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Network Time Transport: Measurements, Asymmetry, and Metrics

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Introduction

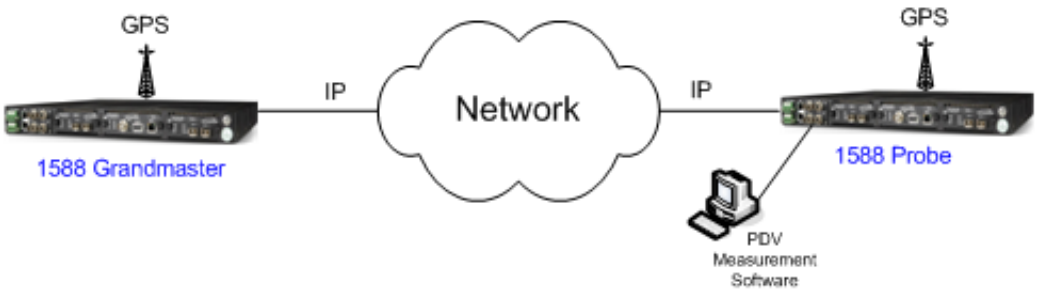
- Frequency transport
  - One-way: forward & reverse packet streams can be used separately
  - Asymmetry is irrelevant
  - Stable frequency needed
  - PRC (primary reference clock) needed
  - GNSS/GPS antenna cable compensation/calibration not needed
  - GSM frequency backhaul (50 ppb) is example technology

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

Packet Time Transport Measurements

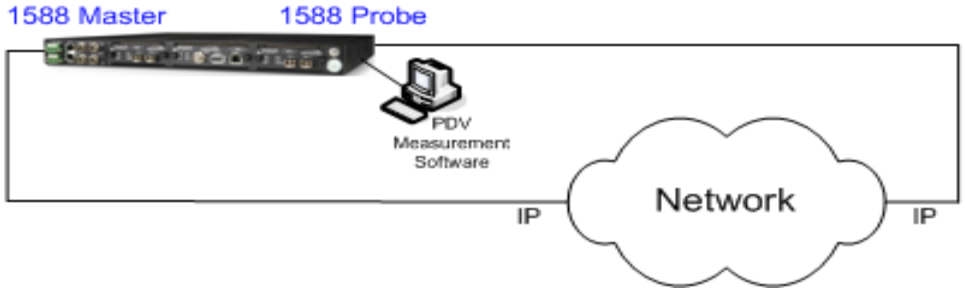
"PDV" measurement setup for time transport

✓ – Ideal setup - two packet timestampers with common timescale (eg. GPS reference) so absolute latency can be measured as well as PDV over small to large areas



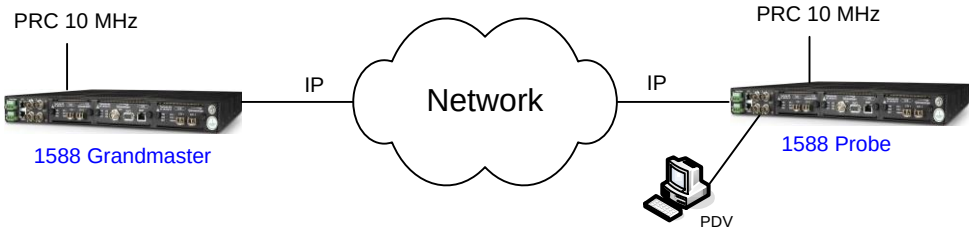
Time or Frequency

✓ – Alternative setup (lab) – frequency (or GPS) locked single shelf with two packet timestampers



Time or Frequency

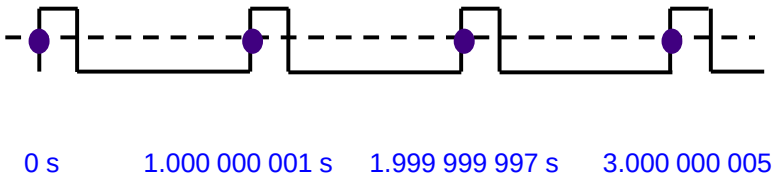
✗ – Alternative setup (field) – frequency locked packet timestampers – PDV but neither <u>latency</u> nor <u>asymmetry</u> can be measured

