Update: Ethernet Time Transfer through a U.S. Commercial Optical Telecommunications Network

ITSF 2016

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Outline

- Review of Motivation/History/Project Plan
- Review of Boulder (NIST) to Schriever (USNO)
  - Transfer results using two transports
  - Check baseline then add traffic
  - Diagnostic efforts to determine cause of asymmetry
- New this presentation
  - Fwd/rev latency variations cancel out
  - PTP fiber vs. GPS carrier phase
  - Long-term measurements
- Solving asymmetry – APTS – New Standard
- Next steps
  - Develop circuit from Boulder to Chicago

Motivation

- Need to back up critical infrastructure for time at microsecond (µs) or better
  - NTP over internet no better than ~ 1millisecond (ms)
- Research use of public telecom networks to transfer time
  - Optical fibers excellent for two-way time transfer
  - Public network fibers are unidirectional
- Need a method that is commercially viable
  - PTP is a new standard for time transfer
  - Commercial equipment exists

History of Project

- CenturyLink provider agreed in principle to two-year experiment linking NIST Boulder and USNO AMC at Schriever AFB (Source of UTC from GPS)
- DHS issued RFI, December 2011
- One vendor, Symmetricom-Microsemi, gave a detailed plan
- Tri-lateral MOU written: DoC (NIST)-DHS-DoD (USNO)
- Three-way Cooperative Research and Development Agreement (CRADA) NIST with CenturyLink and Symmetricom-Microsemi signed in January 2013
- CRADA extended to January 2017 and working on extension to January 2019

DHS: Department of Homeland Security
DoC: Department of Commerce
DoD: Department of Defense

USNO: US Naval Observatory
AMC: Alternate Master Clock
AFB: Air Force Base

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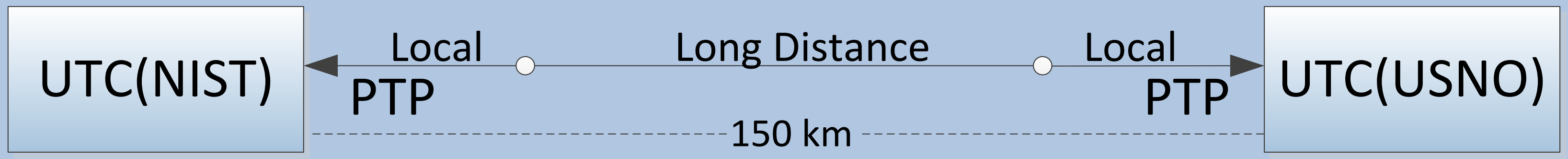
NIST-AMC Timing Experiment
Microsemi PTP + CenturyLink Circuit

- Microsemi provides PTP timing signals over Gigabit Ethernet
- CenturyLink provides two different circuits to carry the timing signals
  - STS over SONET with varied bandwidths on an OC-192
  - OTN on an ODU-0, within an ODU-2 transport

Time Transfer Experiment

- Two-way time transfer using neighboring unidirectional fibers
  - No time-awareness anywhere in network
  - No routers in path
  - No real traffic, though traffic noise can be added
- Measurements at NIST and AMC against UTC(NIST) and UTC(USNO)



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PTP Over SONET/OTN

- April 2014 - July 2014: studied SONET
- July 2014 – present: studying OTN
  - Better performance
  - Better for studying asymmetry
- PDV measurements made in two directions
  - GM at USNO AMC and PTP probe at NIST
  - Forward means USNO AMC to NIST
  - Reverse means NIST to USNO AMC
- PTP over SONET vs. PTP over OTN
  - **Asymmetry**: Both show large asymmetry of 40 µs between forward and reverse directions
  - **Delay**: Both show ~2 ms delay over 150 km of fiber
  - **Jitter**: SONET: 200 ns; OTN: <4ns
  - **Wander**: SONET: Variations on order of 300 ns; OTN: Usually close to 0 ns, occasional excursions 10's of ns

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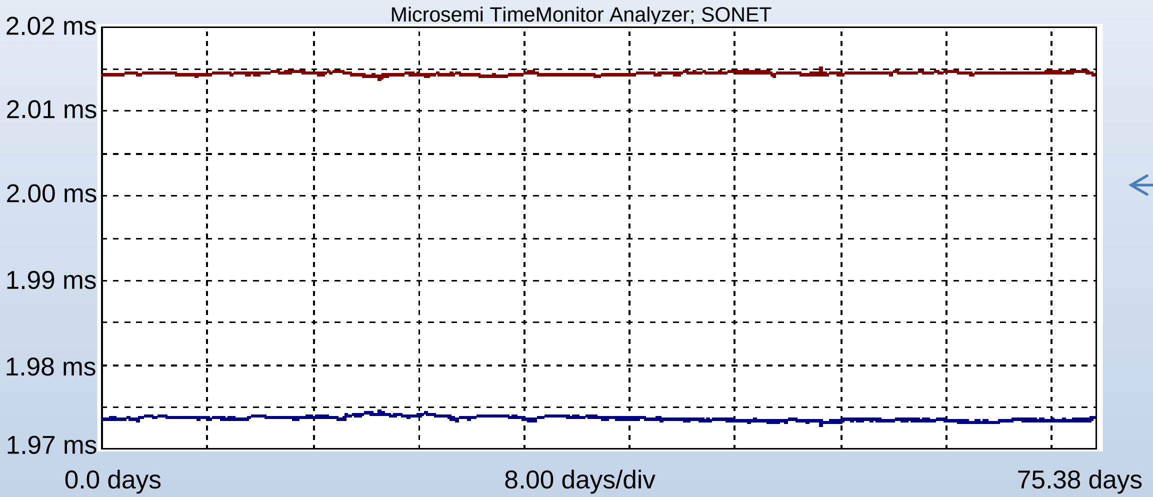
PTP over SONET/OTN

