GM Clock Drift Min	-1.5	ppm/s
Clock Drift Max (non-GM)	+1.5	ppm/s
Clock Drift Min (non-GM)	-1.5	ppm/s
Timestamp Granularity TX	2	±ns
Timestamp Granularity RX	2	±ns
Dynamic Time Stamp Error TX	2	±ns
Dynamic Time Stamp Error RX	2	±ns
Input Parameters		
pDelay Interval	31.25	ms
Sync Interval	125	ms
pDelay Response Time	10	ms
residenceTime	10	ms
Input Correction Factors		
Mean Link Delay Averaging	0	%
NRR Drift Rate Correction	0	%
RR Drift Rate Error Correction	0	%
pDelayResponse → Sync	0	%
mNRR Smoothing N	1	
mNRR Smoothing M	1	
Configuration		
Hops	100	
Runs	1,000,000	

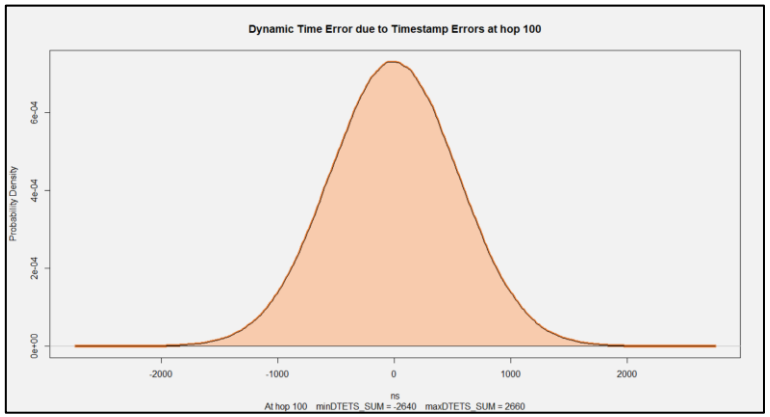
Case E – Timestamp Errors Halved

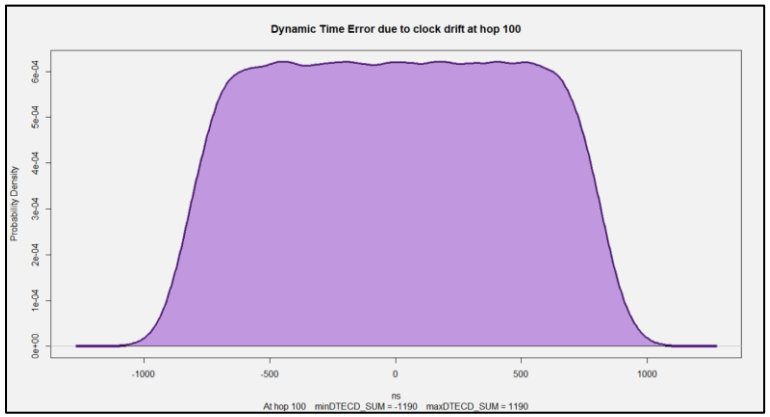
pDelay Interval 31.25ms

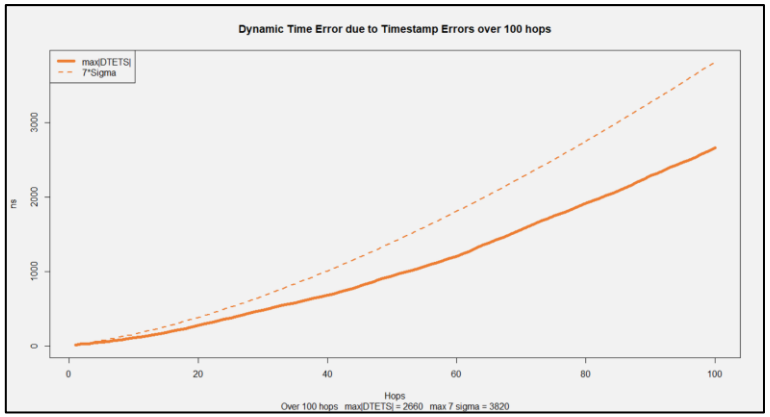


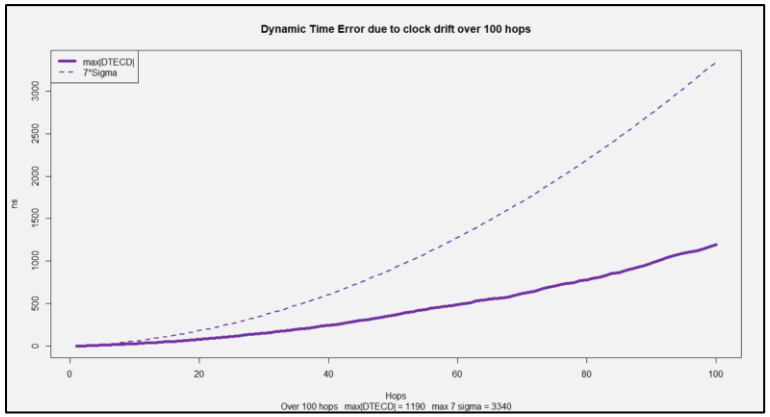
Case E – Timestamp Errors Halved

pDelay Interval 31.25ms



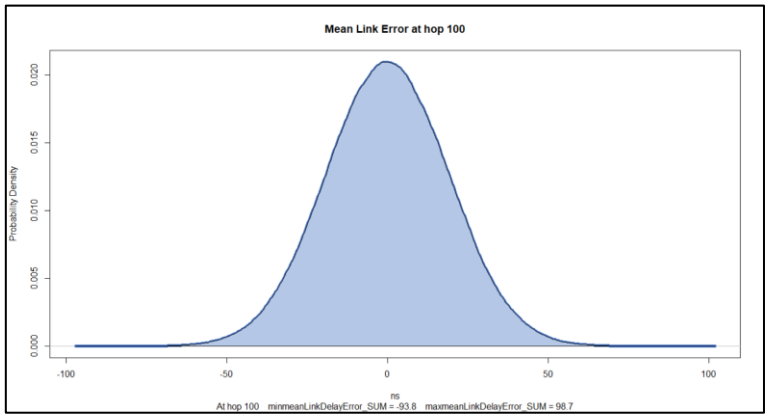


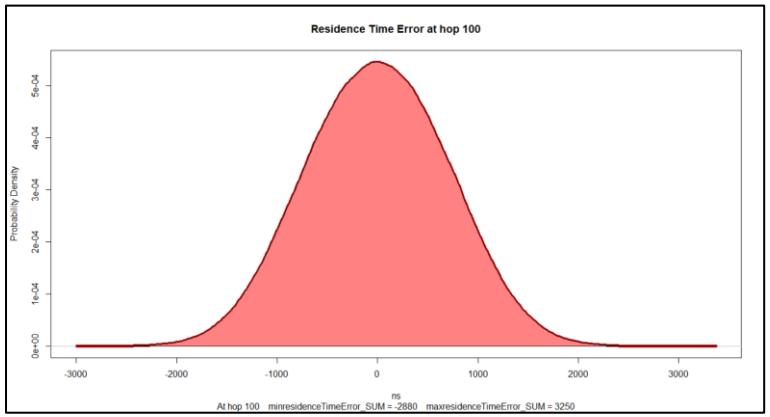