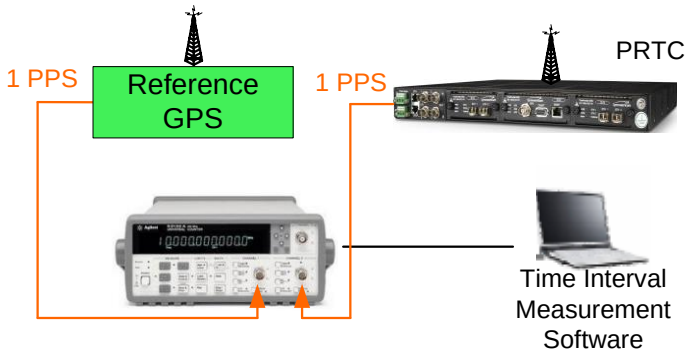


Frequency Only

PRTC Testing “Physical” vs. “Packet”

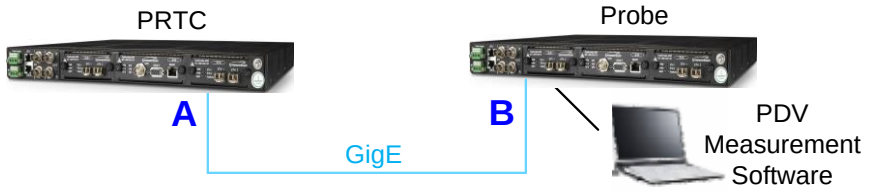
- “1 PPS” (Single Point Measurement)
  - Measurements are made at a single point – a single piece of equipment in a single location - a phase detector with reference - is needed





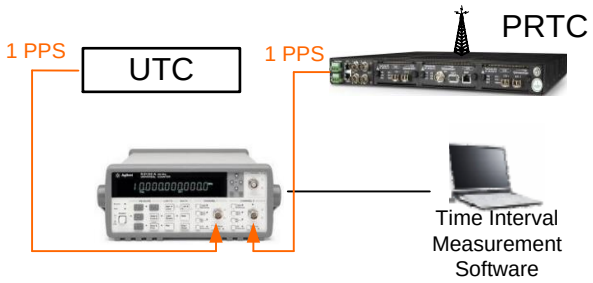
- “Packet” (Dual Point Measurement)
  - Measurements are constructed from packets time-stamped at two points – in general two pieces of equipment, each with a reference, at two different locations – are needed