~2 ms total delay, 40 µs asymmetry

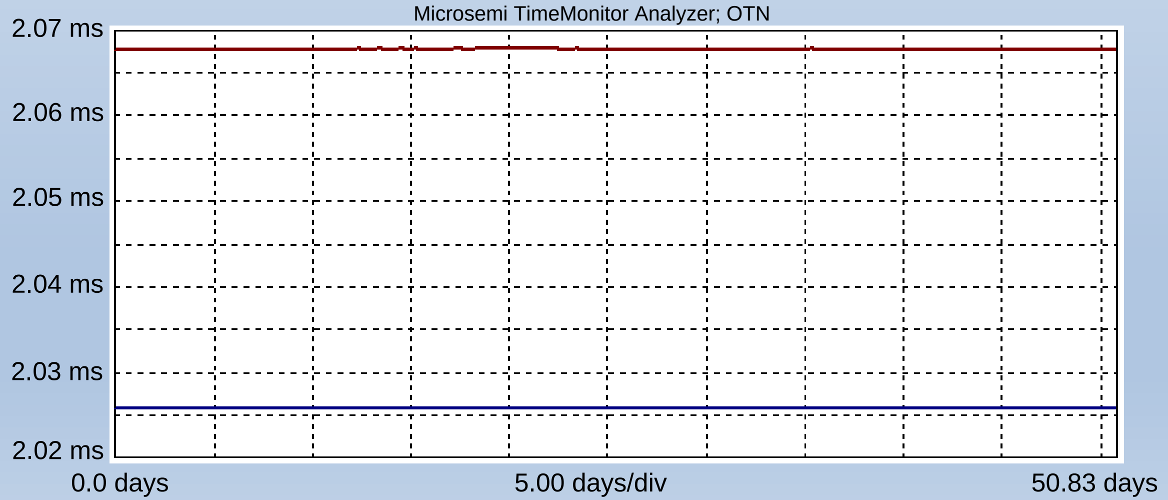
OC192 forward (blue) and reverse (red) packet delay



SONET

OTN fwd (blue) and rev (red) PDV

OTN



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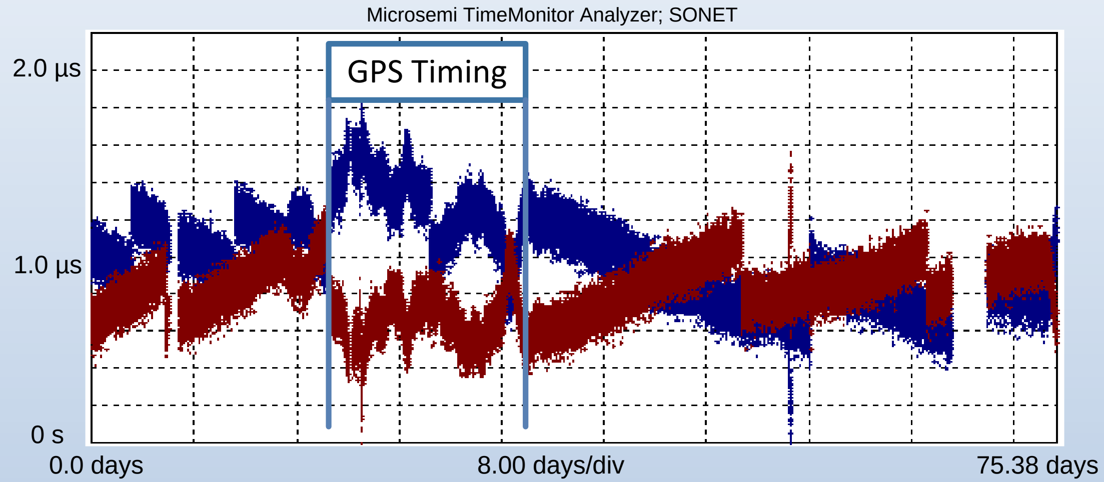
PTP over SONET/OTN

