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

M. Weiss, *NIST Time and Frequency Division*, mweiss@nist.gov
L. Cosart, *Microsemi Corporation*, lee.cosart@microsemi.com
J. Hanssen, *Time Service Department, US Naval Observatory*, james.hanssen@usno.navy.mil
S. Hicks, C. Chase, C. Brown, C. Allen, P. Johnson, G. Wiltsie, D. Coleman, *CenturyLink Inc.*

BIOGRAPHIES

Dr. Marc Weiss worked at NIST (the National Institute of Standards and Technology--formerly NBS, the National Bureau of Standards) from 1979. As of January 2014 he is now a contractor for NIST. He received the NBS Applied Research Award for a first GPS timing receiver in 1983. He was awarded a patent for the Smart Clock algorithm in 1993. Dr. Weiss won the 2013 NIST William P. Slichter Award, "For pioneering highly productive industry/ government partnerships to advance telecommunications and data networks through precision synchronization." Marc founded and has led WSTS, the Workshop on Sync in Telecom Systems, annually since 1992. Dr. Weiss has also led the NIST program to support the GPS program office in developing their clocks and timing systems since 1980.

Lee Cosart is a Senior Technologist with Microsemi. A graduate of Stanford University, his R&D activities have included measurement algorithms and mathematical analysis for which he holds several patents. He serves on, as chair, contributor and editor, the ATIS and ITU-T committees responsible for network synchronization standardization. His TimeMonitor software is used to collect and analyze synchronization and packet timing data and has been used in laboratories and networks throughout the world.

James Hanssen is a research physicist in the Clock Development Division at the U.S. Naval Observatory in Washington, DC. He earned a BA in physics and mathematics from Rice University in 1998 and a PhD in physics from the University of Texas at Austin in 2004. He has been with the Clock Development Division since 2008.

ABSTRACT

There is a need to back up critical timing infrastructure at the national level. This paper describes a joint project employing commercial equipment to send national timing signals through a telecommunication network. This experiment connects UTC(NIST) in Boulder, Colorado with UTC(USNO) at the Alternate Master Clock at Schriever AFB via a telecommunication provider's optical network using the Precise Time Protocol (PTP) to compare the time standards. The experiment was started in April 2014 and will run through the end of 2014. The paper provides insight into both the planning and validation of the transport path as well as analysis of the experimental data. The focus here is using a US commercial telecom carrier to transfer time between two national real-time standards of UTC. While many researchers have shown that fiber can transfer time and frequency with high accuracy, this experiment addresses the practicality of using the US telecom infrastructure for timing. Our results thus far show a bias of about 40 microseconds between the two one-way directions of PTP signals, with the best method having a variation of under about 50 nanoseconds peak-to-peak. Research is continuing to determine the cause of the bias.

INTRODUCTION

A number of government agencies have discussed a need to back up critical timing infrastructure at the national level [1]. In September 2011, Centurylink, a local Colorado telecom provider, agreed in principle to a two-year experiment linking the UTC timescale of the National Institute of Standards and Technology (NIST) in Boulder, Colorado and the US Naval Observatory (USNO) Alternate Master Clock (AMC) at Schriever AFB, where GPS is controlled. The US Department of Homeland Security (DHS) issued a Request for Information (RFI), Solicitation Number: RUIO-12-A0009 "Transferring of Time via Fiber Network Technologies," in December 2011, requesting information on how vendors could support this project [2]. One vendor, Symmetricom at the time, now Microsemi, gave a detailed plan. A three-way Cooperative Research and Development Agreement (CRADA) was agreed to among

NIST, Centurylink, and Symmetricom-Microsemi and signed in January 2013, to last until December 31, 2014. We are currently working to extend this past December 2014 to December 2015. The goal of the CRADA was to transfer time through a commercial telecom network with an accuracy below 1 µs, and a stability below 100 ns.

The experiment employs the Precision Time Protocol (PTP), IEEE1588-2008 [3], to transfer time across a public telecom network, with real-time standards of UTC at each end: UTC(NIST) and UTC(USNO). This has not been done before, to the best knowledge of the authors. Microsemi is providing the PTP equipment that transmits and receives timing signals over Gigabit Ethernet (GigE) [4] on optical fibers. The fibers run from the two national timing labs to respective Centurylink offices, where the signals are multiplexed into their network on a specific optical wavelength that is not shared with any other customers. The experiment has used two different transport methods. First has been to transport the GigE as a SONET [5] payload on an OC-192 [6] system. The second has been to use the Optical Transport Network (OTN) [7] system to transport the GigE in an ODU0 within an ODU2 transport.