	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



Time Accuracy and Stability Requirements

PRTC



G.8272

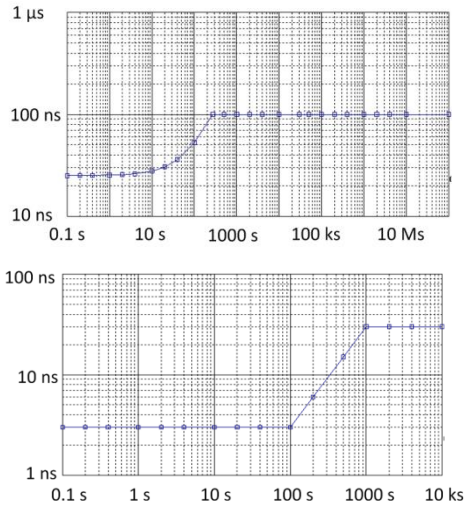
Time Accuracy

Time Error: <=100ns

Time Stability

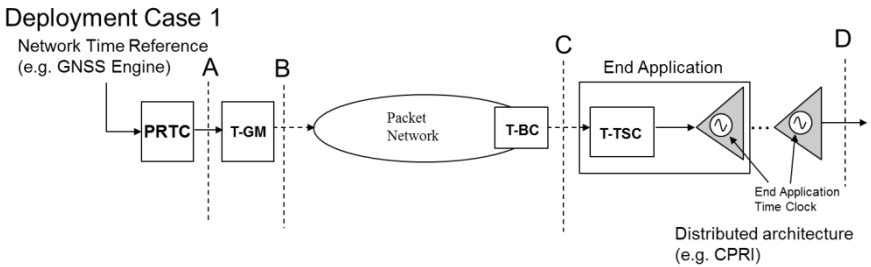
MTIE

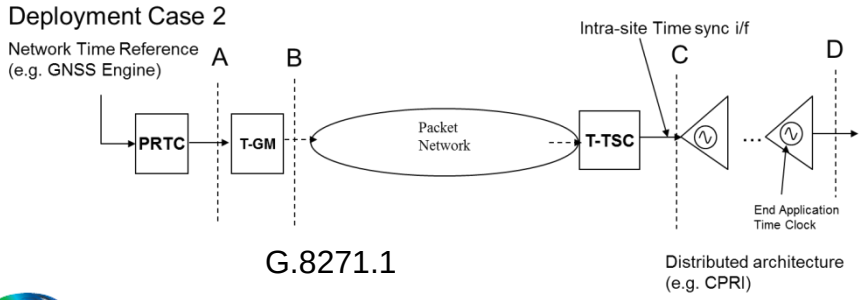
TDEV



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

Frequency Transport: One-way packet delay

Packet Delay Sequence

```
R,00162; 1223305830.478035356; 1223305830.474701511
F,00167; 1223305830.488078908; 1223305830.490552012
R,00163; 1223305830.492882604; 1223305830.489969511
F,00168; 1223305830.503473436; 1223305830.505803244
R,00164; 1223305830.508647148; 1223305830.505821031
F,00169; 1223305830.519029300; 1223305830.521302172
R,00165; 1223305830.524413852; 1223305830.521446071
F,00170; 1223305830.534542972; 1223305830.536801164
R,00166; 1223305830.540181132; 1223305830.537115991
F,00171; 1223305830.550229692; 1223305830.552551628
```

Packet Timestamps

Forward

Reverse

#Start: 2009/10/06 15:10:30

0.0000, 2.473E-3
0.0155, 2.330E-3
0.0312, 2.273E-3
0.0467, 2.258E-3
0.0623, 2.322E-3

One-way Data Set

#Start: 2009/10/06 15:10:30

0.0000, 3.334E-3
0.0153, 2.913E-3
0.0311, 2.826E-3
0.0467, 2.968E-3
0.0624, 3.065E-3

One-way Data Set

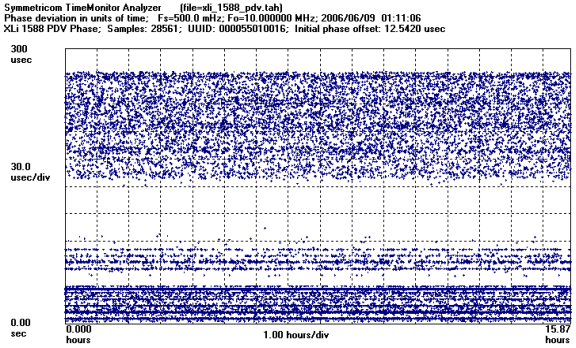
Frequency Transport: One-way metrics

Calculations made on either forward PDV sequence or reverse PDV sequence *individually*

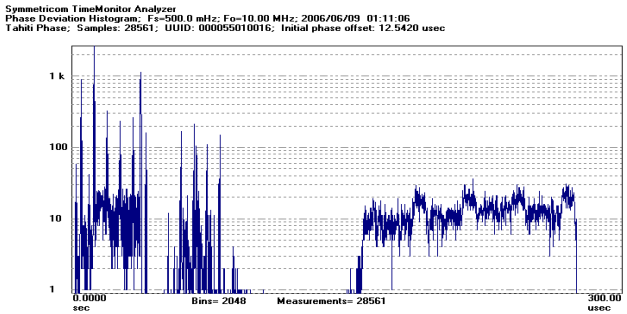
- PDV phase
- PDV histogram/PDF*,CDF**, statistics
- PDV dynamic statistics
- MATIE/MAFE
- TDEV/minTDEV/bandTDEV
- FPC/FPR/FPP (floor packet count/rate/percent)

* *PDF = probability density function*

** *CDF = cumulative distribution function*



PDV



PDV Histogram

Frequency packet metrics focused on *variations*; knowledge of *latency* and *asymmetry* not needed