SONET: a few µs p-p; OTN: a few ns p-p

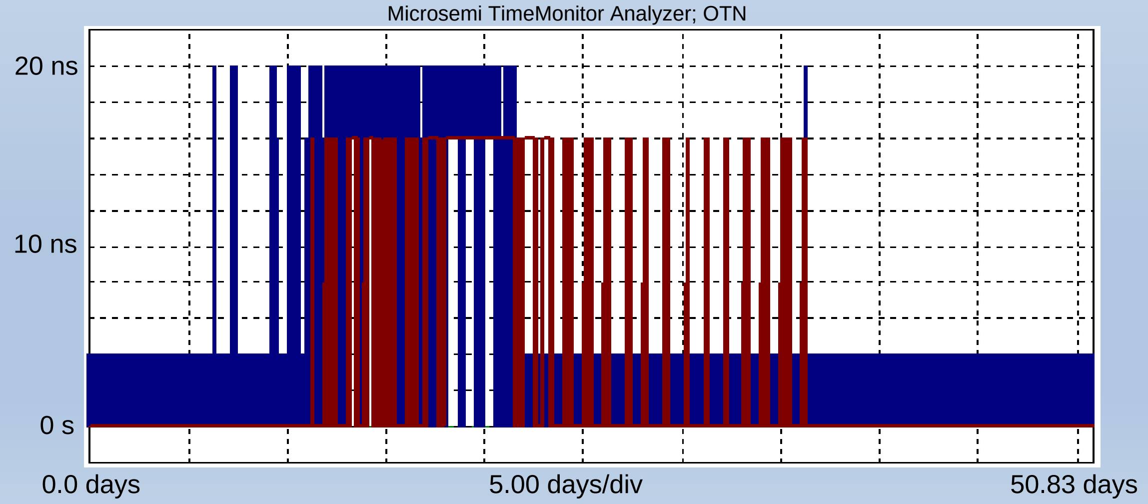
OC192 forward (blue) and reverse (red) packet delay



SONET

OTN

OTN fwd (blue) and rev (red) PDV



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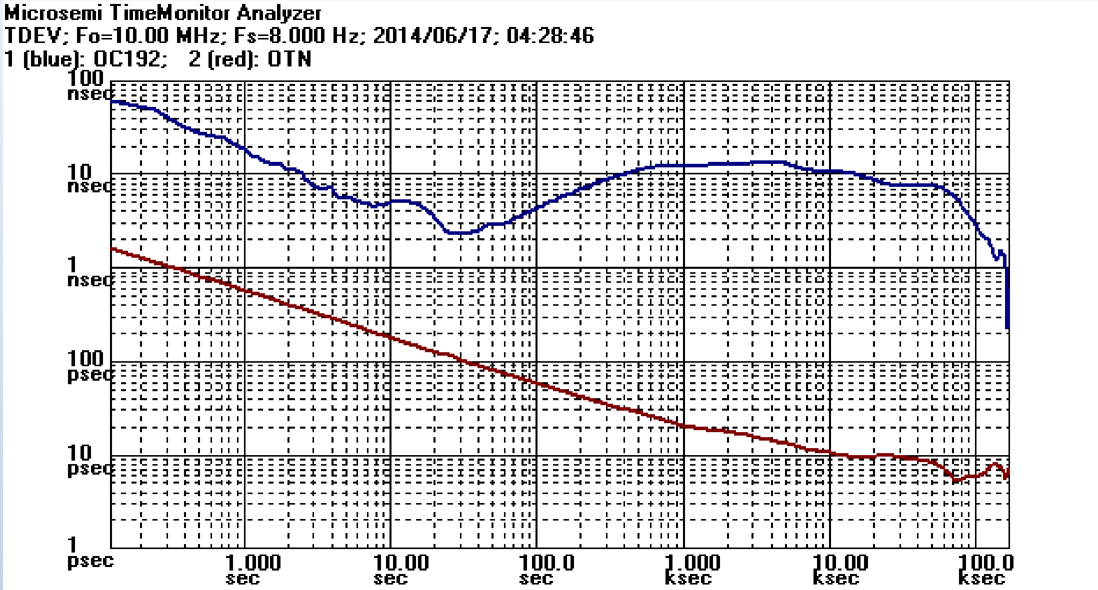
PTP over SONET/OTN

