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Measuring and Characterizing Network Time

Lee Cosart
lee.cosart@microsemi.com

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Introduction

- Frequency transport
  - One-way: forward & reverse packet streams can be used separately
  - Asymmetry is irrelevant
  - Stable frequency needed
  - PRC (primary reference clock) needed
  - GNSS/GPS antenna cable compensation/calibration not needed
  - GSM frequency backhaul (50 ppb) is example technology

- Time transport
  - Two-way: forward & reverse packet streams used together
  - Asymmetry is critical
  - Stable time and frequency needed
  - PRTC (primary reference time clock) or ePRTC (enhanced PRTC) needed
  - GNSS/GPS antenna cable compensation/calibration needed
  - LTE-TDD time/phase (1.5 µsec) is example technology

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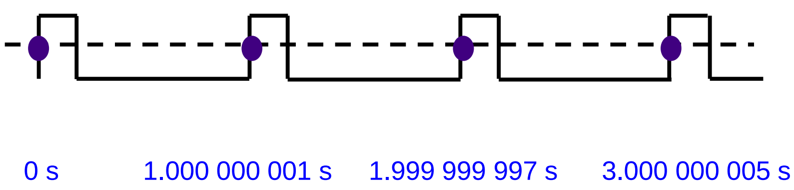
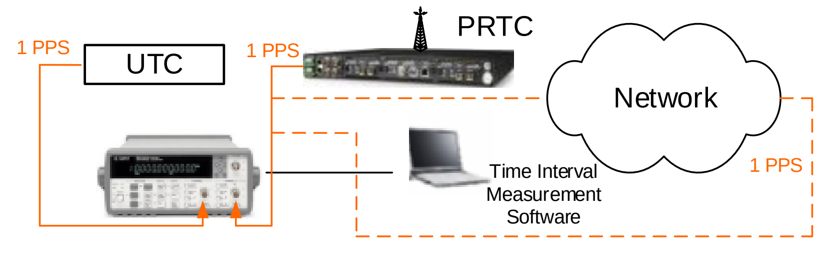
Testing Time “Physical” vs. “Packet”

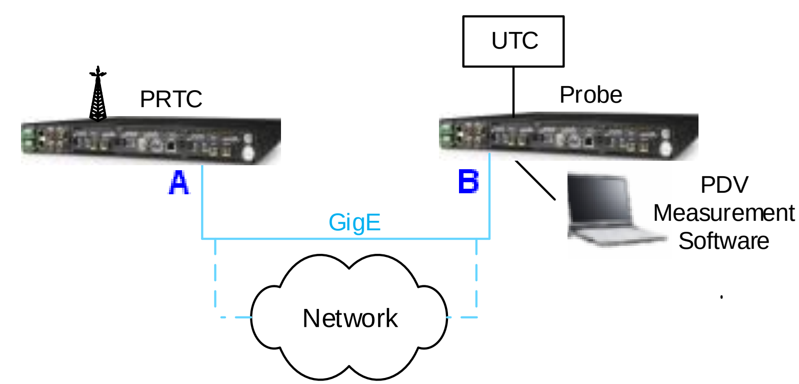
- “1 PPS” (Single Point Measurement)
  - Measurements are made at a single point – a single piece of equipment in a single location - a phase detector with reference - is needed





