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

WSTS 2016

Marc Weiss, mweiss@nist.gov, 303-497-3261
NIST Time and Frequency Division

Lee Cosart, lee.cosart@microsemi.com, 408-428-6950
Microsemi, Corp.

Outline

- Motivation
- Project plan
- Current results, October 2015
  - Transfer results using two transports
  - Check baseline then add traffic
  - Diagnostic efforts to determine cause of asymmetry
  - Long-term measurements
- Next steps

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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
  - Format cannot improve accuracy - requires access to physical signal

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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)
  - Not yet signed
- Three-way Cooperative Research and Development Agreement (CRADA) NIST with CenturyLink and Symmetricom-Microsemi signed in January 2013
- CRADA extended to January 2017

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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

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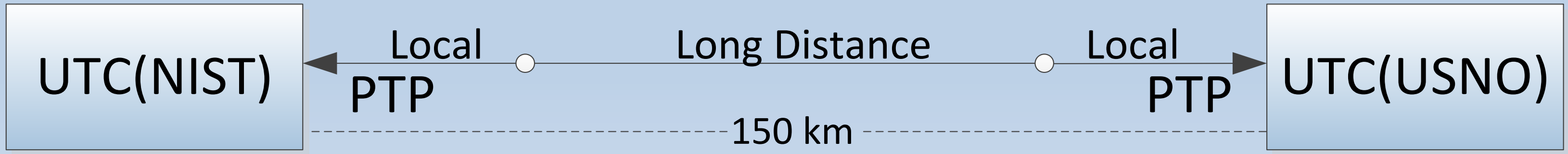
Time Transfer Experiment

- 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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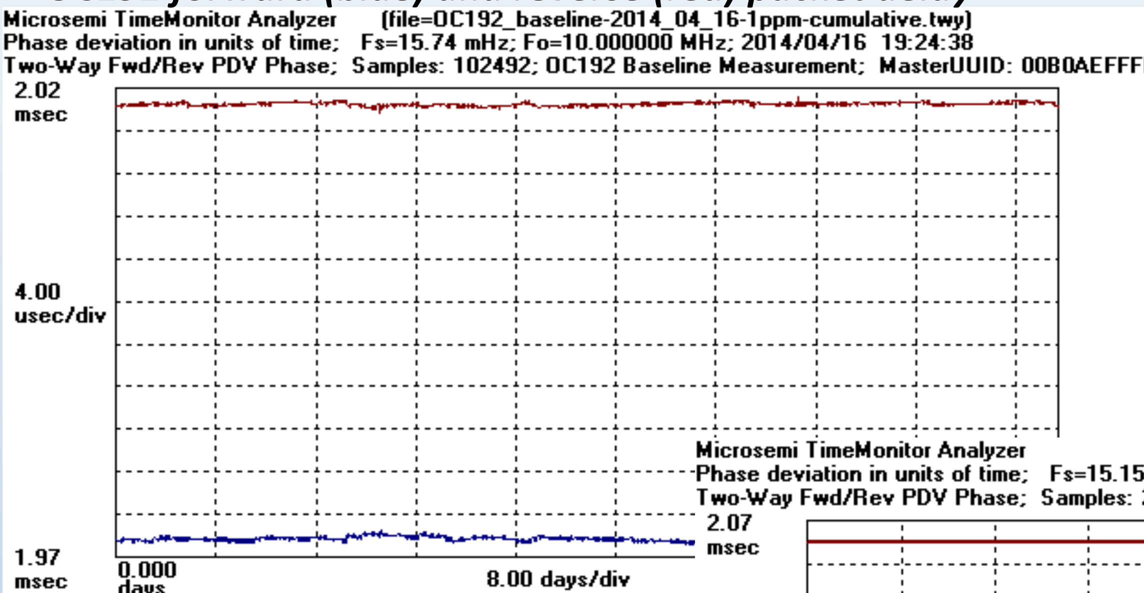
PTP over SONET/OTN