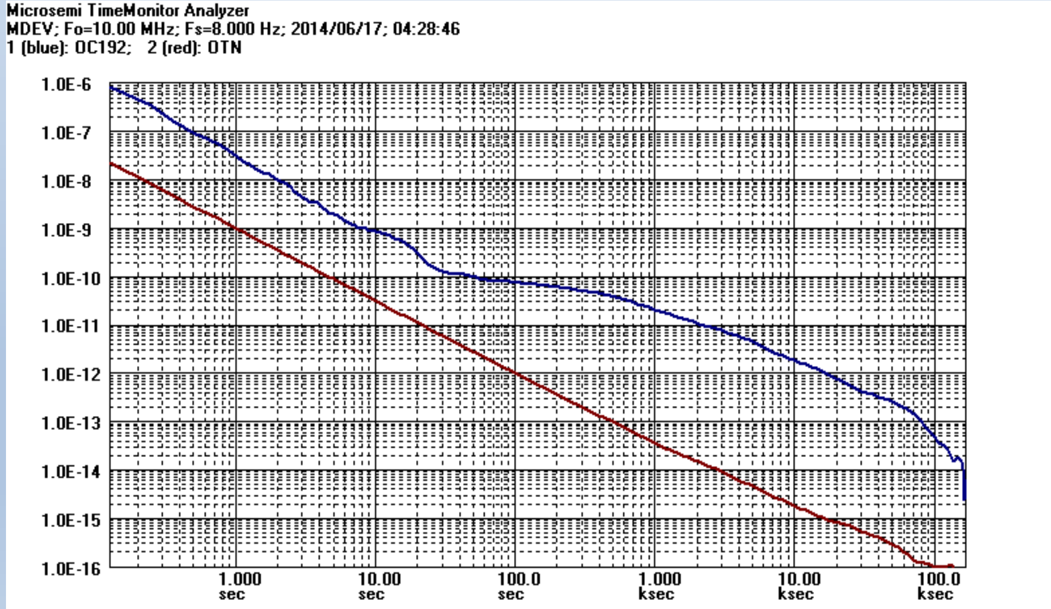
OC192 (blue) and OTN (red) TDEV



← TDEV

OC192 (blue) and OTN (red) MDEV

MDEV →



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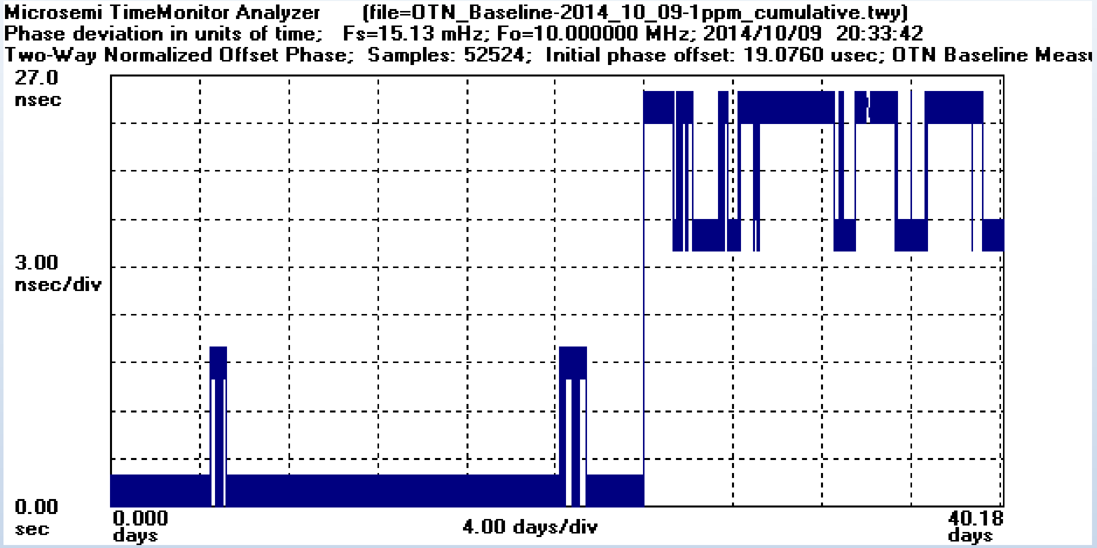
PTP Over OTN Time Transfer

Baseline: No traffic

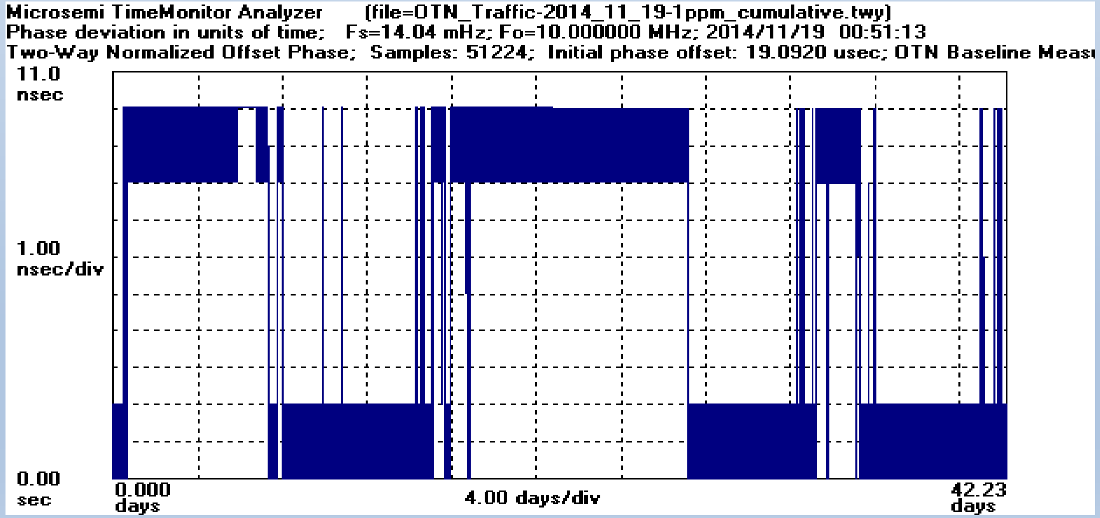
40 days of data; Max deviation 26 ns two-way



With traffic

42 days of data; Max deviation 10 ns two-way

- ***Performance not affected by the addition of traffic***



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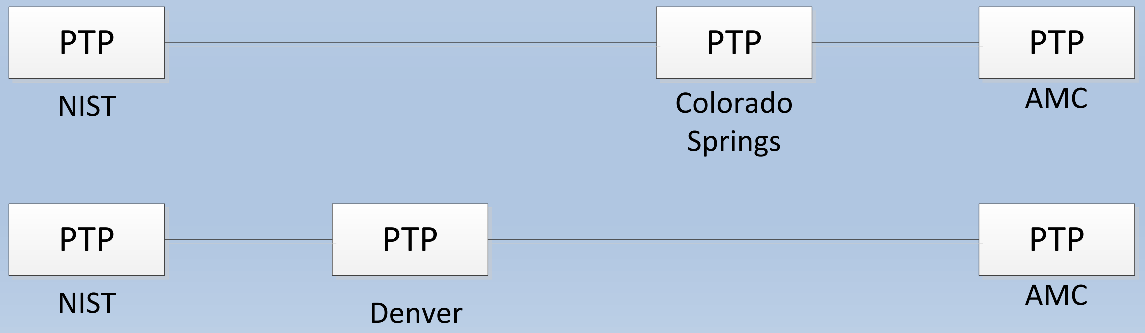
Asymmetry Investigation