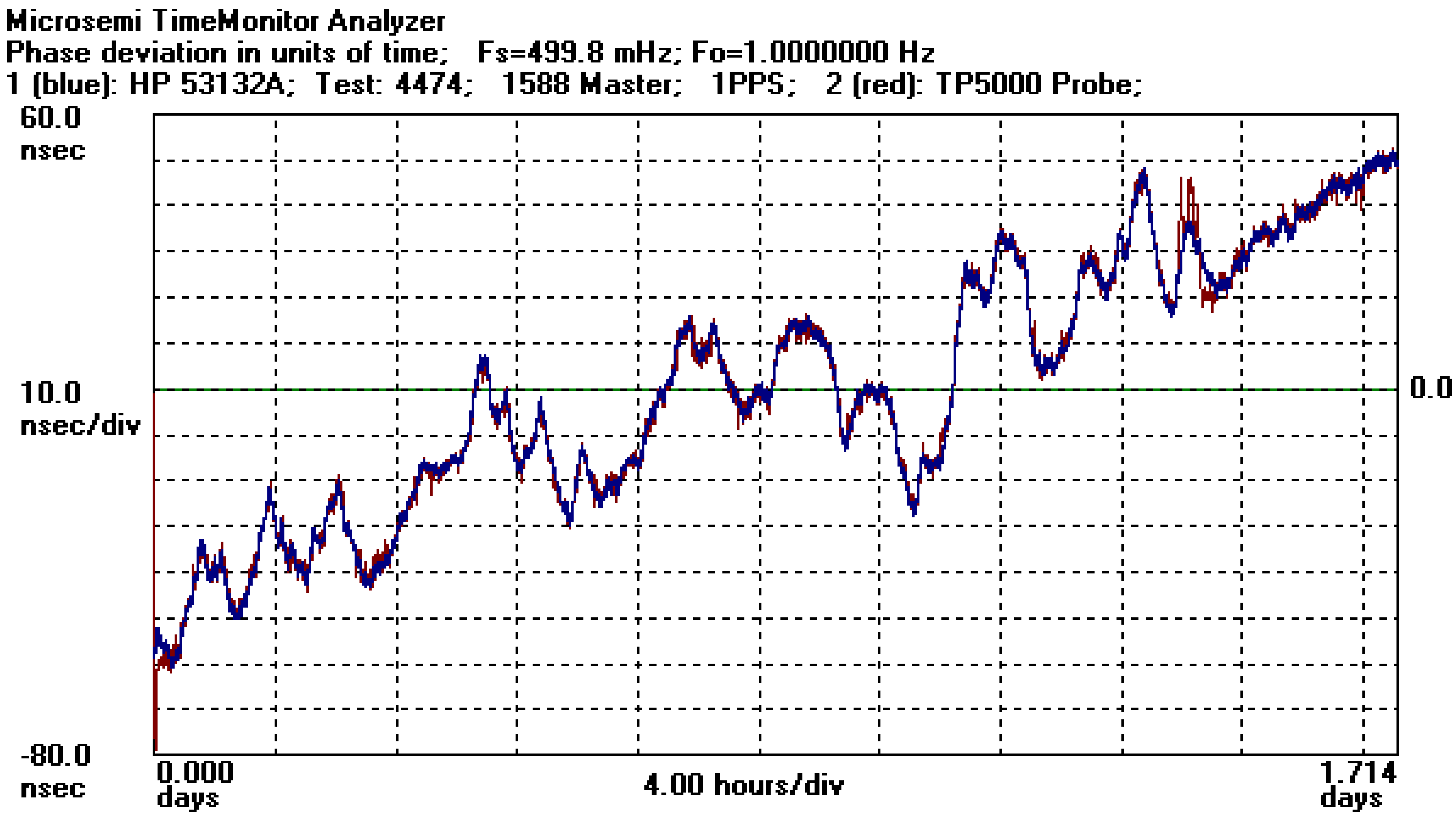
- “Packet” (Dual Point Measurement)
  - Measurements are constructed from packets time-stamped at two points – in general two pieces of equipment, each with a reference, at two different locations – are needed

	Timestamp A	Timestamp B
F	1286231440.883338640	1286231440.883338796
R	1286231441.506929352	1286231441.506929500
F	1286231441.883338640	1286231441.883338796
R	1286231442.506929352	1286231442.506929500
F	1286231442.883338640	1286231442.883338796
R	1286231443.506929352	1286231443.506929516