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

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

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		

Minimum Search Sequence

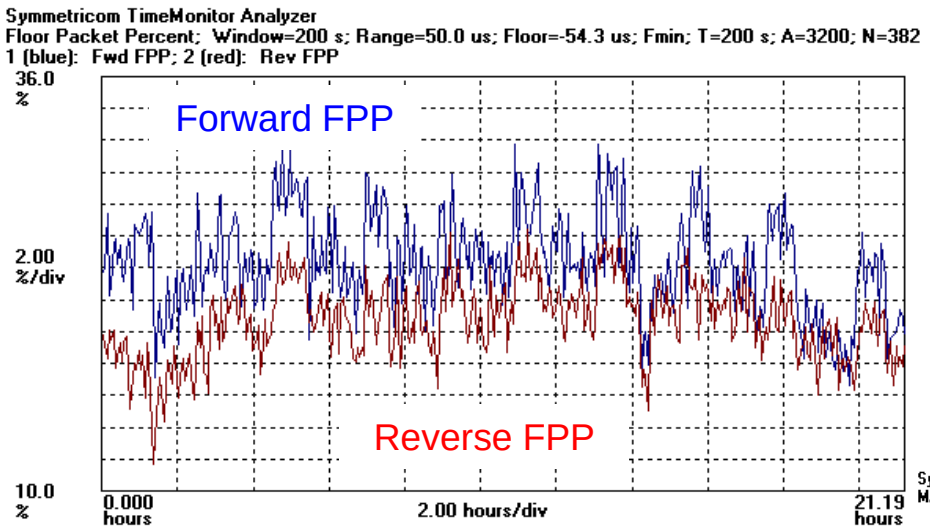
0.1	0.07
0.4	0.18

minOffset

$$\eta_2'(n') = \left(\frac{1}{2}\right) \cdot \left[F'(n') - R'(n')\right]$$

Time Transport: Two-way metrics

Forward/Reverse FPP



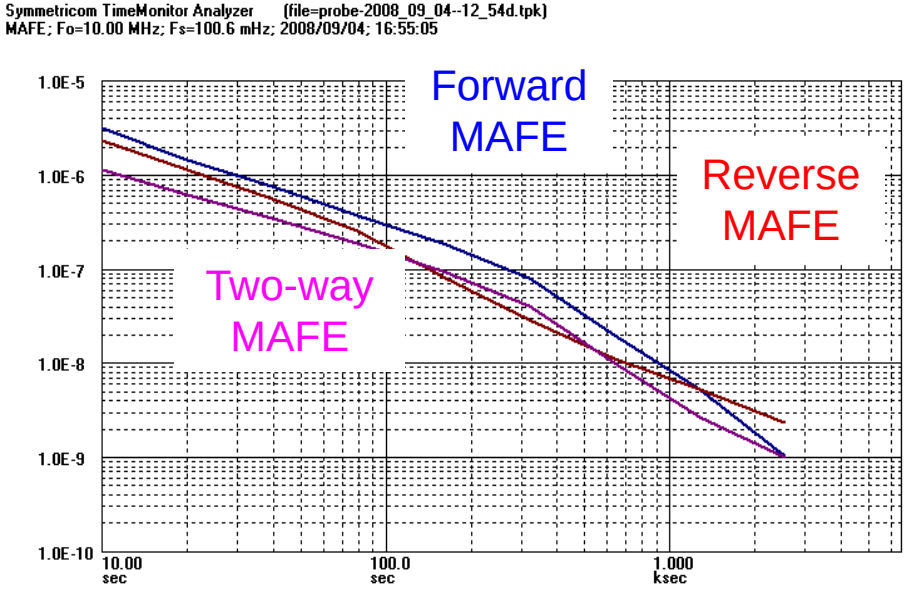
Approaches:

(1) Based on both one-way sequences

(2) Based on a single sequence constructed from both one-way sequences (e.g. offset)

Two-way MAFE

(MAFE of minOffset)



Comments:

(1) Knowledge of asymmetry and latency in both directions is critical

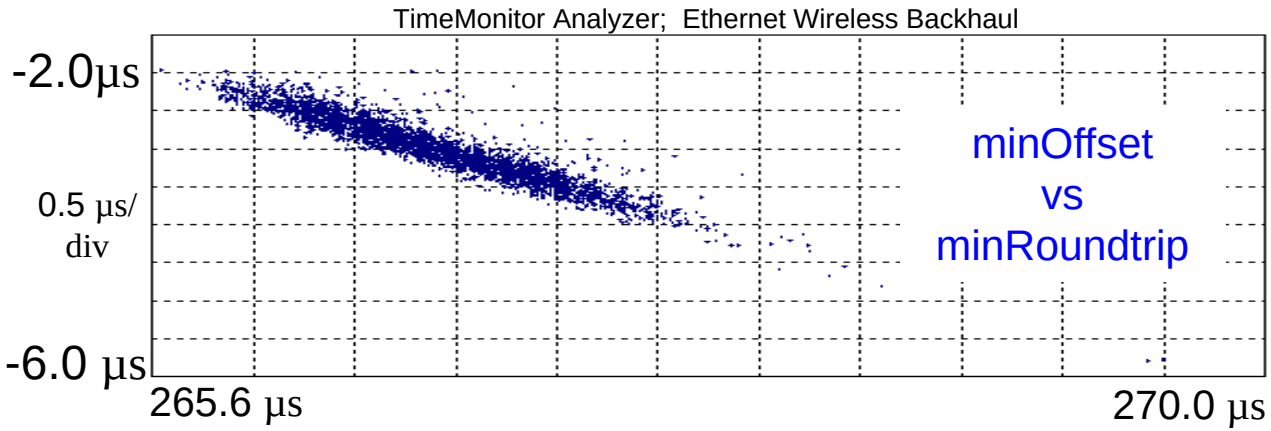
(2) Offset is a fundamental two-way calculation