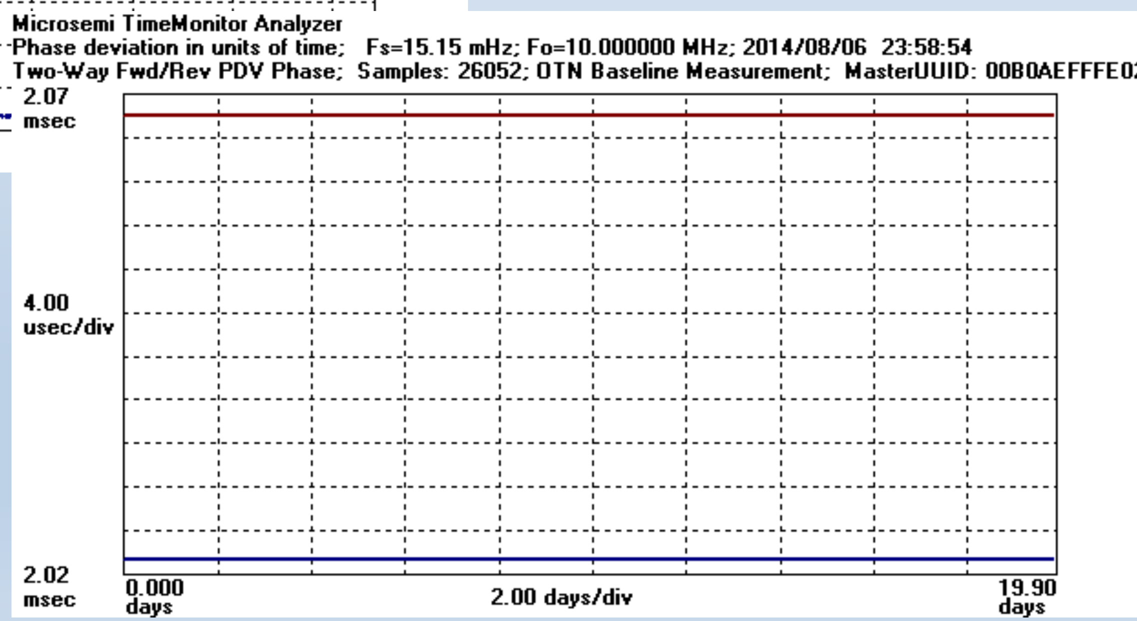
~2 ms total delay, 40 μs asymmetry

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



← SONET

OTN fwd (blue) and rev (red) PDV

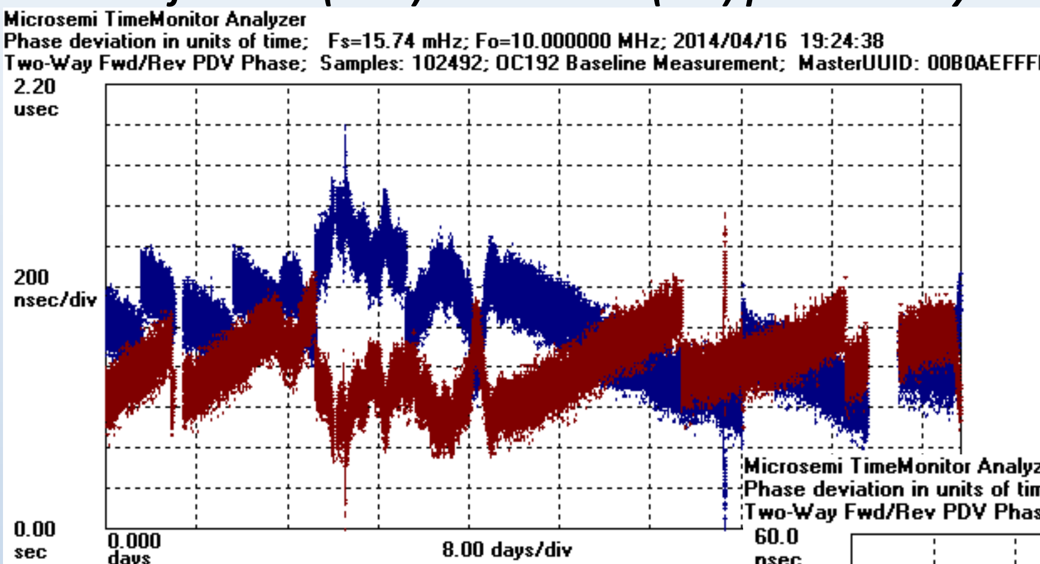


OTN →

PTP over SONET/OTN

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