Placed Microsemi PTP Equipment in CenturyLink Offices

- Placed two PTP+GPS devices, TP5000, same model as what is at NIST and USNO AMC now
- Placed TP5000s at Denver and Colorado Springs offices
- Allow for direct two-way time transfer in three sections
  - Between NIST, Boulder and Denver
  - Between Denver and Colorado Springs
  - Between Colorado Springs and USNO AMC, Schriever AFB
- Show time transfer capabilities
  - Currently, with calibration of constant offset, using OTN transport the data show we can maintain accuracies within 10's of nanoseconds
  - A 40 microsecond error would imply a 20 microsecond time transfer offset if uncalibrated



Results from “Asymmetry” Experiment

- Isolated sources of 40 microsecond asymmetry
  - Latency divided approximately equally between NIST-D, D-CS, CS-AMC
  - 75% of the asymmetry is accounted for by the Denver-Colorado Springs link

	AMC to NIST delay	NIST to AMC delay	Asymmetry
Direct circuit	2025 µs	2066 µs	40.5 µs
Circuit broken in Colorado Springs	2270 µs	2300 µs	30.2 µs
Circuit broken in Denver	2232 µs	2278 µs	46.5 µs

- Two important points
  - When circuits are rebuilt, latency and asymmetry change (see table above)
  - Asymmetry is static and can be calibrated out as long as the circuit stays up (several measurements of two to three months or more have shown this to be the case)

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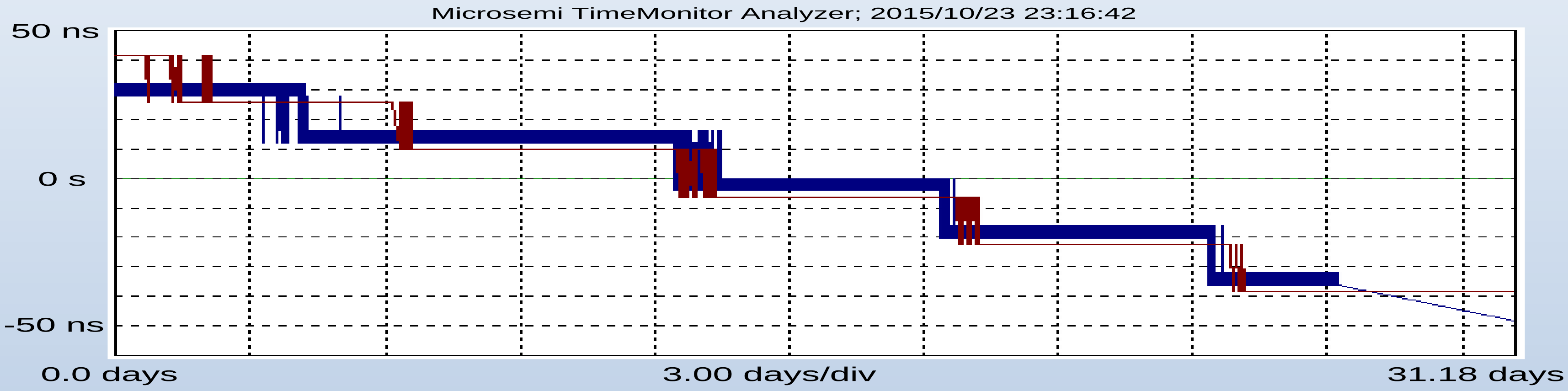
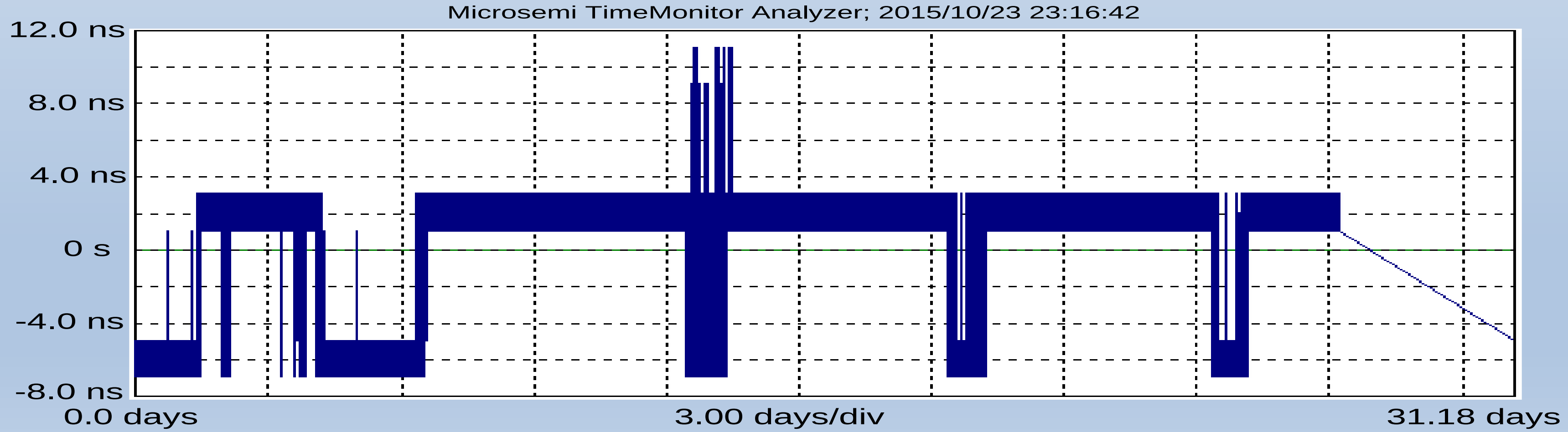
Fwd/Rev Latency Variations Cancel Out

