60802 Time Sync – Monte Carlo Simulations with RR & NRR Drift Tracking and Compensation – Initial Results

David McCall – Intel Corporation

Version 2
References

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Overview of Simulation

• Simulation continues to model many “runs” of a single Sync message.
  • Each run is independent of any other run.
  • Typical number of runs is 100,000 (10mins) to 3,000,000 (well over 5 hours; does not scale entirely linearly)

• Mostly models errors, not the passage of time, but...

• Includes limited model of time for clock drift via temperature ramp
  • Hybrid Monte Carlo / Time Series at this point...but time series aspect is very limited.

• All calculations for a given hop are done in parallel for all runs.

• Each run includes limited modelling of prior Sync messages and Pdelay_Req / _Resp messages necessary to calculate errors.
Initial Results
Default Configuration

hops <- 100 # Minimum 1 hop
runs <- 100000
#
# Input Errors, Parameters & Correction Factors
driftType <- 4
# 1 = DO NOT USE - Historical - Uniform Probability Distribution between MIN & MAX ppm/s
# 2 = Probability Based on Linear Temp Ramp
# 3 = Probability Based on Half-Sinusoidal Temp Ramp
# 4 = Probability Based on Quarter-Sinusoidal Temp Ramp
# Clock Drift Probability from Temp Curve & XO Offset/Temp Relationship
tempMax <- +85 # degC - Maximum temperature
tempMin <- -40 # degC - Minimum temperature
tempRampRate <- 1 # degC/s - Drift Rate for Linear Temp Ramp
tempRampPeriod <- 125 # s - Drift Period for Sinusoidal & Half-Sinusoidal Temp Ramps
tempHold <- 30 # s - Hold Period at MIN and MAX temps before next temp ramp down or up
GMscale <- 1 # Ratio of GM stability vs. standard XO. 1 is same. 0 is perfectly stable.
nonGMscale <- 1 # Ratio of non-GM (and non-ES) node stability vs. standard XO. 1 is same. 0 is perfectly stable.
Default Configuration

TSGEtx <- 4 # +/- ns - Error due to Timestamp Granularity on TX
TSGErx <- 4 # +/- ns - Error due to Timestamp Granularity on RX
DTSEtx <- 6 # +/- ns - Dynamic Timestamp Error on TX
DTSErx <- 6 # +/- ns - Dynamic Timestamp Error on RX
pDelayInterval <- 125 # ms - Nominal Interval between two pDelay measurements
PDImax <- 1.3 # Max factor for TpDelay2pDelay (uniform linear distribution max of pDelayInterval x PDImax)
PDImin <- 0.9 # Min factor for TpDelay2pDelay (uniform linear distribution min of pDelayInterval x PDImin)
syncInterval <- 125 # ms - Nominal Interval between two Sync messages
SImode <- 3 # Mode for generating Tsync2sync *HARD CODED to MODE 3*
    # 1 = Gamma Distribution, defaulting to 90% of Tsync2sync falling within 10% of the nominal syncInterval. Truncated at SImax (higher values above are reduced to SImax)
    # No truncation of low values
    # 2 = Gamma Distribution, defaulting to 90% of Tsync2sync falling within 10% of the nominal syncInterval. Truncated at SImax (higher values are reduced to SImax)
    # Truncated at SImin (lower values are increased to SImin)
    # 3 = Uniform, linear distribution between syncInterval x SImin and syncInterval x SImax
Default Configuration

SIScale <- 1 # Scaling factor for Mode 1 & 2 Tsync2sync vs regular distribution.
   # Scaling factor of 3 would mean 90% of Tsync2sync falling within 30% of the nominal syncInterval
SImax <- 1.048 # For mode 1 & 2, Max truncation factor (e.g. 2x syncInterval) limit for Tsync2sync; higher values reduced to SImax
   # For mode 3, upper limit of uniform linear distribution
SImin <- 0.952 # For mode 1 & 2, Min truncation factor (e.g. 0.5 x syncInterval) limit for Tsync2sync; higher values reduced to SImin
   # For mode 3, lower limit of uniform linear distribution
pDelayTurnaround <- 15 ms - TpdelayTurnaround maximum; higher values truncated
pathDelayMin <- 5 ns - 1m cable = 5ns path delay
pathDelayMax <- 500 ns - 100m cable = 500ns path delay
PDTmin <- 1 # TpdelayTurnaround minimum; lower values truncated
PDTmean <- 10 # TpdelayTurnaround mean
PDTsd <- 1.8 # TpdelayTurnaround sigma; 3.4ppm will fall outside 6-sigma either side of the mean
residenceTime <- 15 ms - TresidenceTime maximum; higher values truncated
RTmin <- 1 # TresidenceTime minimum; lower values truncated
RTmean <- 5 # TresidenceTime mean
RTsd <- 1.8 # TresidenceTime sigma; 3.4ppm will fall outside 6-sigma either side of the mean
Default Configuration