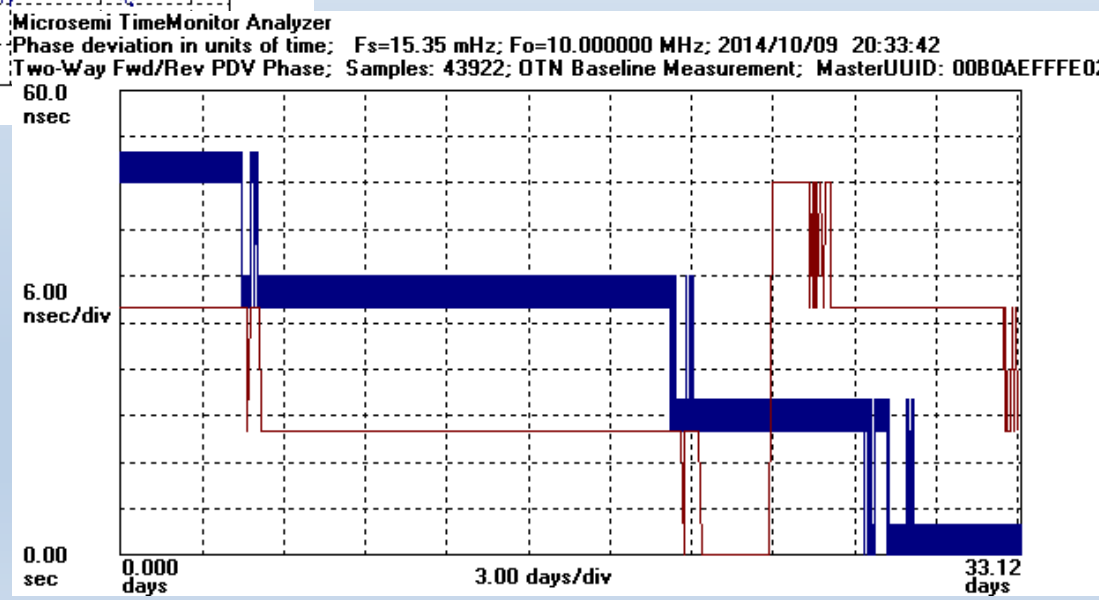
OC192 forward (blue) and reverse (red) packet delay



SONET

OTN fwd (blue) and rev (red) PDV

OTN



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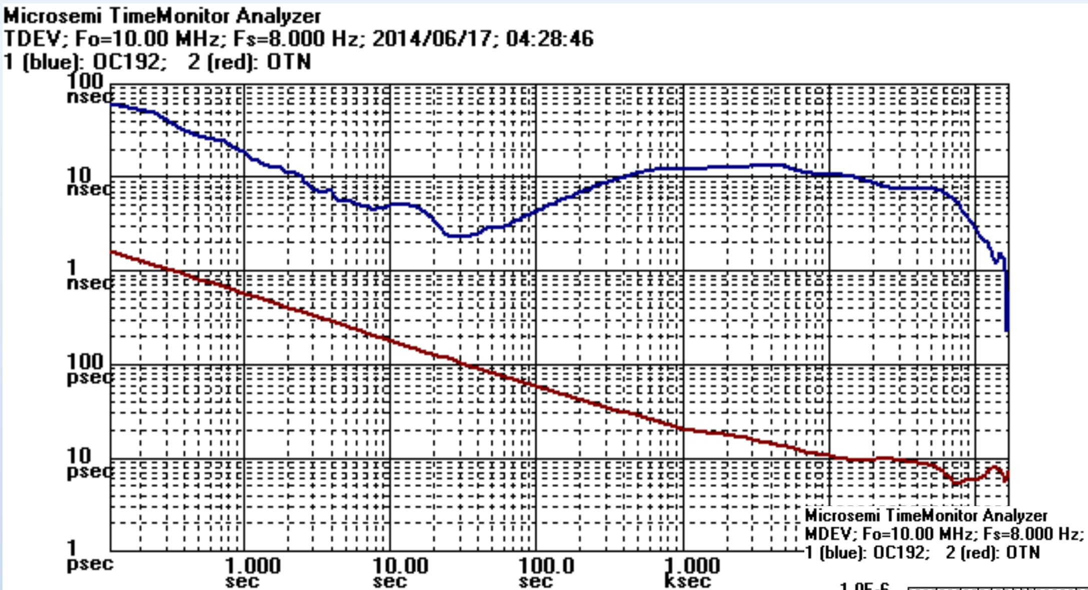
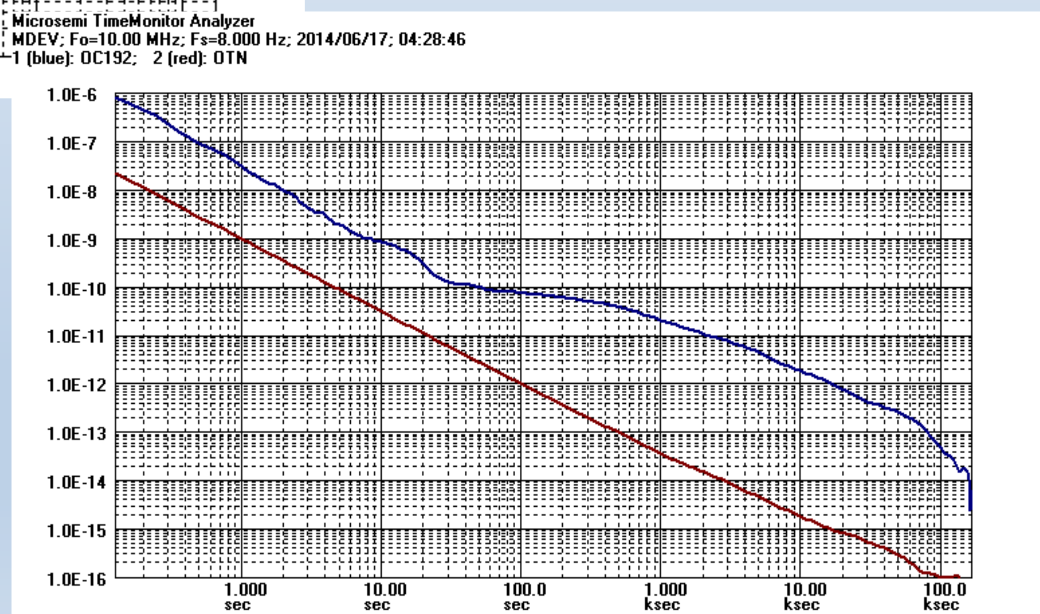
PTP over SONET/OTN