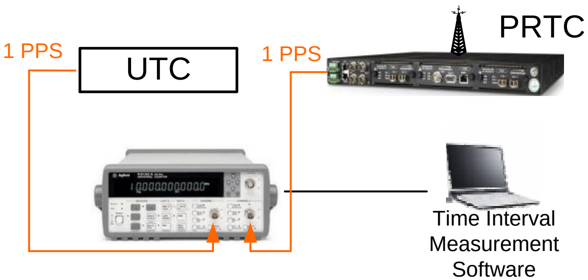
Grandmaster Test PPS and Packet Probe

Physical 1PPS signal measurement and packet signal tested with probe match



Time Accuracy and Stability Requirements

PRTC



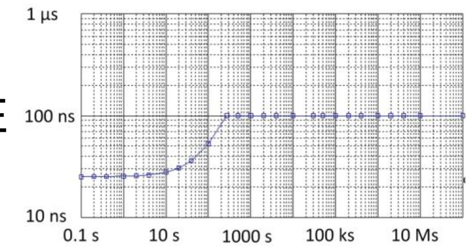
G.8272

Time Accuracy

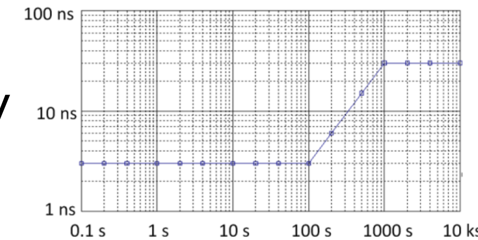
Time Error: <=100ns

Time Stability

MTIE

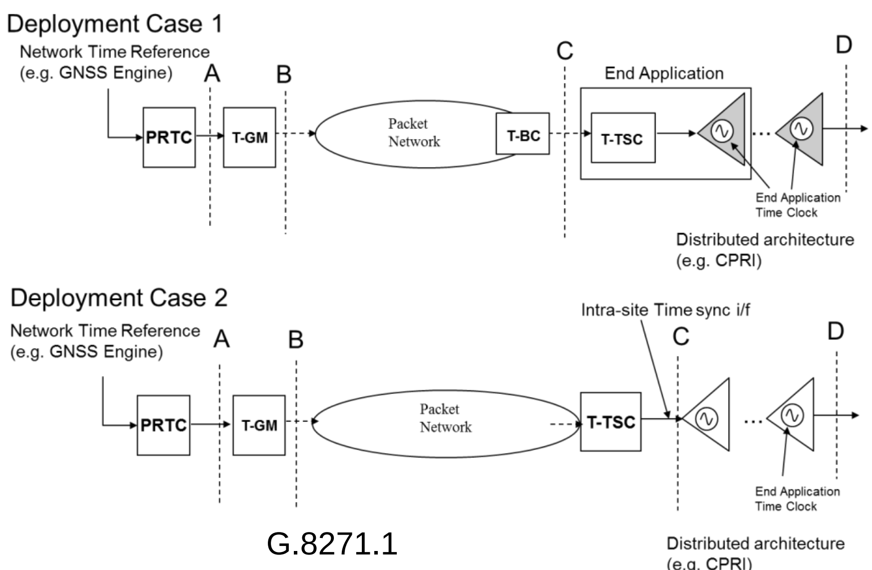


TDEV



MTIE is G.811 with 100 ns maximum
TDEV is G.811 exactly

Packet Network Limits



G.8271.1

A: Time Error: <=100ns

C: Time Error: <=1.1µs

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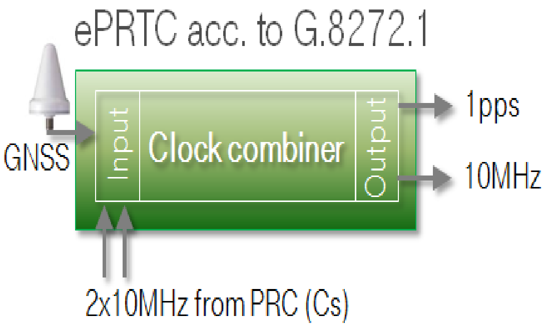
ePRTC: Enhanced PRTC G.8272.1

ePRTC

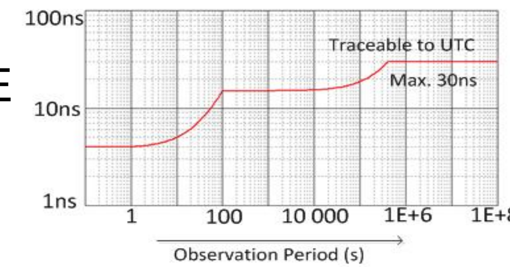


Time Accuracy

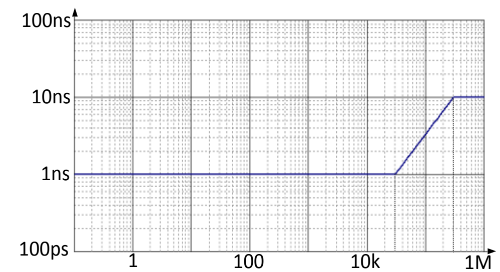
Time Error: <=30ns

Time Stability

MTIE



TDEV



ePRTC Attributes

- Reliability: Immune from local jamming or outages
- Autonomy: Atomic clock sustained timescale with & without GNSS connection
- Coherency: 30ns coordination assures overall PRTC budget
- Holdover: 14-day time holdover <= 100 ns