(3) Ideal fwd/rev packet: floor Ideal offset: zero

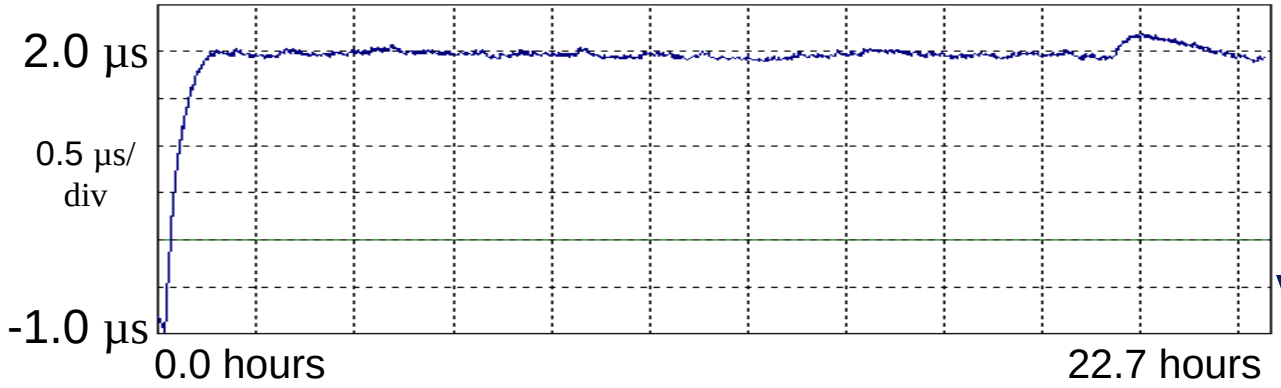
Network Asymmetry

Asymmetry in Wireless Backhaul

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



Min TDISP