OC192 (blue) and OTN (red) TDEV



TDEV

OC192 (blue) and OTN (red) MDEV



MDEV

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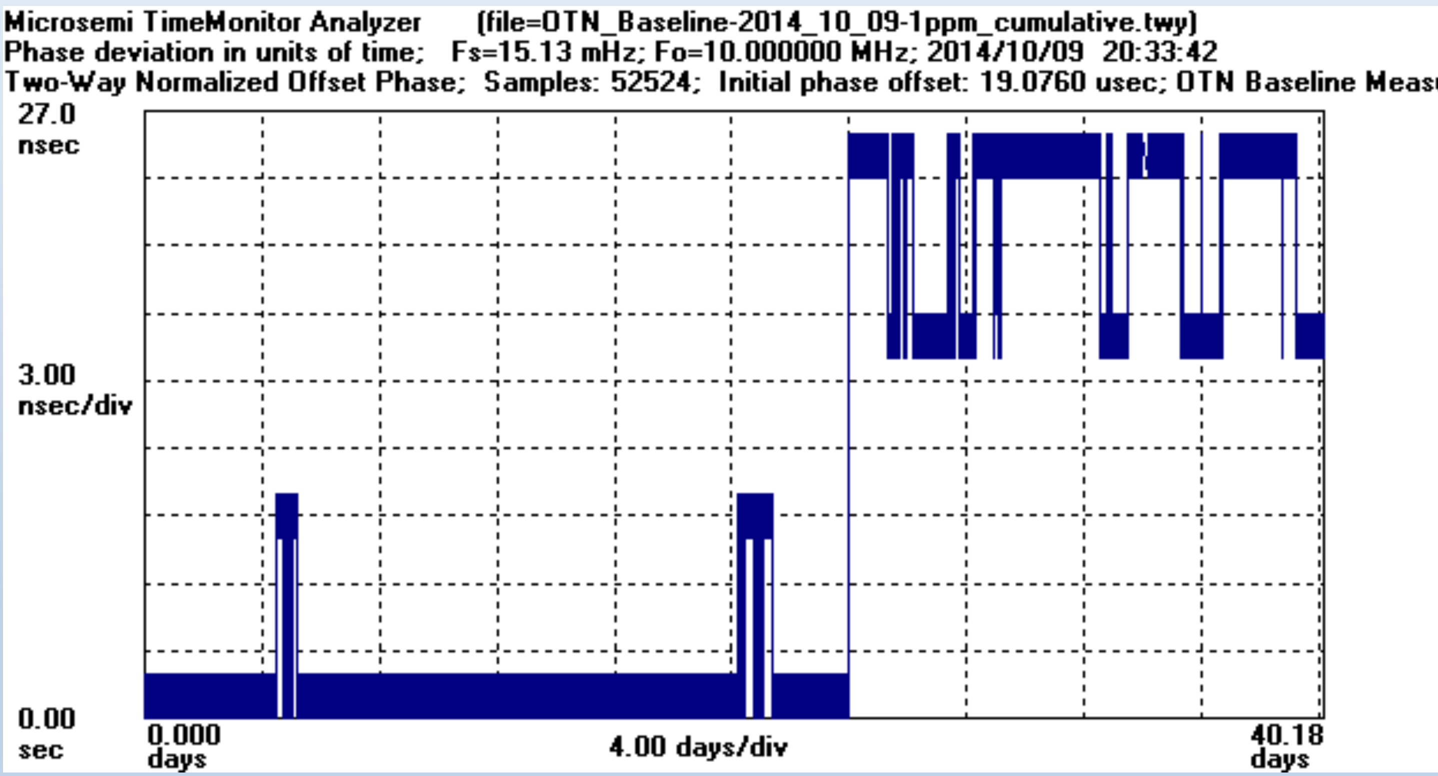
PTP Over OTN Time Transfer