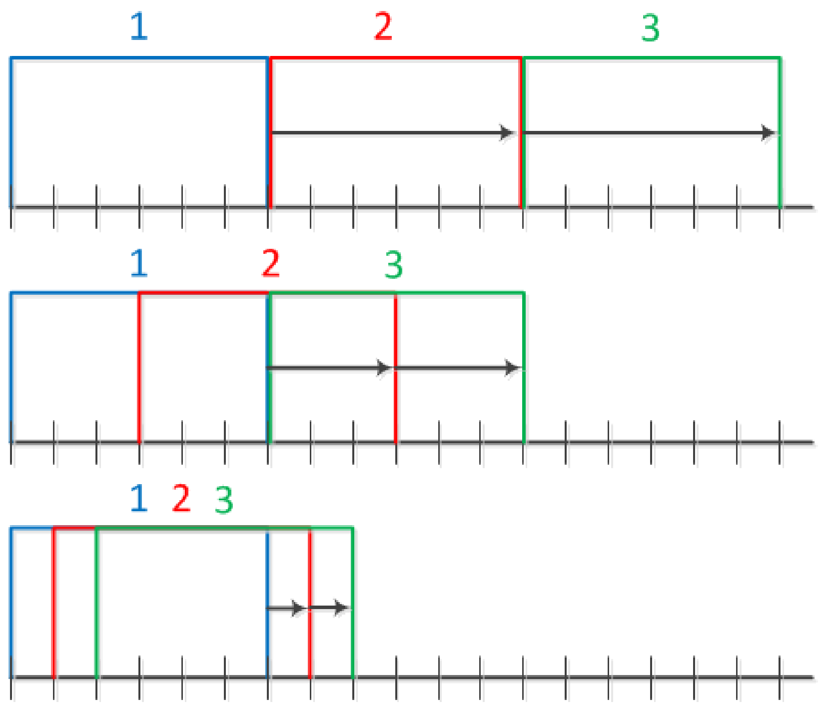
Stability metrics for PDV

- Packet Selection Processes
  1) ***Pre-processed:*** packet selection step prior to calculation
     - Example: ***TDEV***(*PDVmin*) where *PDVmin* is a new sequence based on minimum searches on the original PDV sequence
  2) ***Integrated:*** packet selection integrated into calculation
     - Example: ***minTDEV***(*PDV*)

- Packet Selection Methods
  - Minimum: $x_{\min}(i) = \min\left[x_j\right] for\ \left(i <= \ j <= \ i + n - 1\right)$
  - Percentile: $x'_{pct\_mean}(i) = \frac{1}{m}\sum_{j=0}^{b} x'_{j+i}$
  - Band: $x'_{band\_mean}(i) = \frac{1}{m}\sum_{j=a}^{b} x'_{j+i}$
  - Cluster: $x(n\tau_0) = \frac{\sum_{i=0}^{(K-1)} w((nK+i)\tau_P)\cdot\phi(n,i)}{\sum_{i=0}^{(K-1)}\phi(n,i)}$ $\phi(n,i) = \begin{cases} 1 & for \quad \left|w(nK+i) - \alpha(n)\right| < \delta \\ 0 & otherwise \end{cases}$

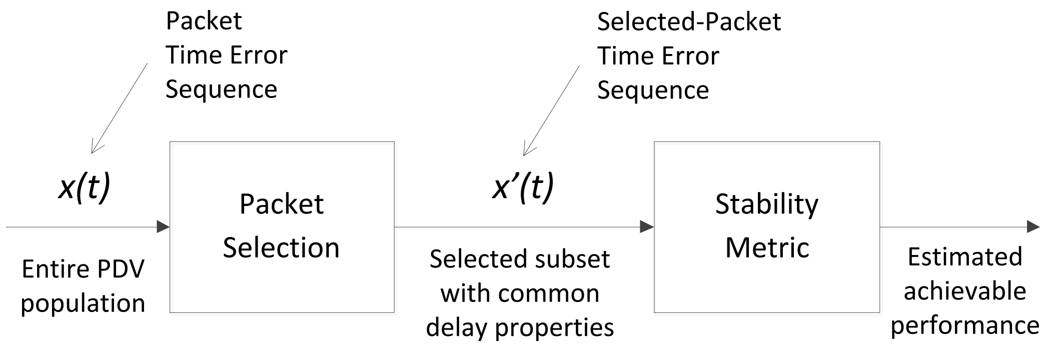
Packet Selection Windows

- Windows
  - ***Non-overlapping windows*** (next window starts at prior window stop)
  - ***Skip-overlapping windows*** (windows overlap but starting points skip over N samples)
  - ***Overlapping windows*** (windows slide sample by sample)