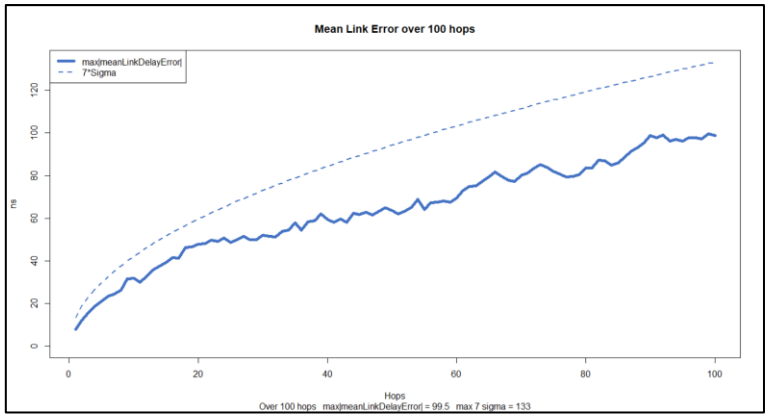


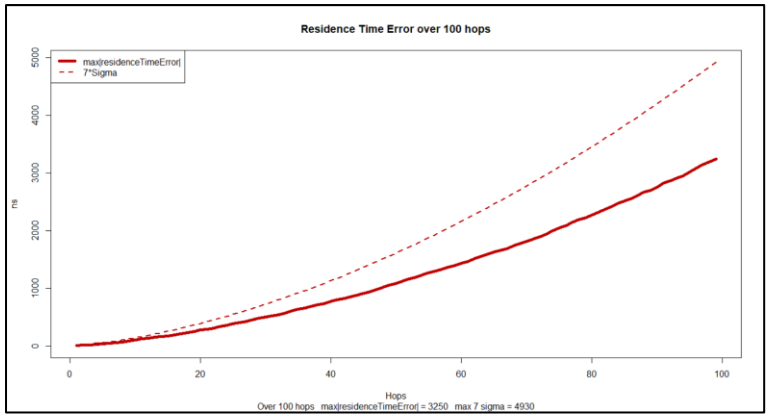
Case E – Timestamp Errors Halved

pDelay Interval 31.25ms



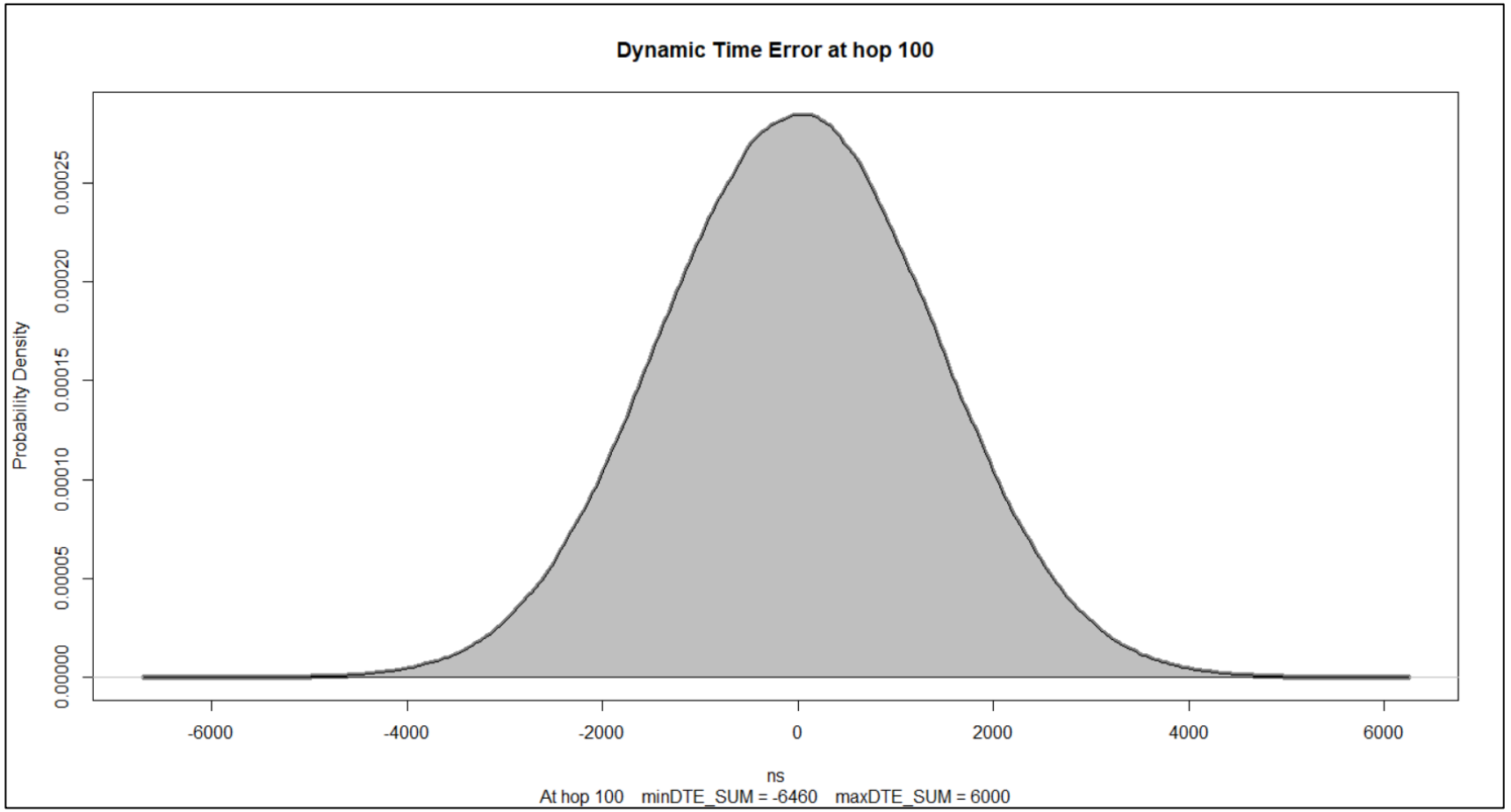






Case F – Clock Drift Halved

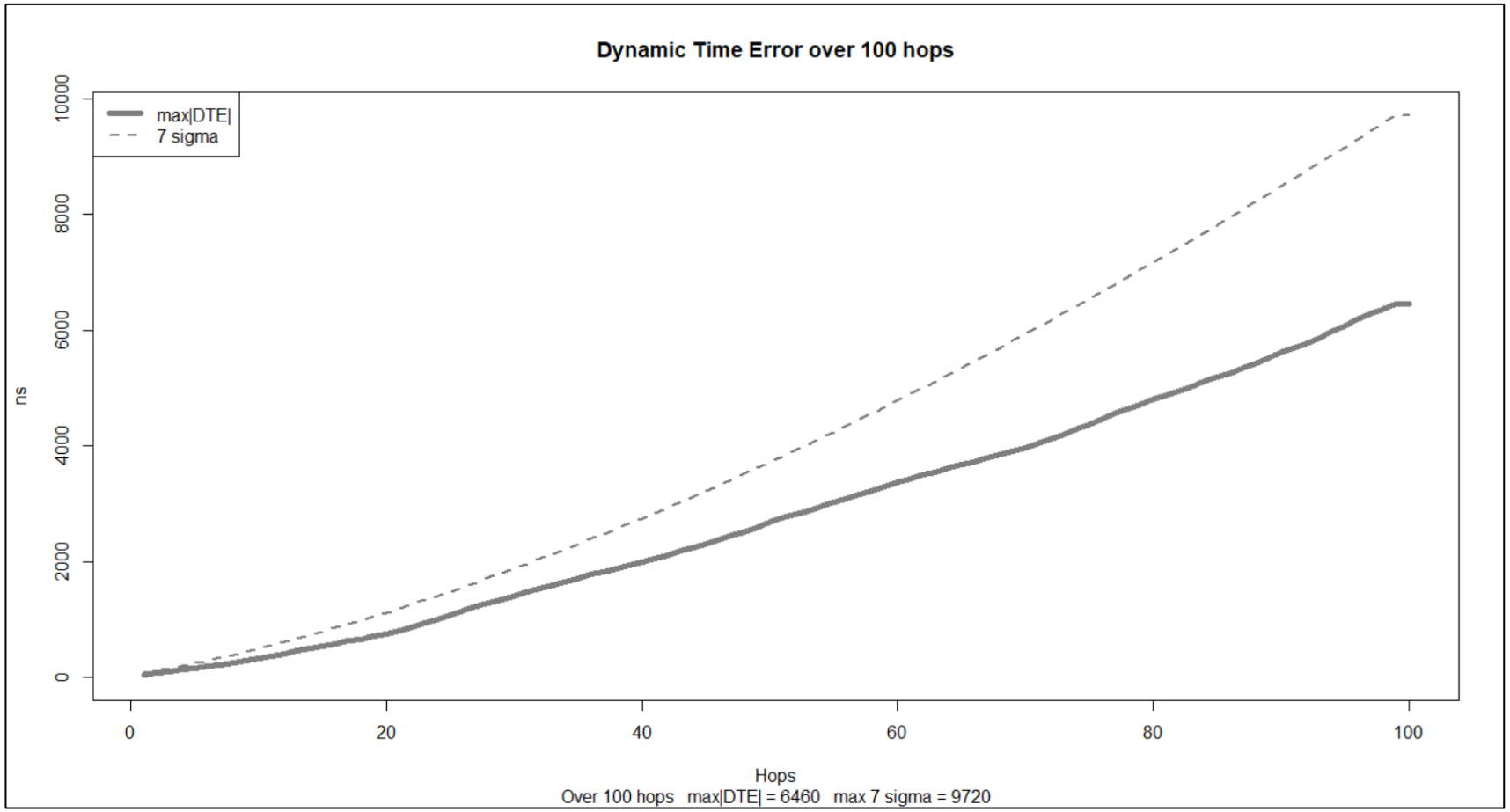
pDelay Interval 1000ms



Input Errors		
GM Clock Drift Max	+0.75	ppm/s
GM Clock Drift Min	-0.75	ppm/s
Clock Drift Max (non-GM)	+0.75	ppm/s
Clock Drift Min (non-GM)	-0.75	ppm/s
Timestamp Granularity TX	4	±ns
Timestamp Granularity RX	4	±ns
Dynamic Time Stamp Error TX	4	±ns
Dynamic Time Stamp Error RX	4	±ns
Input Parameters		
pDelay Interval	1000	ms
Sync Interval	125	ms
pDelay Response Time	10	ms
residenceTime	10	ms
Input Correction Factors		
Mean Link Delay Averaging	0	%
NRR Drift Rate Correction	0	%
RR Drift Rate Error Correction	0	%
pDelayResponse → Sync	0	%
mNRR Smoothing N	1	
mNRR Smoothing M	1	
Configuration		
Hops	100	
Runs	1,000,000	