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

Baseline: No traffic

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

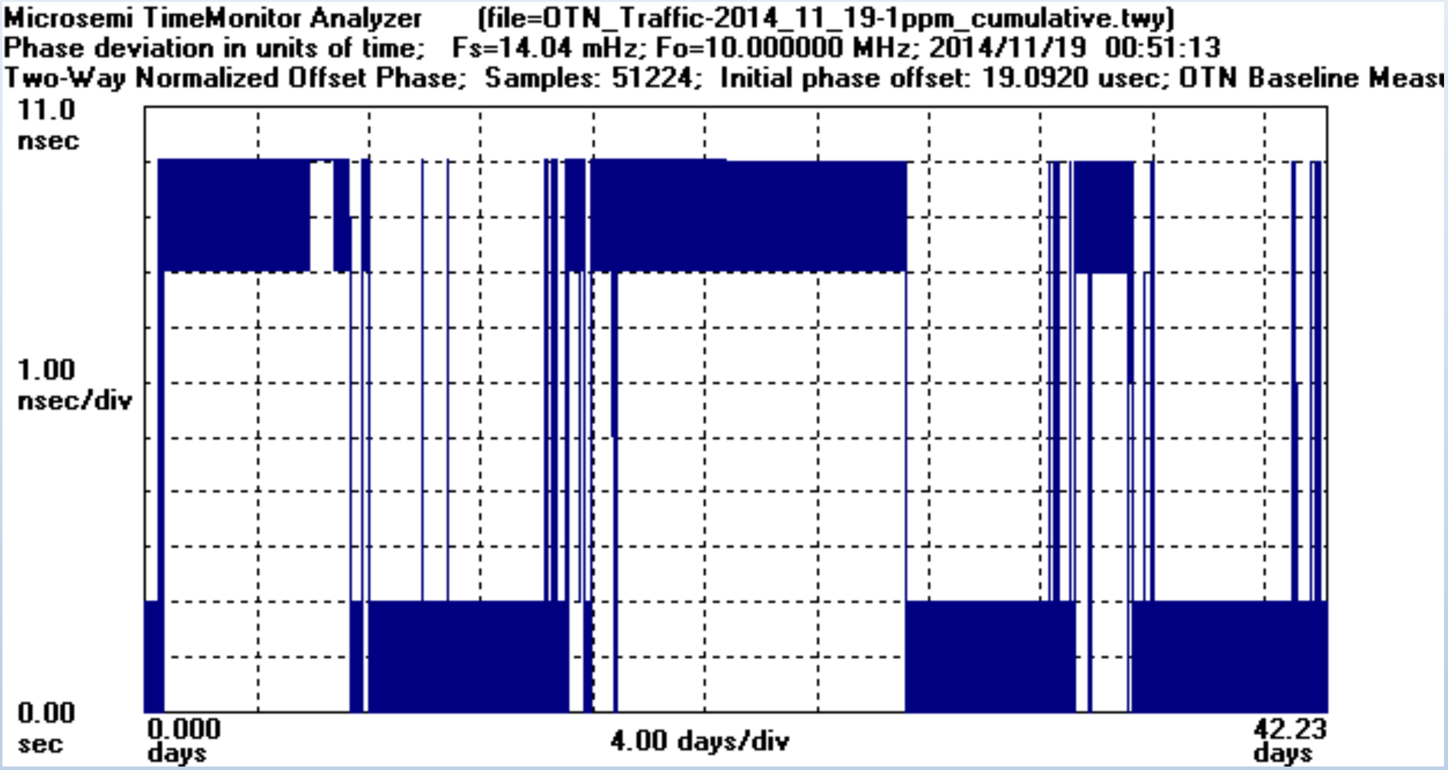


PTP Over OTN Time Transfer

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

With traffic

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



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

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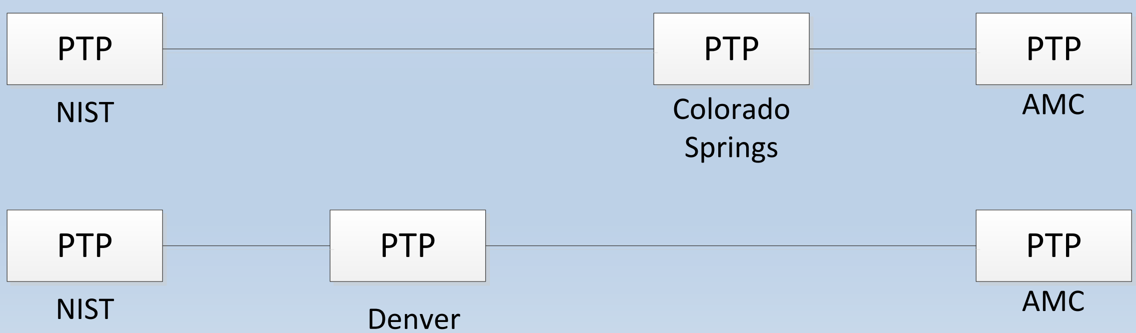
Asymmetry Investigation