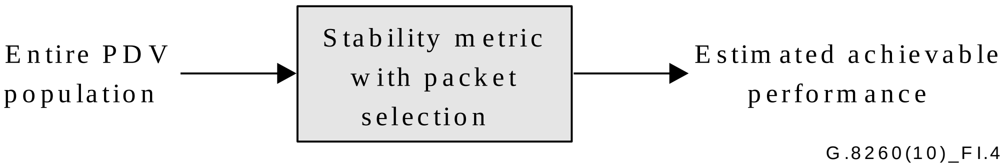


- Packet Selection Approaches (e.g. selecting fastest packets)
  - Select X% fastest packets (e.g. 2%)
  - Select N fastest packets (e.g. 10 fastest packets in a window)
  - Select all packets faster than Y (e.g. all packets faster than 150µs)

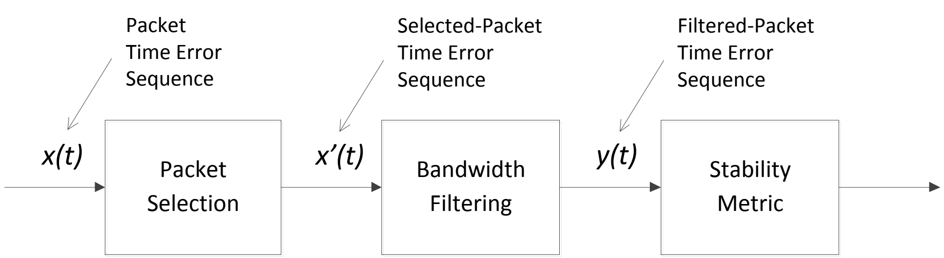
G.8260 Appendix I Metrics



Pre-processed packet selection



Integrated packet selection



Metrics including pre-filtering

FPC, FPR, FPP: Floor Packet Count/Rate/Percent

PDV metrics studying minimum floor delay packet population

Time Transport: Two-way metrics

Packet Time Transport Metrics

MeanPathDelay: $$r(n) = \left(\frac{1}{2}\right) \cdot [R(n) + F(n)]$$

TwowayTimeError: $$r_2(n) = \left(\frac{1}{2}\right) \cdot [R(n) - F(n)]$$

pktSelectedMeanPathDelay: $$r'(n') = \left(\frac{1}{2}\right) \cdot [R'(n') + F'(n')]$$

pktSelectedTwowayTimeError: $$r_2'(n') = \left(\frac{1}{2}\right) \cdot [R'(n') - F'(n')]$$

Ideal F/R: floor
("lucky" packets: fastest)

min2wayTE: $$r_2^m(n) = \left(\frac{1}{2}\right) \cdot [R^m(n) - F^m(n)]$$

pct2wayTE $$r_2^p(n) = \left(\frac{1}{2}\right) \cdot [R^p(n) - F^p(n)]$$

cluster2wayTE $$r_2^c(n) = \left(\frac{1}{2}\right) \cdot [R^c(n) - F^c(n)]$$

Ideal 2way TE: zero
(no asymmetry)

psTDISP (min/pct/clst time dispersion): ps2wayTE{y} plotted against psMeanPathDelay{x} as a scatter plot

ps2wayTE statistics: ps2wayTE statistic such as mean, standard deviation, median, 95 percentile plotted as a function of time window tau; min/maxATE

Weighted average: $$w(n) = [\alpha \cdot F(n) + (1-\alpha) \cdot R(n)]$$ where $0 \le \alpha \le 1$

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Time Transport: Two-way packet delay

Forward Packet Delay Sequence

#Start: 2010/03/06 17:15:30
0.0000, 1.47E-6
0.1000, 1.54E-6
0.2000, 1.23E-6
0.3000, 1.40E-6
0.4000, 1.47E-6
0.5000, 1.51E-6

Packet Delay SequenceReverse

#Start: 2010/03/06 17:15:30
0.0000, 1.11E-6
0.1000, 1.09E-6
0.2000, 1.12E-6
0.3000, 1.13E-6
0.4000, 1.22E-6
0.5000, 1.05E-6