mLinkDelayAverage <- 50 # Number of Path Delay calculations, from Pdelay_Req & _Resp messages
    # that are averaged to generate mLinkDelay
mNRRsmoothingNA <- 4 # Whole Number >=1 - Combined N & A value for "smoothing" calculated mNRR (mNRRc)
    # Calculate mNRR using timestamps from Nth Sync message in the past
    # Then take average of previous A mNRRcalculations.

mNRRcompNAP <- 4 # Whole Number >=1
    # For NRR drift rate error correction calculations, take two measurements, mNRRa and mNRRb.
    # Both use timestamps from Nth Sync message in the past, then take average of previous A calculations.
    # Calculation mNRRb starts P calculations in the past from mNRRa, where P = mNRRcompNAP * 2.
    # If 0, there is no NRR drift rate error correction.
Default Configuration Results

Dynamic Time Error at hop 100

At hop 100, \( \text{minDTE}_{\text{SUM}} = -1300 \) and \( \text{maxDTE}_{\text{SUM}} = 1010 \).
Default Configuration Results

Dynamic Time Error due to Timestamp Errors at hop 100

At hop 100  minDTETS_SUM = -323  maxDTETS_SUM = 335
Default Configuration Results

Dynamic Time Error due to clock drift at hop 100

At hop 100  minDTECD_SUM = -1240  maxDTECD_SUM = 879
Default Configuration Results

![End Station error at hop 100](image)

At hop 100

minEError = -324
maxEError = 317
Default Configuration Results

![Residence Time error at hop 99](image)

At hop 99, \( \text{minRError} = -1010 \) ns, \( \text{maxRError} = 768 \) ns.
Default Configuration Results

Station Error due to Clock Drift (direct and via component of mNRR via Rate Ratio) at hop 100

At hop 100  min ErrorCD_X = -327   max ErrorCD_X = 308
Default Configuration Results

At hop 100, minRTerrorCD_SUM = -906, maxRTerrorCD_SUM = 600
Half-Sinusoidal Temp Ramp

Dynamic Time Error at hop 100

At hop 100  minDTE_SUM = -620  maxDTE_SUM = 610
Half-Sinusoidal Temp Ramp
Half-Sinusoidal Temp Ramp

Dynamic Time Error due to clock drift at hop 100

At hop 100  minDTECD_SUM = -385  maxDTECD_SUM = 416
Half-Sinusoidal Temp Ramp

End Station error at hop 100

At hop 100  minError = -167  maxError = 176
Half-Sinusoidal Temp Ramp

Residence Time error at hop 99

At hop 99  
minRTErr = -466  
maxRTErr = 454

-400  -200  0  200  400
ns

Probability Density

0.000  0.001  0.002  0.003
Half-Sinusoidal Temp Ramp
Half-Sinusoidal Temp Ramp

 chimpance Time Error due to Clock Drift (direct and via component of mNRR via Rate Ratio

![Graph showing probability density over ns with annotations: At hop 100, minRErrorCD_SUM = -250, maxRErrorCD_SUM = 272.](image)
Half-Sinusoidal, (Default 125s Temp Ramp) GMscale 0.5 (±25ppm equivalent)
Half-Sinusoidal, 250s Temp Ramp
GMscale 0.5 (±25ppm equivalent)

Dynamic Time Error at hop 100

At hop 100  minDTE_SUM = -450  maxDTE_SUM = 511
Half-Sinusoidal, (Default 125s Temp Ramp) GMscale 0.5 (±25ppm equivalent), mNRRcompNAP 3
To Investigate...

• Varying mNRRcompNAP (and mNRRsmoothingNA)
• More Stable GM
• ±1 ppm/s Drift Rate (change Temp Cycle to generate this maximum)
• Longer periods of stability (more nodes stable per run)
• Shorter residenceTime
Thank you!