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



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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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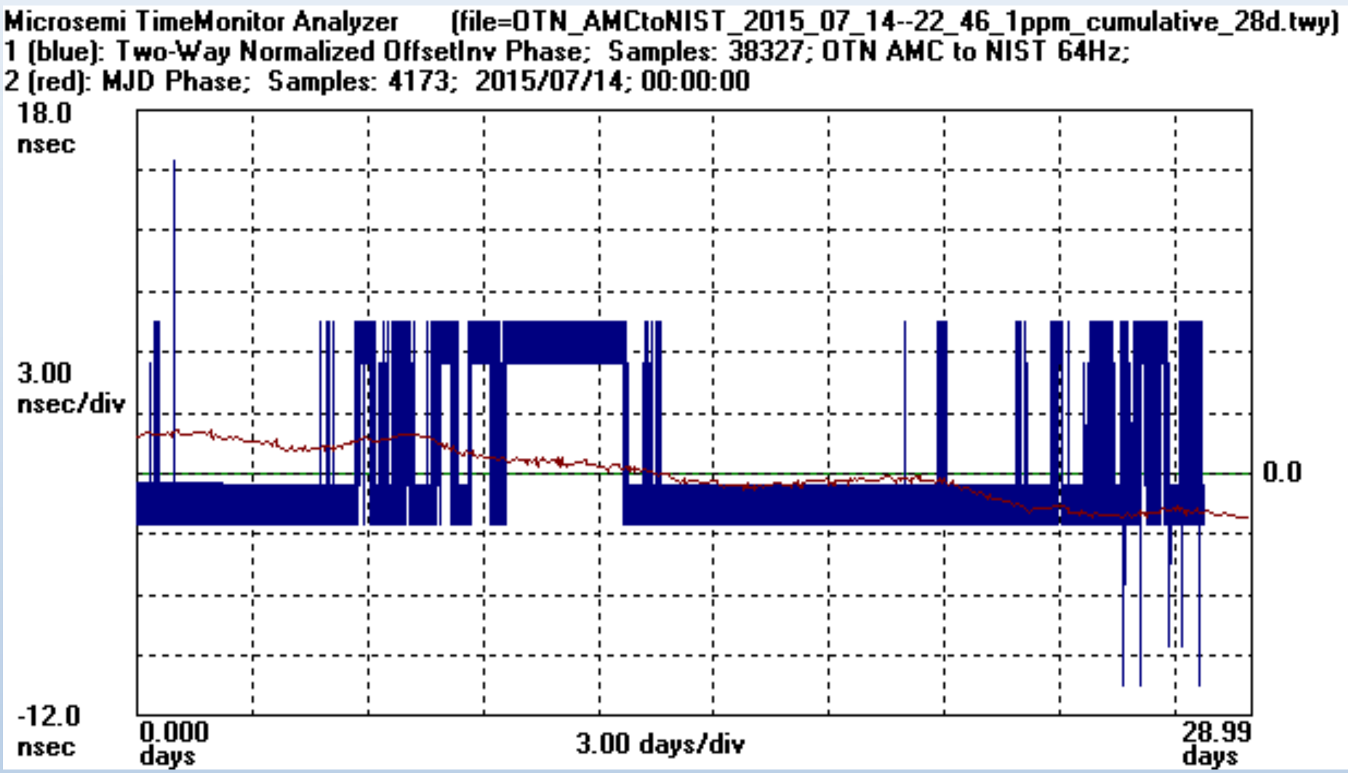
PTP fiber vs. GPS Carrier Phase

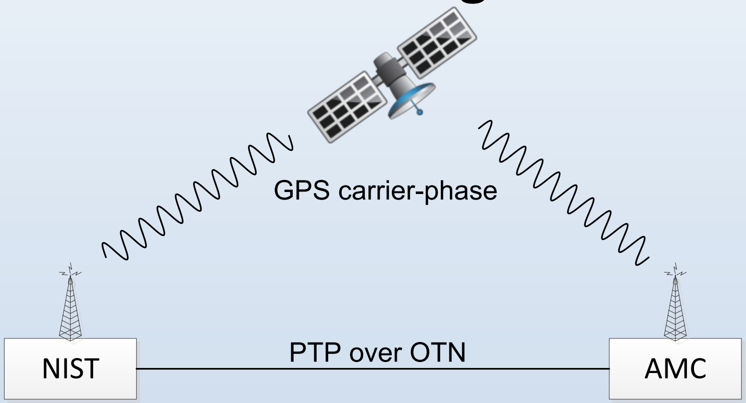
PTP (blue) and GPS carrier-phase (red) measurements both comparing UTC(NIST) and UTC (USNO)