PTP employs two-way time transfer, meaning the timing packets are sent in both directions: from NIST to the AMC and from the AMC to NIST. For convenience we refer to the direction from NIST to the AMC as forward, and from the AMC to NIST as reverse.

RESULTS

First we discuss the PTP over SONET results. We found an asymmetry of 40 µs between the forward and reverse directions. The cause is currently unknown. In addition, we found variations in the one-way delay on the order of 300 ns. These were approximately deterministic when nodes were timed by Cs frequency standards, and had more random wander if the nodes were timed by GPS. It may be that the variation during the GPS timing has a sinusoid element. These results are illustrated in the following plots. Figure 1 shows the forward measurements in blue, and the reverse in red. There is a total delay of about 2 ms and the 40 µs asymmetry. A 2 ms total delay at the speed of light would mean a distance of 600 km, or perhaps 400 km in fiber. Given that the distance between the two in a straight line is just under 200km, it becomes clear that the signals must be buffered and forwarded by equipment in the path. We also note that variations in one direction are somewhat mirrored in the reverse direction. That is, a slope up in one direction is matched by a slope down in the opposite direction. However, jumps do not seem to be matched.

In Figure 2 we have set the minimum offset of each plot to 0.0 from both paths to see the deviation in the measurements. For most of this period nodes were timed by Cs. clocks, showing a slope of about 50 ns/d with occasional resets of about 300 ns. A period in the middle is marked where GPS timing was used. Here, the system accumulated wander with no clear systematic behavior. There could perhaps be a sinusoid effect.

Following these results we switched to using the OTN as the transport. There were two reasons for doing so. First, we wanted to begin to find the cause of the 40 µs asymmetry. Changing the transport was accomplished simply by changing the card that encoded the GigE signals into and out of the Centurylink network. Switching to OTN would allow us to see if the 40 µs asymmetry was due to the card that encoded the signal into the SONET system. Secondly, we wanted to see if the OTN system would be more stable than SONET. We show plots of the results in what follows. In brief, we found that the OTN data were much more stable, but that the 40 µs asymmetry remained. Figure 3 and Figure 4 show data for the OTN analogous to how Figure 1 and Figure 2 show data for the SONET system.

In Figure 3 we see with OTN a similar total delay and asymmetry as for the SONET data, but even here we can see that the lines appear more stable. In Figure 4, we set the minimum offset of each plot to 0 as in Figure 2, and we see a peak-to-peak variation of 50 ns over 33 days. Part of this is an apparent trend in the data. In the short term, the stability is 4 ns, which is the granularity of the PTP measurement system.

If we subtract the forward packets from the reverse and divide by two, we see the time transfer capability. This combination of data is the method in using two-way time transfer data for cancelling the path delay. Figure 5 shows this over a 40 day period. We see a peak-to-peak deviation of 26 ns, and a time transfer offset of -19.1 µs. This is the time-transfer capability of this system if used independent of any other time transfer system, such as GPS.