Two-way Data Set

#Start: 2010/03/06 17:15:30
0.0000, 1.47E-6, 1.11E-6
0.1000, 1.54E-6, 1.09E-6
0.2000, 1.23E-6, 1.12E-6
0.3000, 1.40E-6, 1.13E-6
0.4000, 1.47E-6, 1.22E-6
0.5000, 1.51E-6, 1.05E-6

Minimum Search Sequence

Time(s)	f(μs)	r(μs)	f'(μs)	r'(μs)
0.0	1.47	1.11		
0.1	1.54	1.09	1.23	1.09
0.2	1.23	1.12		
0.3	1.40	1.13		
0.4	1.47	1.22	1.40	1.05
0.5	1.51	1.05		

Constructing *f´* and *r´* from *f* and *r* with a 3-sample time window

min2wayTE

0.1	-0.07
0.4	-0.18

$$r_2'(n) = \left(\frac{1}{2}\right)\cdot[R'(n) - F'(n)]$$

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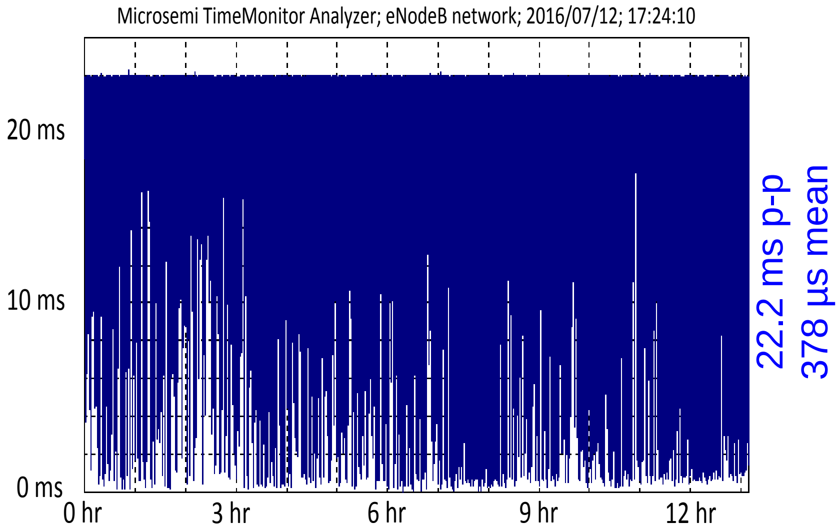
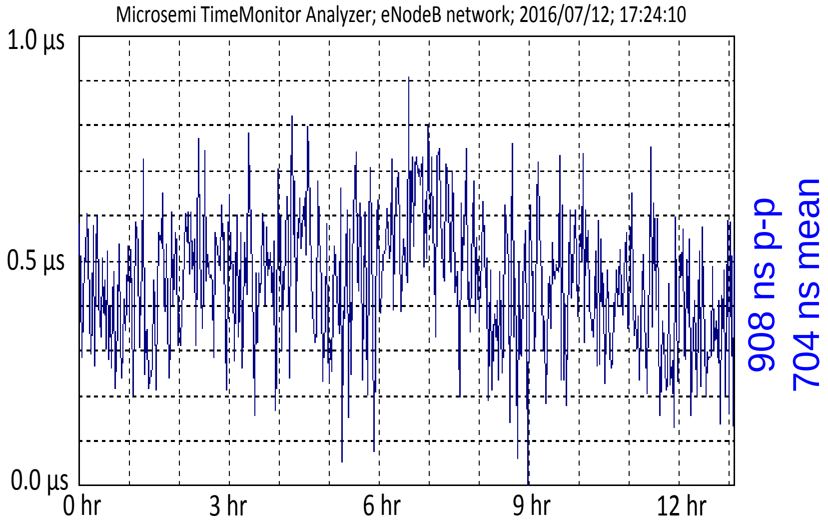
Time Transport: Two-way metrics