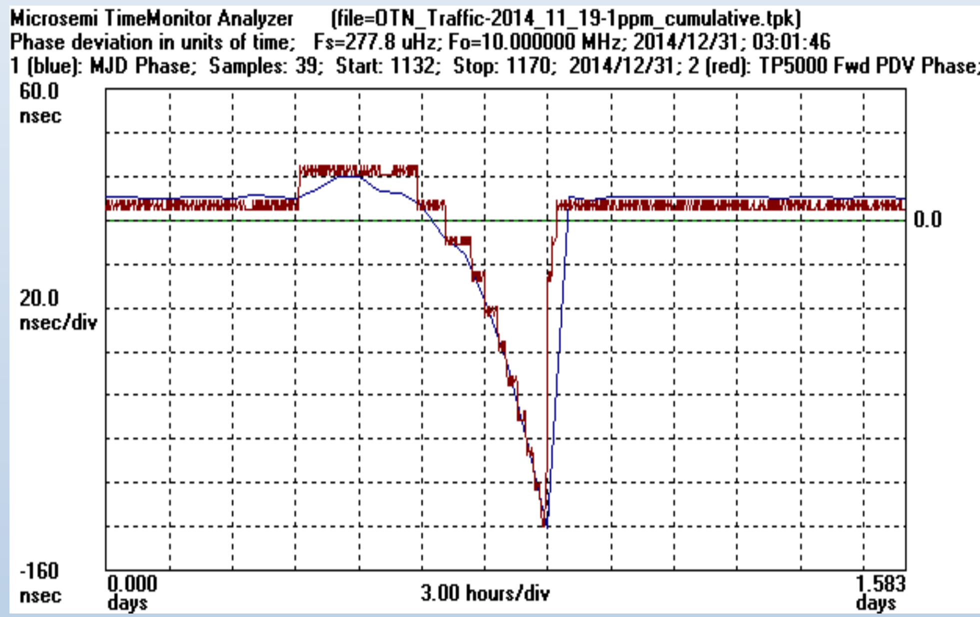


The two measurements generally match though the timestamp resolution of the PTP equipment does not have the precision to show the sub-nanosecond movement

PTP fiber vs. GPS Carrier Phase

PTP (blue) and GPS carrier-phase (red) measurements during a failure of timing distribution equipment at one of the UTC sites