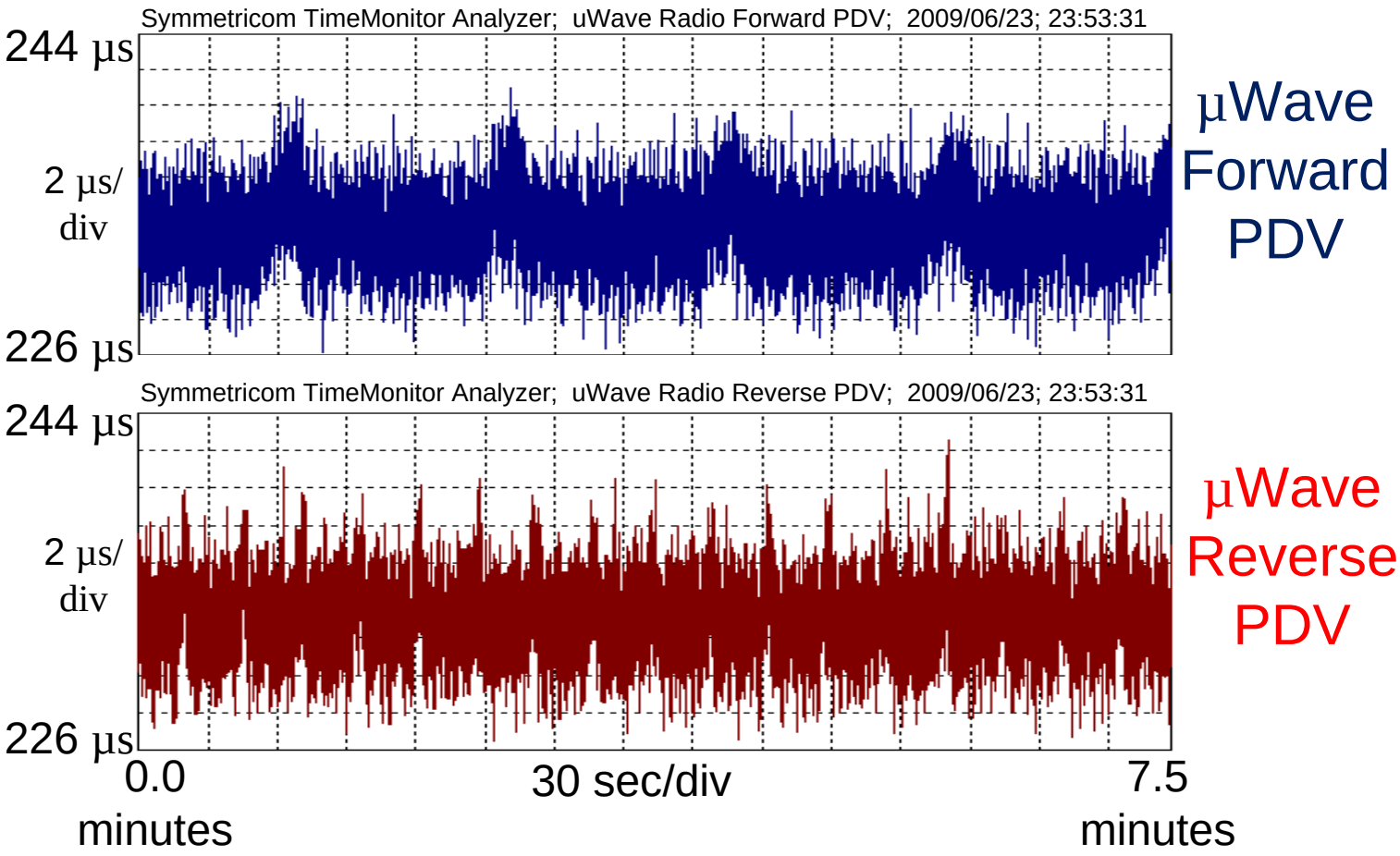


1588 Slave 1 PPS vs.GPS

Network Asymmetry

Asymmetry in Microwave Transport

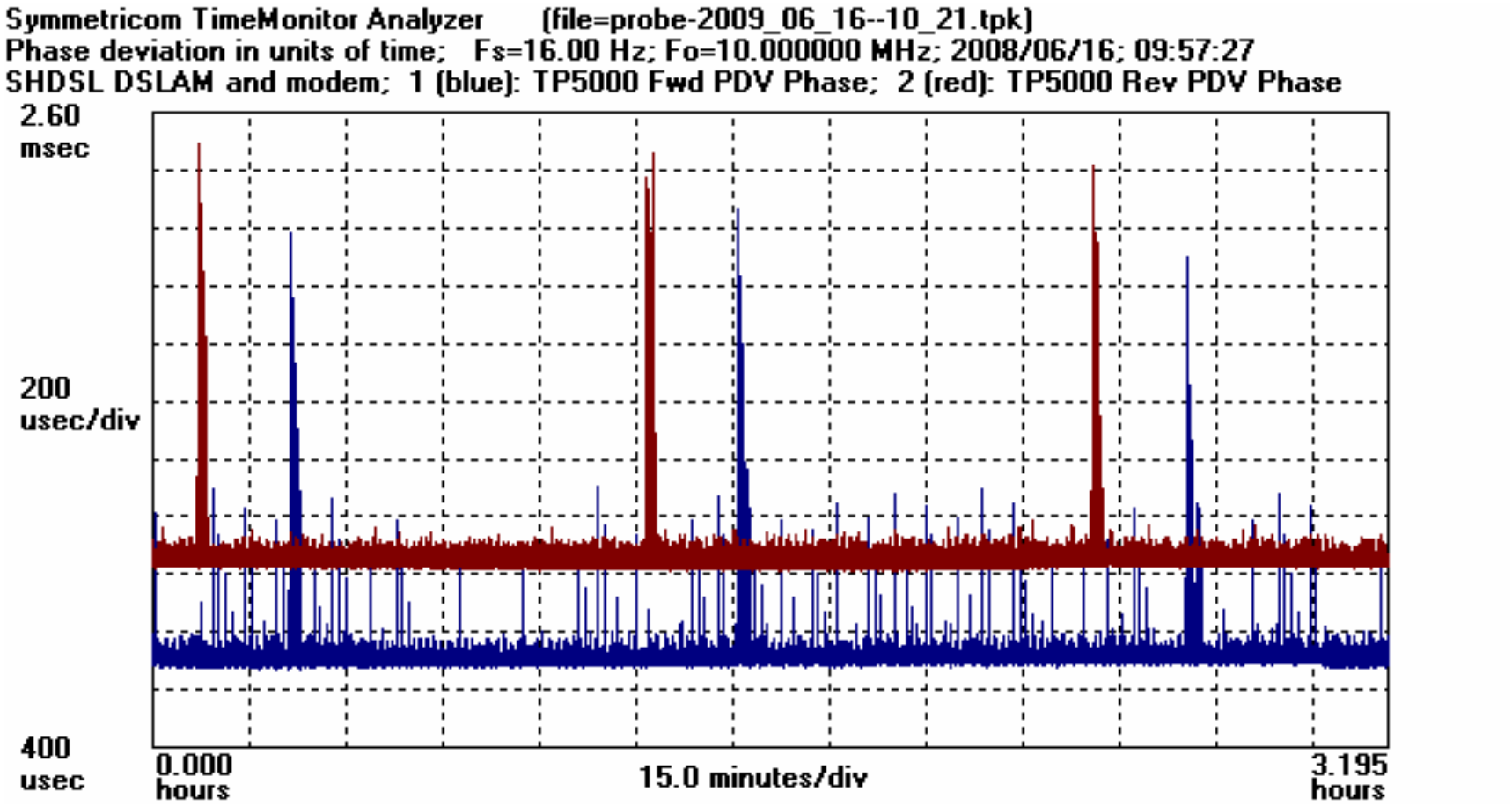
(Ethernet microwave radio packet delay pattern asymmetry)