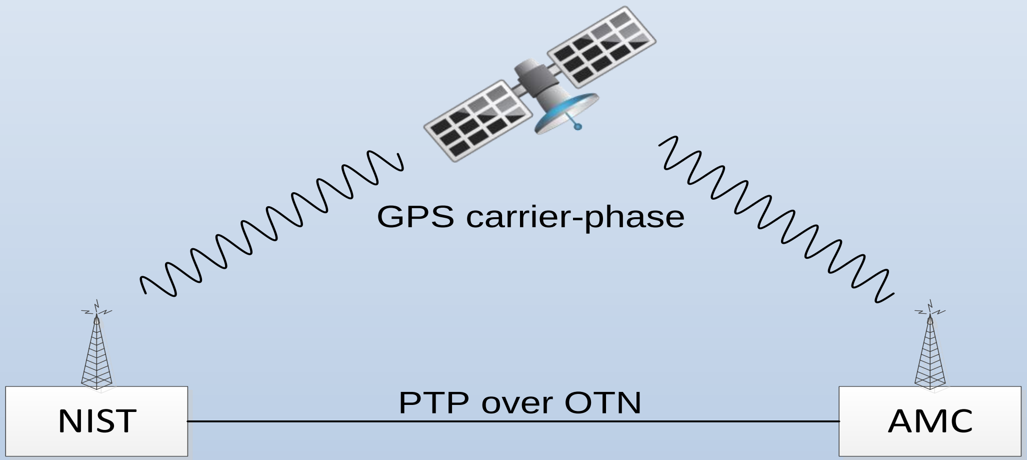
Slope is -3ns/day over 31 days both for forward and reverse directions; two-way is 16ns p-p with no slope



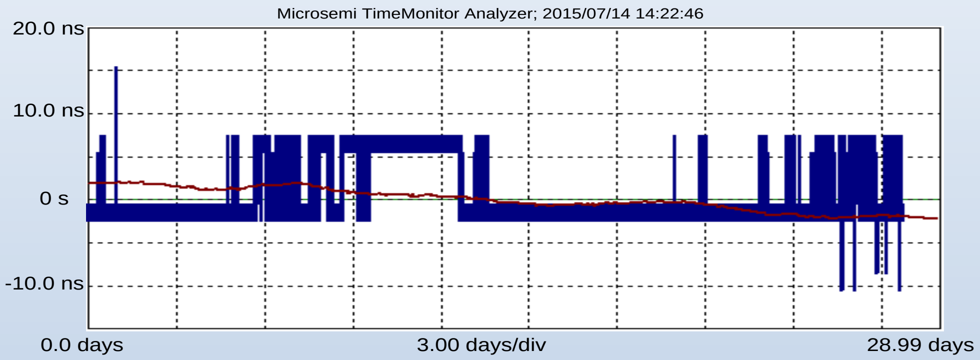


PTP fiber vs. GPS Carrier Phase

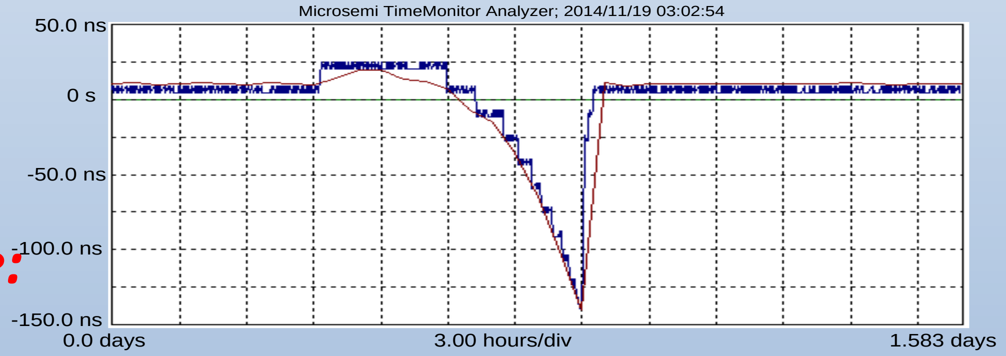
PTP (blue) and GPS carrier-phase (red) measurements comparing UTC(NIST) and UTC (USNO) sites



Normal:



Failure:



Normal: The two measurements generally match though the timestamp resolution of the PTP equipment does not have the precision to show the sub-nanosecond movement
Failure: The two measurements match well with the 180 ns excursion occurring over the 12-hour period of timing distribution equipment failure at one of the UTC sites. The PTP timestamp resolution can be seen in the 4 nanosecond quantization and 16 nanosecond steps.