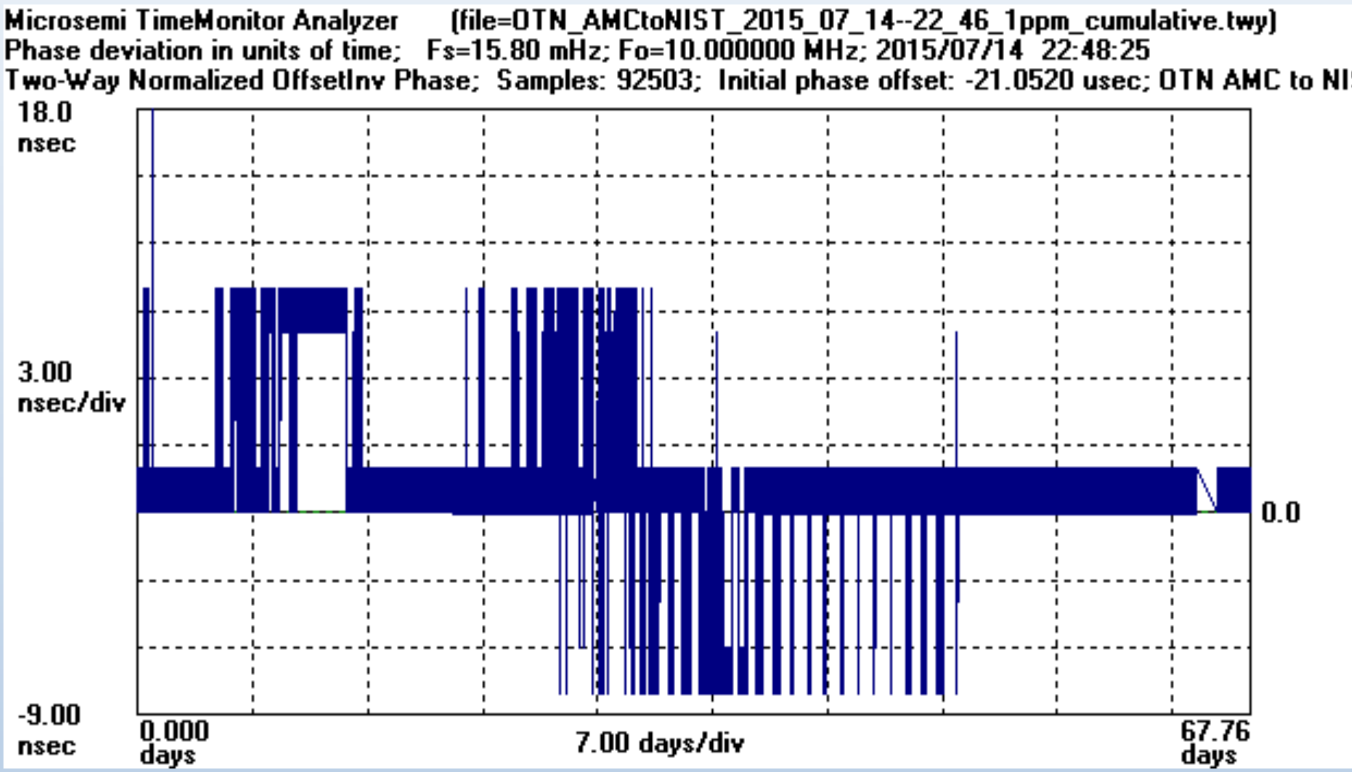




The two measurements match well with the 180 ns excursion occurring over the 12-hour period of timing distribution equipment failure at one of the UTC sites. The PTP timestamp resolution can be seen in the 4 nanosecond quantization and 16 nanosecond steps.

Long-term PTP fiber measurement

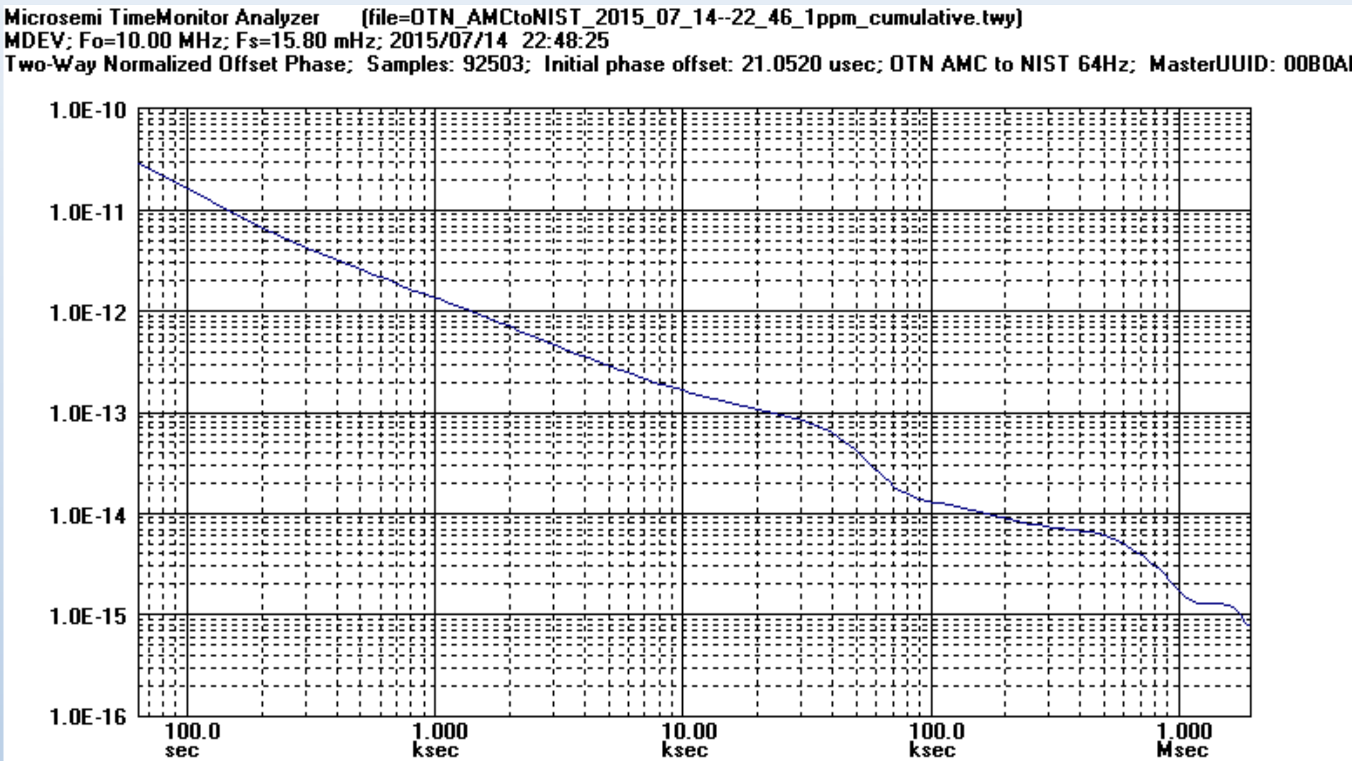
Two-way offset calculation on 68-day measurement shows 26 ns peak-to-peak over the entire run



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

Long-term PTP fiber measurement

MDEV calculation on 68-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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Next Steps

- Experiment in next phase to extend to ultra-long range equipment in a network extending over 1000s of kilometers
- 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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