Network Asymmetry

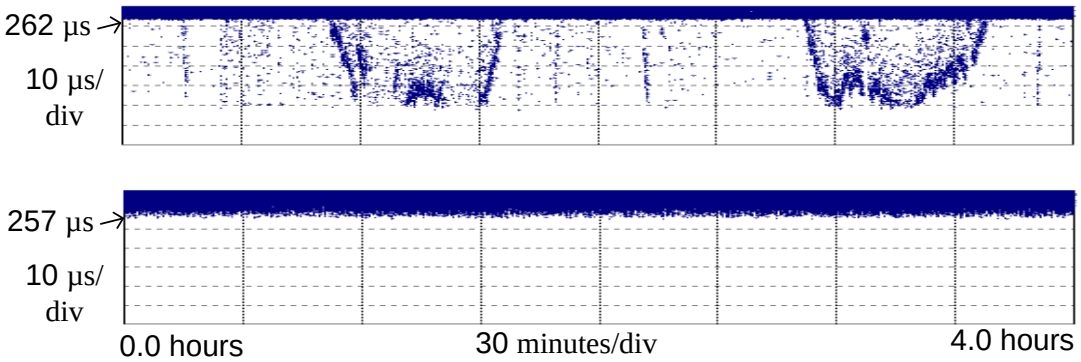
Asymmetry in SHDSL

(SHDSL forward/reverse packet delay asymmetry)