2wayTE



pktSelected2wayTE



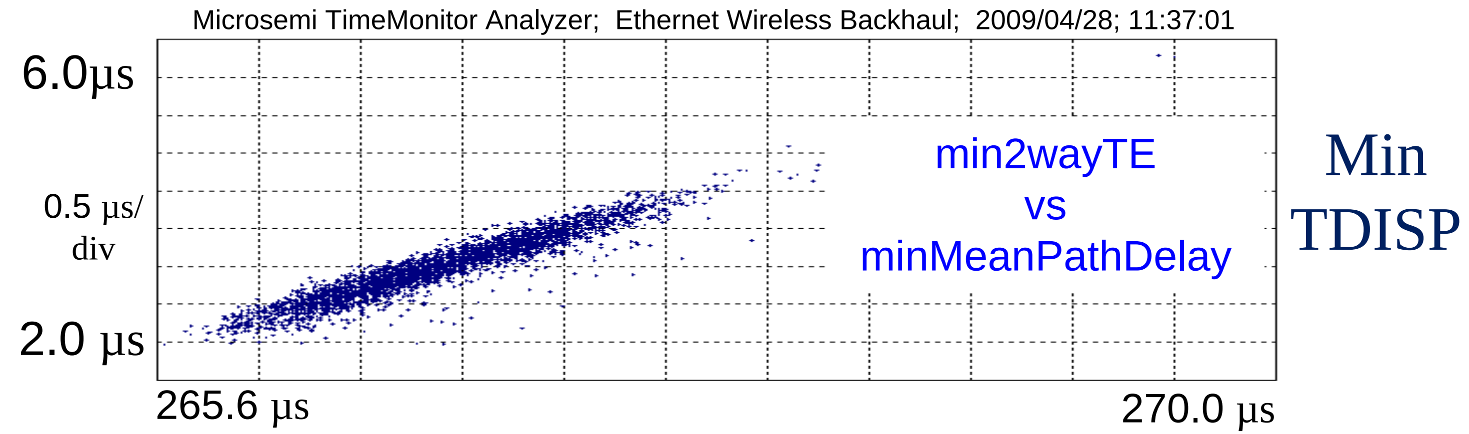
Both 2wayTE and pktSelected2wayTE plots with minimum set to 0. Mean value from unadjusted data.

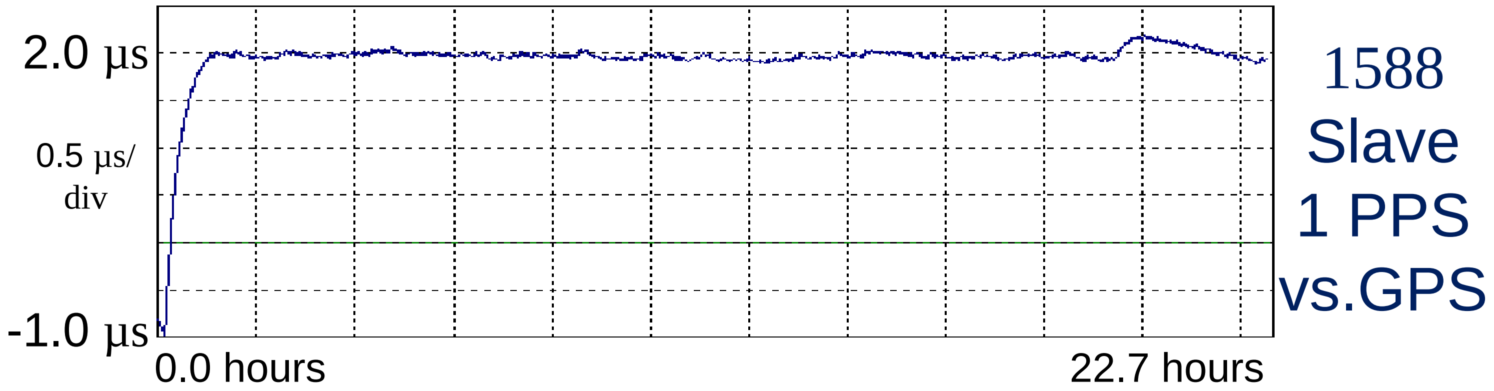
Selection window = 100s
Selection percentage = 0.5%
Peak-to-peak pktSelected2wayTE = 908 ns
(G.8271.2 draft APTS limit: <1150 ns)

Two-way Time Error ⇔ Network Asymmetry

Asymmetry in Wireless Backhaul

(Ethernet wireless backhaul asymmetry and IEEE 1588 slave 1PPS under these asymmetrical network conditions)