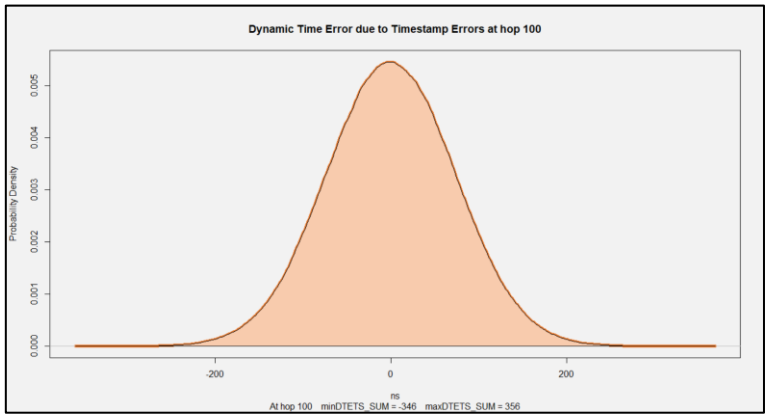
Case F – Clock Drift Halved

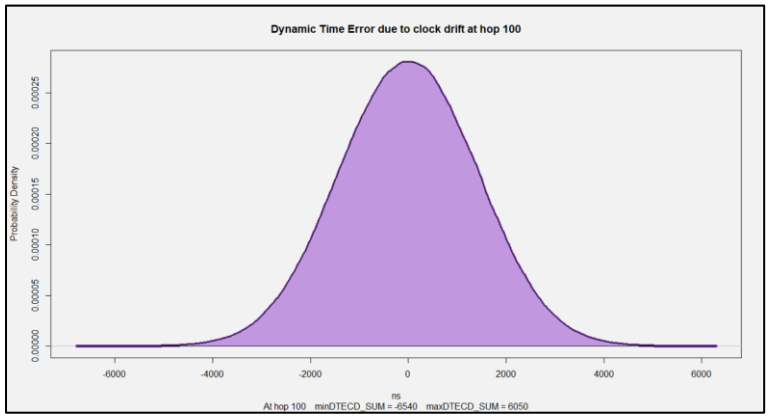
pDelay Interval 1000ms

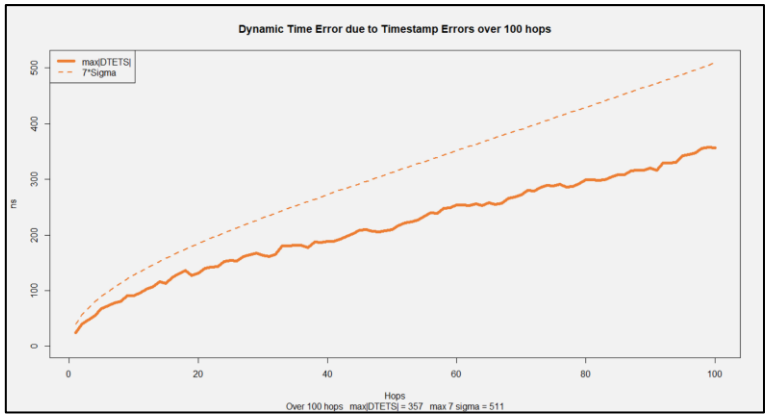


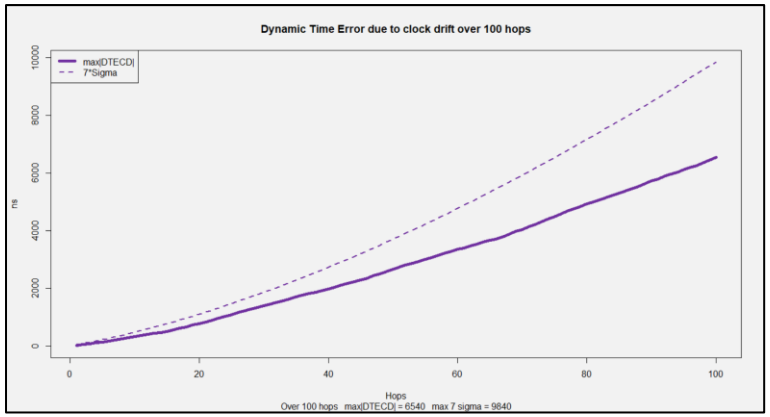
Case F – Clock Drift Halved

pDelay Interval 1000ms









Case F – Clock Drift Halved

pDelay Interval 1000ms