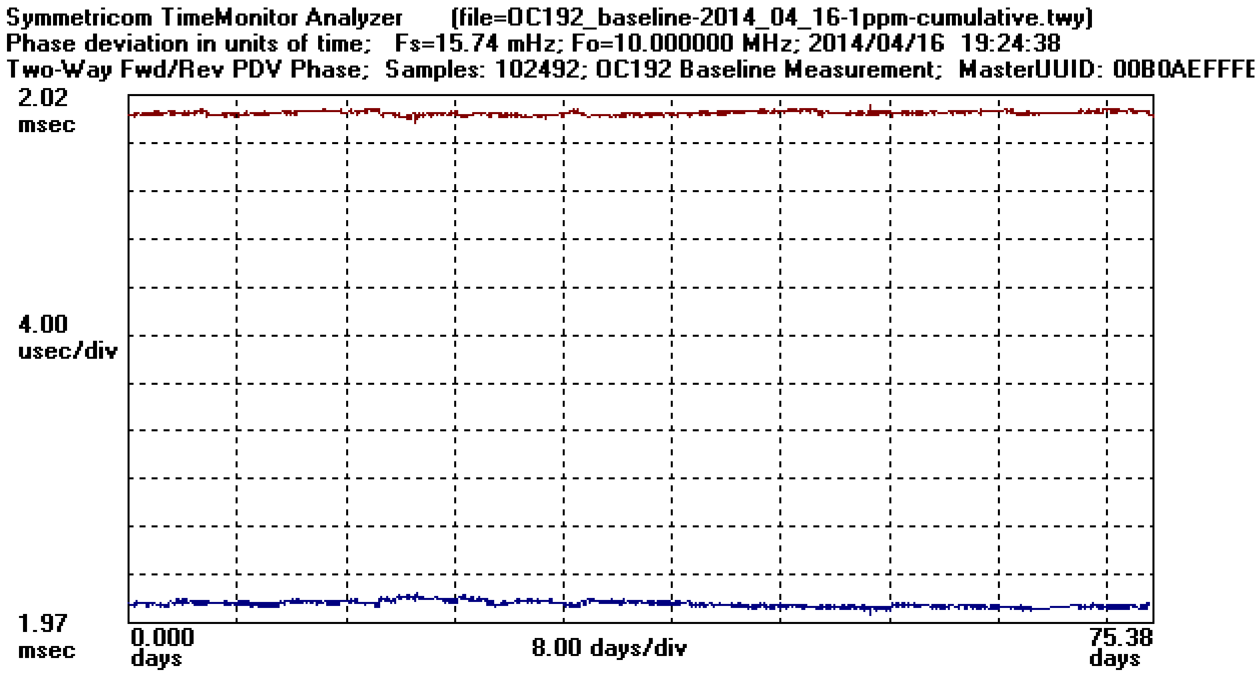

Figure 1: PTP over SONET results over 75 days, showing the forward delay in blue and the reverse in red. The total delay is about 2 ms with about a 40 µs asymmetry.