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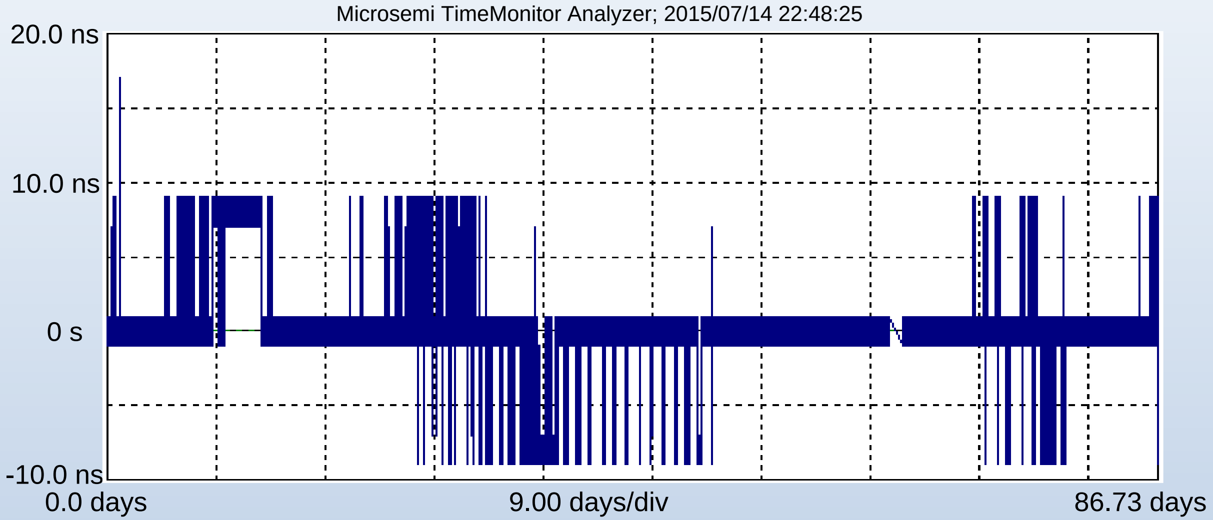
Long-term PTP fiber measurement

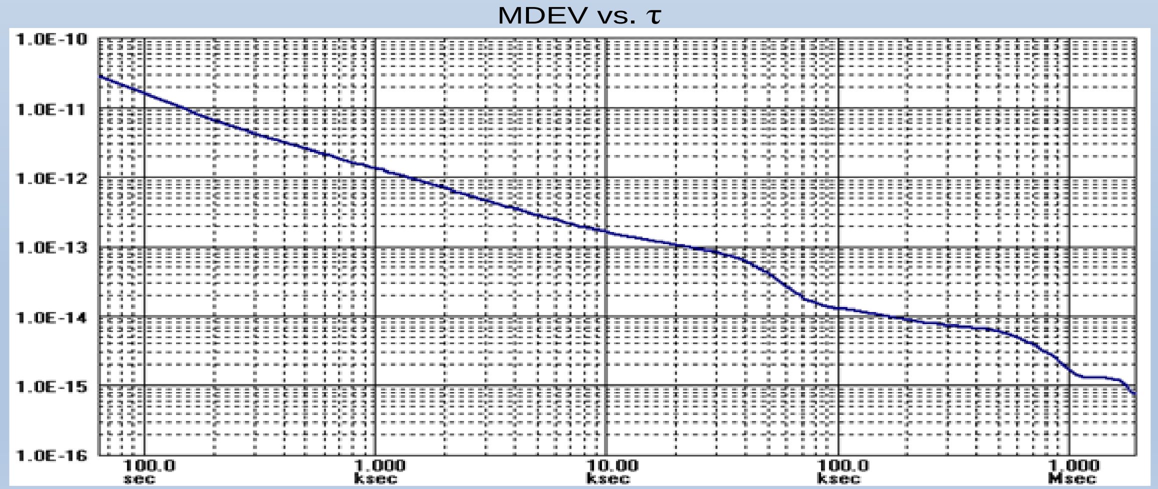
Two-way offset calculation on 87-day measurement shows 26 ns peak-to-peak over the entire run

These results support the possibility that this method could provide time holdover below 100 ns indefinitely



MDEV calculation on 87-day PTP fiber measurement

The Modified Allan Deviation shows the capability of frequency transfer approaching 1 part in 10^{15} at 10 days



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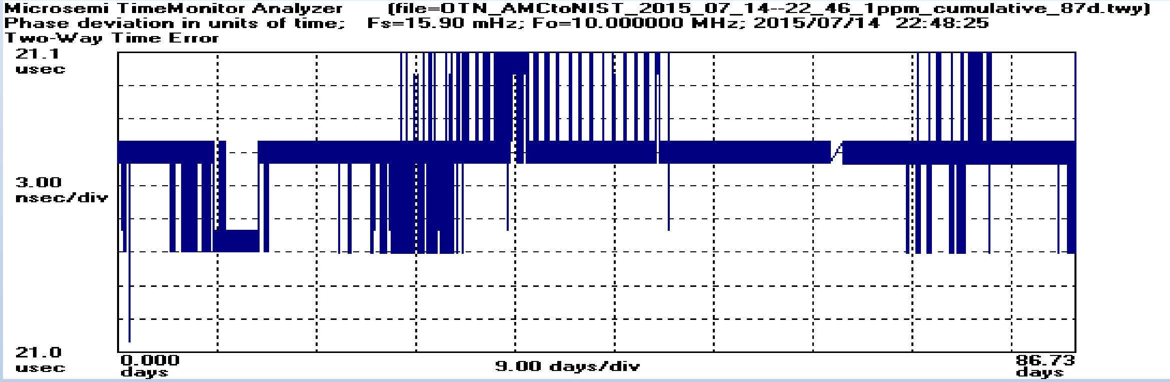
Solving asymmetry - APTS