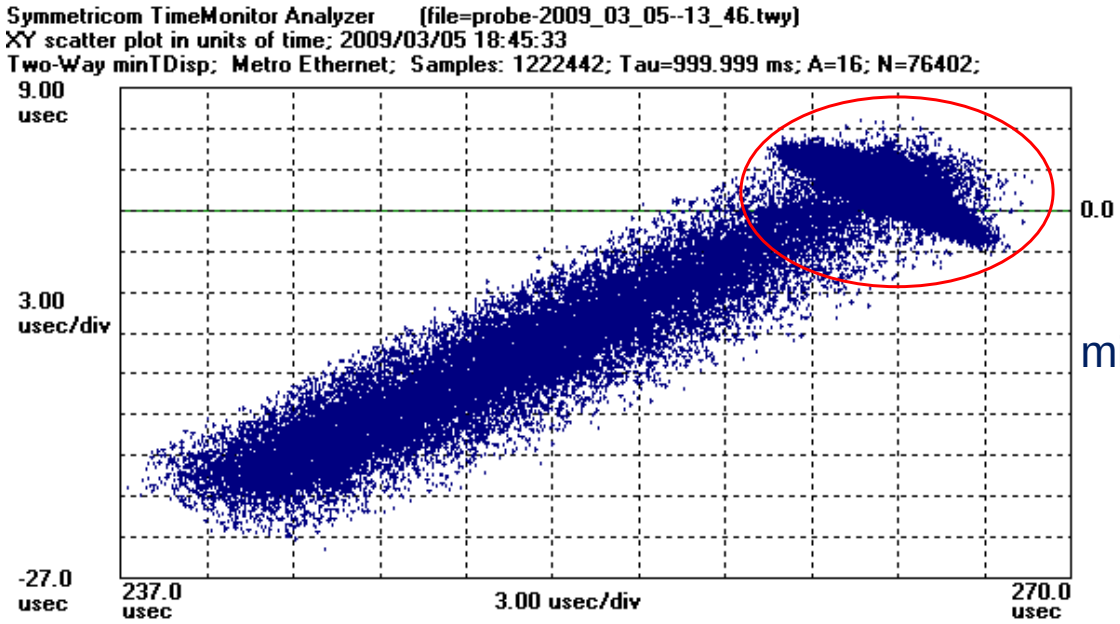
Network Asymmetry

Metro Ethernet Network



Forward PDV floor

Reverse PDV floor



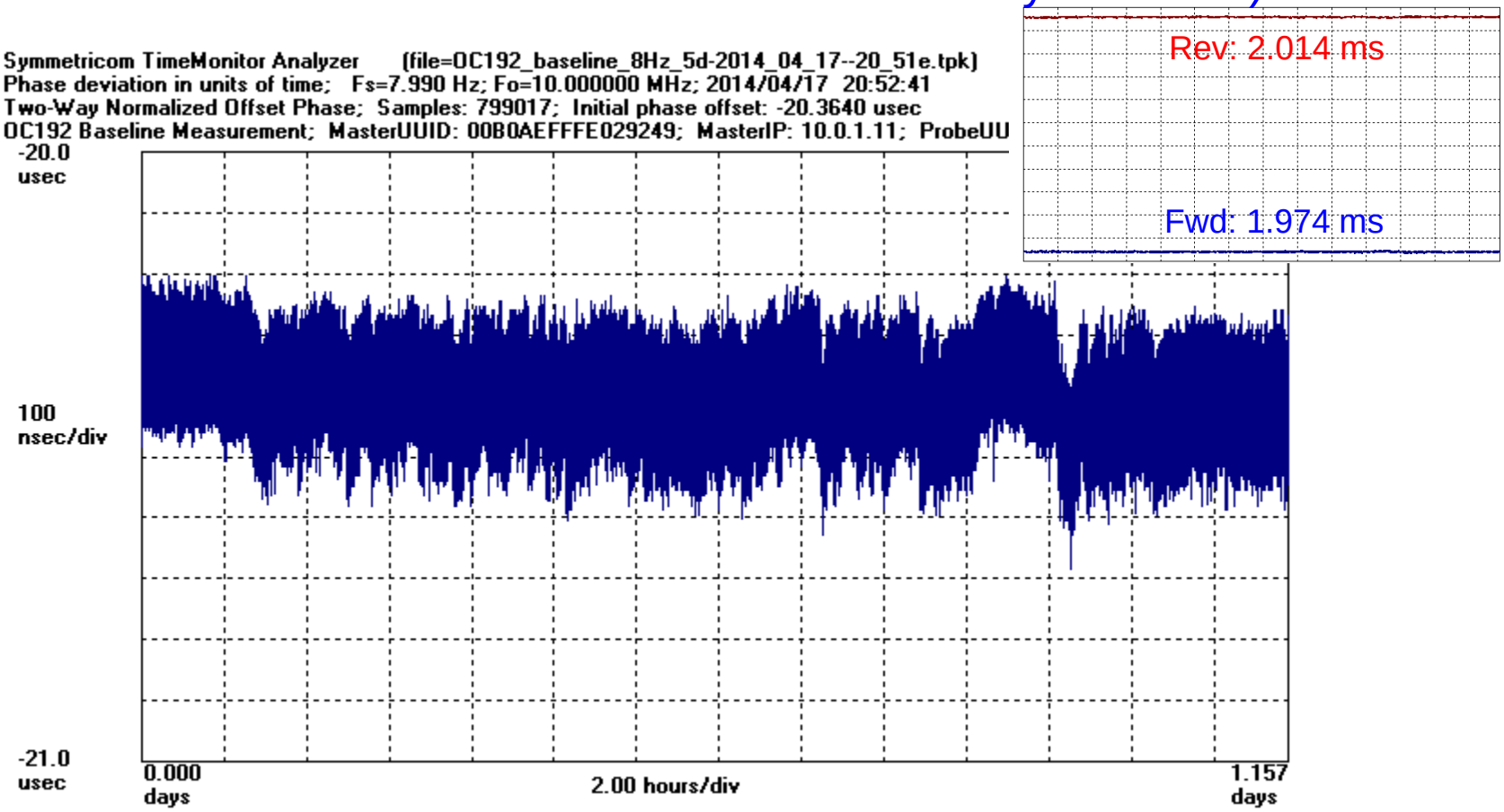
minTDISP

Metro Ethernet forward and reverse packet delay sequences with zooms into the respective floors and minTDISP

Network Asymmetry

150 km fiber SONET transport

(Offset is -20.3 µsec which represent -40.6 µsec difference between forward and reverse one-way latencies)



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 “offset” 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

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