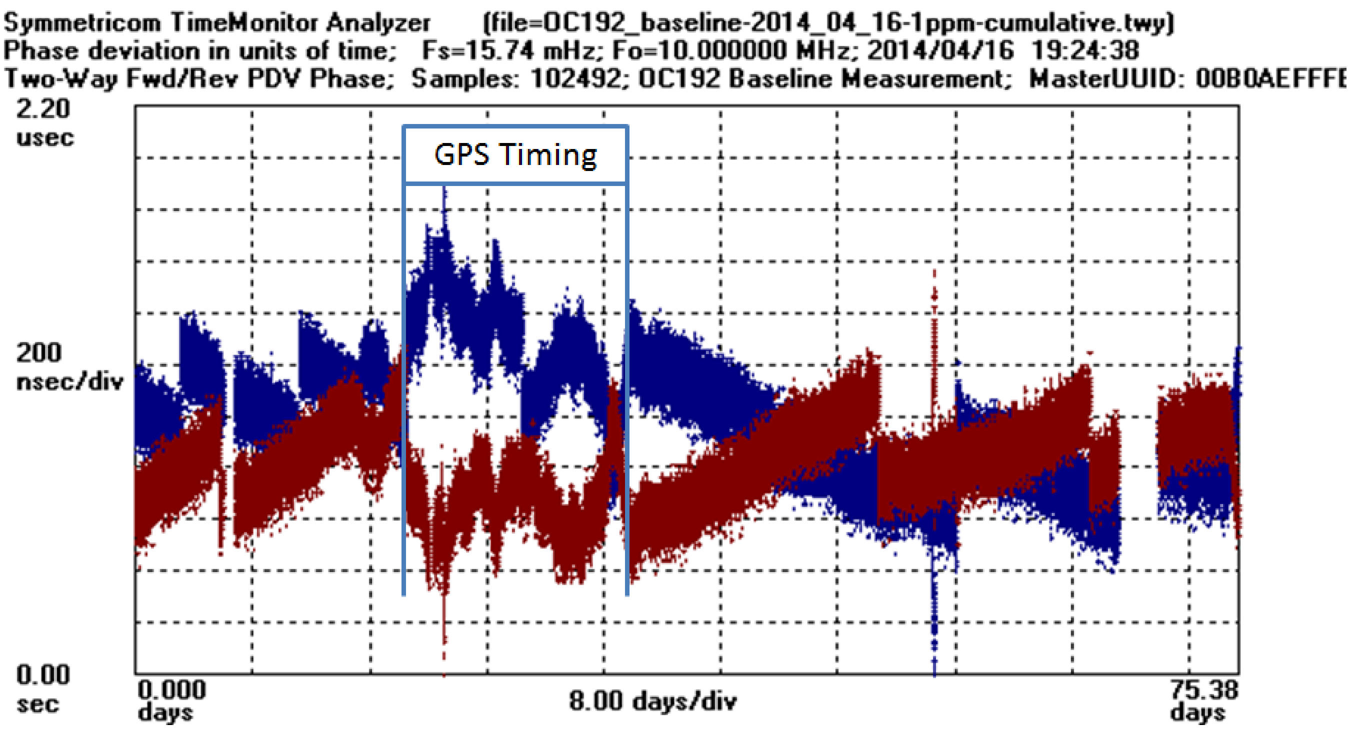

Figure 2: Data as in Figure 1 with the minimum offset of each plot set to 0.0 to show the deviations. For most of this period nodes were timed by Cs clocks, showing a slope of about 50 ns/d with occasional resets of about 300 ns. A period in the middle is marked where GPS timing was used. Here, the system accumulated wander with no apparent systematic behavior.

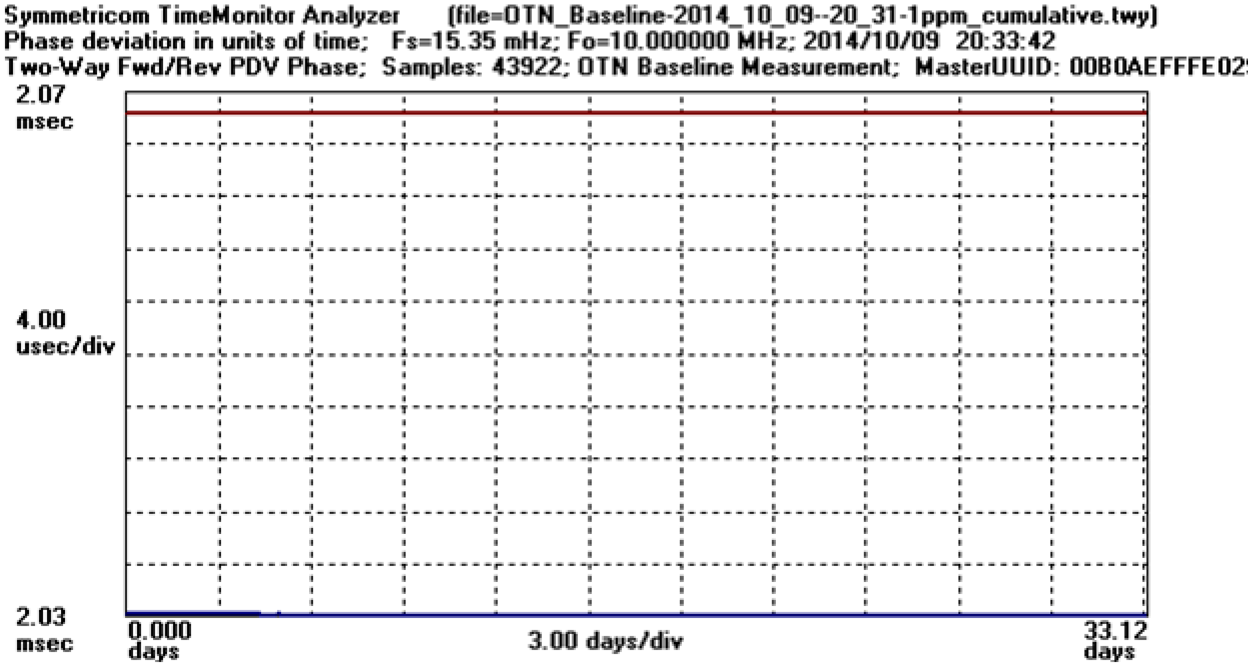

Figure 3: PTP over OTN results over 33 days, showing the forward delay in blue and the reverse in red. As for the SONET case, the total delay is about 2 ms with about a 40 µs asymmetry.