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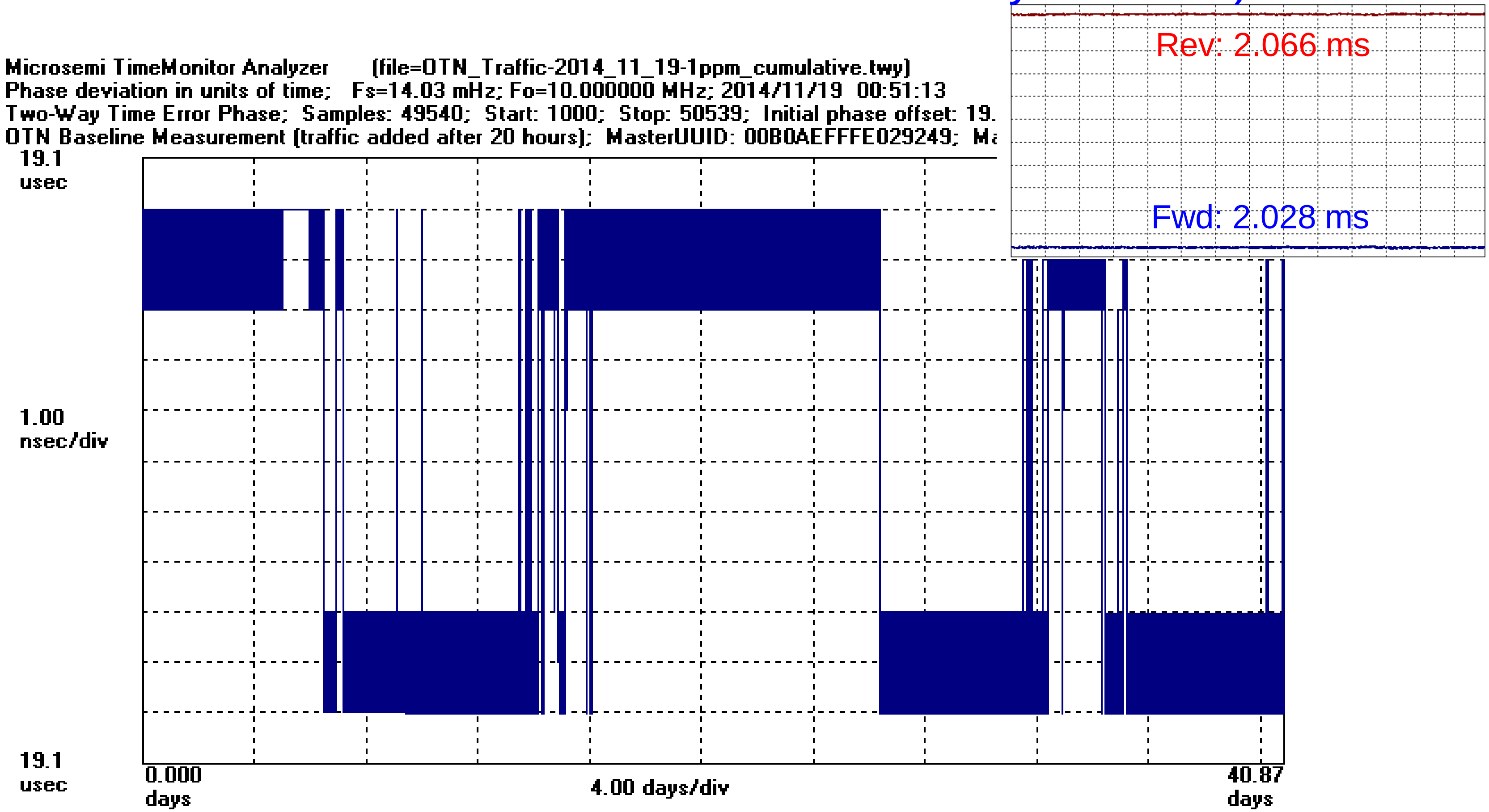
Network Asymmetry

150 km fiber PTP over OTN transport

(2wayTE is 19.1 µsec which represents the 38.2 µsec difference between forward and reverse one-way latencies)



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Conclusions

- Packet time transport measurements require common time scale reference at both ends of the network being studied (GNSS at both ends is a way to do this)
- Asymmetry is everywhere, asymmetry is invisible to the IEEE 1588 protocol, thus asymmetry has a direct bearing on the ability to transport time precisely
- The “two-way time error” calculation is a direct measure of asymmetry
- There are two ways to assess time transport: (1) measuring a 1PPS reference at the node being studied and (2) measuring a packet signal at the node being studied
- Packet metrics for time transport must use both forward and reverse streams together rather than separately as is the case for frequency transport
- Packet metrics for time transport can make use of much of the methodology used for packet frequency transport metrics

Thank You

Lee Cosart

Senior Technologist

Lee.Cosart@microsemi.com

Phone: +1-408-428-7833