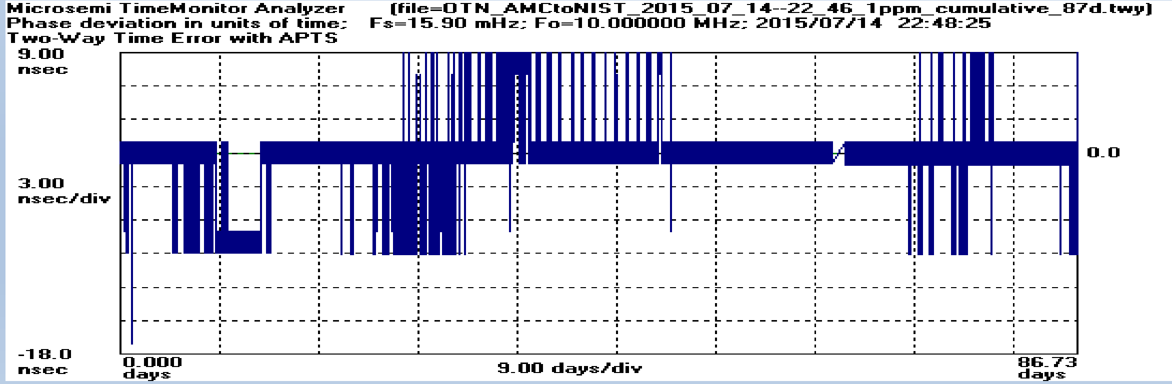
G.8275.2 “*Precision time protocol telecom profile for time/phase synchronization with partial timing support from the network*”

- Published document released August 2016
- Includes “assisted partial timing support” which uses GNSS to calibrate out asymmetry

Raw data 87 day measurement has constant 21 µs bias



With APTS, the constant 21 µs bias is corrected for and removed



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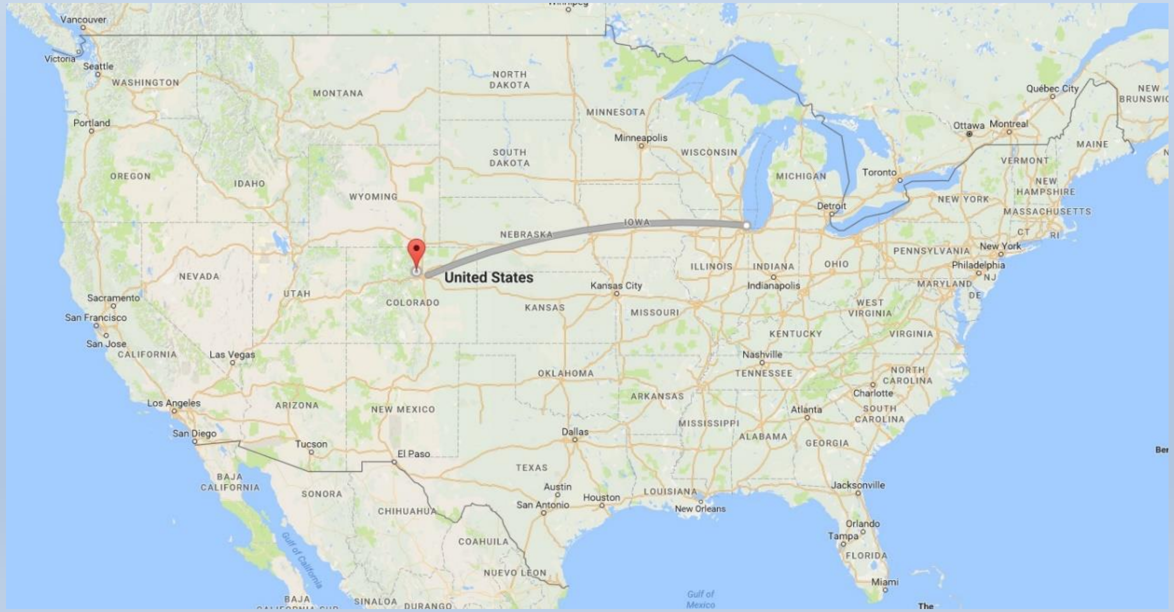
Next phase: Long-range circuit (Early 2017)

Current: Boulder (NIST) to Schriever (USNO) ***180 km***

Next phase: Boulder (NIST) to Chicago ***1700 km***



Next Steps

- Working on extending experiment to ultra-long range equipment in a network extending over 1000s of kilometers (Boulder to Chicago)
- Results of experiment are to be published
- ATIS sync standards committee (COAST-SYNC) has a project for GPS backup
  - This experiment to show capabilities across one commercial carrier
  - Consider extending this experiment to other geographic areas or using other carriers

Thank You for Your Attention

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