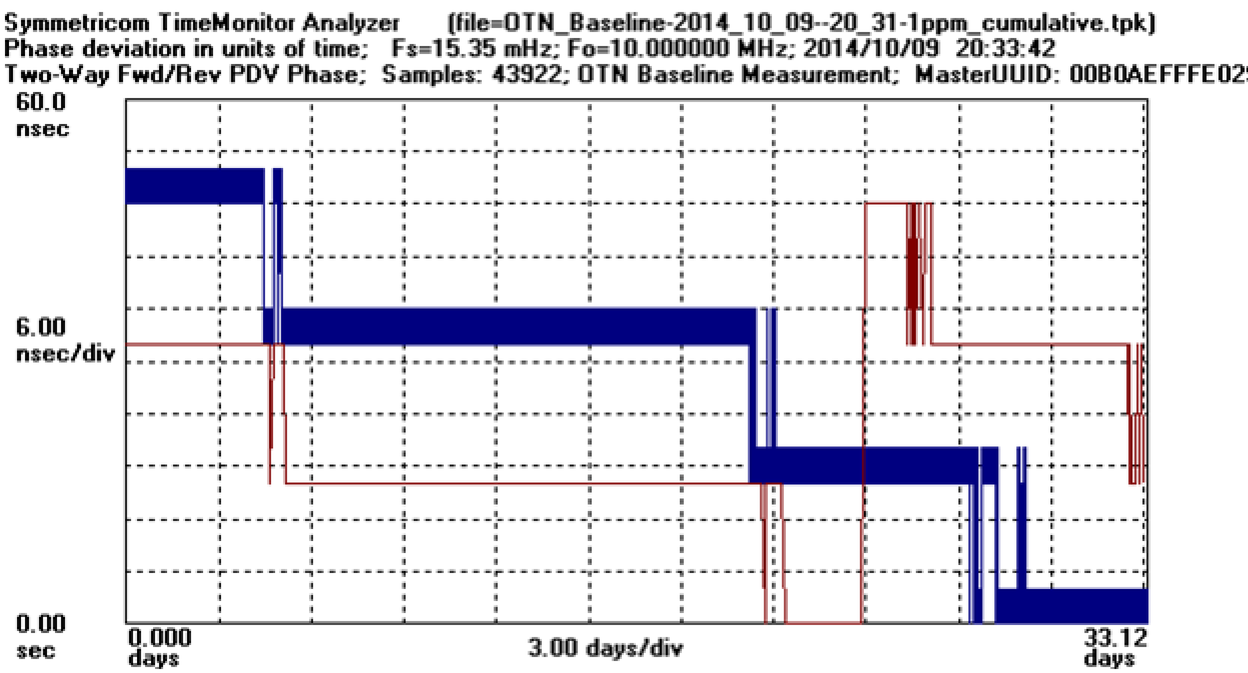

Figure 4: PTP over OTN data with the minimum offset set to 0.0 shows a peak-to-peak variation of 50 ns over 33 days. Part of this is an apparent trend in the data. In the short term, the stability is 4 ns, which is the granularity of the PTP measurement system.

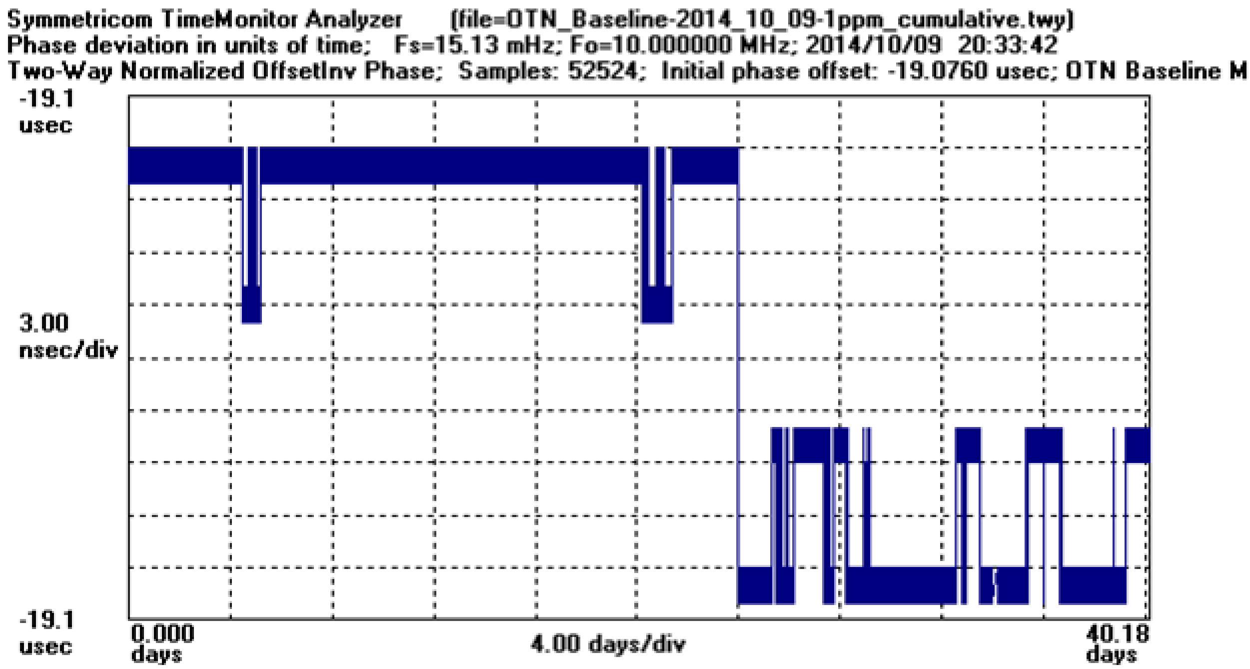

Figure 5: Time transfer capability using the OTN. The value of -19.1 µs is due to an asymmetry of 38.2 µs. The peak-to-peak deviation is 26 ns, with the short term no more than 4 ns.

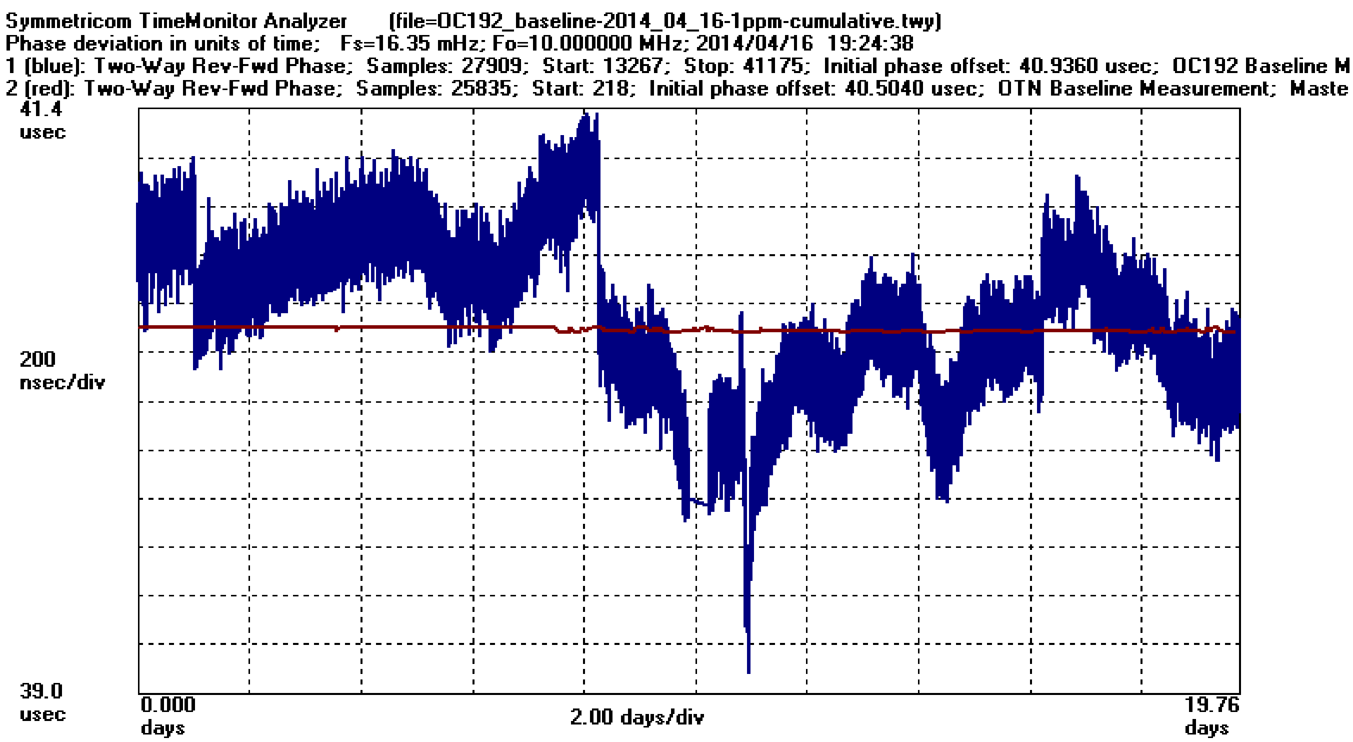

Figure 6: The asymmetry from the reverse minus forward directions for the SONET-based circuit (blue) and the OTN-based circuit (red) plotted on the same graph. The two systems have a very similar average asymmetry.

DIAGNOSTICS

We decided to pursue the cause of the 40 µs asymmetry by breaking the circuit into sections. The path from NIST, Boulder to the AMC at Schriever AFB was chosen to have three segments, by breaking it in a Denver office and in a Colorado Springs office. The plan is to do PTP time transfer from both NIST and the USNO AMC to each of these offices. This will require the use of additional equipment, as we will need PTP masters in each of these central offices as well as a UTC reference. For the UTC reference we will use UTC from GPS. Comparing each realization should allow an uncertainty in the references of no more than a few 10's of ns, i.e. comparing UTC(NIST), UTC(USNO) at the AMC, and UTC(USNO) as transmitted by GPS. This should certainly allow us to find which segments contribute to 40 µs offset. We are currently waiting for the installation of the needed equipment.

In the meanwhile, we performed a number of loopback tests from NIST to these locations. Note that the loopback was actually a loop-back of the two directions individually, i.e. the forward and reverse directions each went from one port of the NIST PTP device out and back to another port of the same device. This method was unable to detect any one-way asymmetry, as it would cancel in the loop back. What we were able to measure was an asymmetry in the initial hardware that converts the GigE to an ODU0 and vice versa. The manufacturer was able to confirm that these devices have a random asymmetry of up to 3 µs that cannot be controlled. Since, in the circuit between NIST and the USNO AMC, there is one of these devices serving each end, this could account for up to 6 µs, but not 40 µs. When the loop-back circuit that goes through only one conversion device is brought up, measured, then released and re-created and measured again, we do indeed see variations of no more than 3 µs. This explains why the total asymmetry in Figure 5 is approximately 38 µs, while in Figure 1 and Figure 3 it is about 40 µs.

The next step for us, as of late November 2014, remains to measure the asymmetry in one-way delays in segments of the circuit. As much as possible, we hope to determine the source or sources of this asymmetry. Of particular interest is the fact that the asymmetry is very close between both the SONET-based circuit and the OTN-based circuit. Figure 6 illustrates this, showing the reverse minus forward one-way delays (i.e. these are not divided by two, as is done for the time transfer illustration). Although the OTN circuit (red curve) is much more stable than the SONET one (blue curve), the mean asymmetry for the two methods seems very close. Recall that there would be a variation in the asymmetry up to 6 µs, i.e. up to 3 µs at each end, due to having taken the circuit down from the SONET system and then brought it back up for the OTN.

CONCLUSIONS

While we have not found a time –transfer accuracy below 1 µs, with the OTN system the stability is well below 100 ns. If one imagines a partial backup to GPS timing, where GPS can be used to calibrate the asymmetry, and where PTP is available for when GPS is unavailable, then it appears that this OTN system would support better than 100 ns time transfer. If for any reason the circuit is lost and re-created, one would need GPS or some alternative time reference to calibrate the new asymmetry.

We look forward to further study of this circuit to learn more about the source of the approximately 40 µs asymmetry. The long-term plan is to extend this research to other circuits, perhaps spanning the continental US, and perhaps establishing standards supporting such time-transfer systems.

DISCLAIMERS

Any mention of company or equipment names is for information only and not meant is an endorsement.

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