OPTICAL LINK TIME TRANSFER BETWEEN IPE AND BEV

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Abstract

This paper describes results of long term two-way optical time transfer between Czech and Austrian national time and frequency laboratories in Prague and Vienna. The system utilizes DWDM channels in production telecommunication network. Optical transfer results are compared with GPS Common View and also with official time offset of both national time scales as published in BIPM Circular-T.

INTRODUCTION

The most common way to compare two distant clocks nowadays is to perform the time transfer using satellite navigation or telecommunication systems. Usually the Common-View comparison is done, i.e. the time difference between the clocks is calculated from observations against the same satellites viewed at the both sites at the same moment.

With the increasing number of all-optical networks, the area these networks cover, and number of users they interconnect, the idea of time and frequency transfer over optical fiber arises. Two distant sources of precise time and frequency, e.g. atomic clocks, can be compared using a single or a pair of either dedicated fiber(s) or within an all-optical telecommunication network.

In recent years, several two-way (e.g. utilization of SDH telecommunication links **[1]**) or one-way (e.g. detection of delay variations based on transmission of two wavelengths **[2]**) transfer techniques were designed and implemented. Our optical time transfers system is an instance of two-way transfer method that relies on known and stable asymmetry of transport delay in both directions. We described details of the measurement method in **[3]**.

The basic idea is following: two adapters (**A** and **B**) are connected by a bidirectional optical link. Each adapter is provided with a 1PPS signal from a local clock and has an output representing the 1PPS signal received from the opposite site. The time interval counter (TIC) measures the interval x_A (resp. x_B) between local and remote 1PPS.

On a symmetrical link, the delay in both directions equals $\delta = \delta_{AB} = \delta_{BA}$. In real network, the fiber length in both directions slightly differs (e.g. patch cords in switching boards, fibers compensating the chromatic dispersion), introducing delay asymmetry Δ:

$$\Delta = \delta_{BA} - \delta_{AB}. \tag{1}$$

The clock offset Θ_{AB} may be then calculated as

$$\Theta_{AB} = (x_A - x_B - \Delta) / 2. \tag{2}$$

We compared the national time scales of the Czech Republic and Austria using an optical link in our experiments and we evaluated the properties of this optical transfer together with time transfer using GPS. The national time scale of the Czech Republic, UTC(TP), is generated from the Cesium beam atomic clock 5071A/001 in the Institute of Photonics and Electronics (IPE) in Prague. The clock is housed in dedicated temperature-controlled chamber where the ambient temperature ranges within 0.1ºC. The Austrian time scale, UTC(BEV) is also generated from the 5071A/001 clock in the Federal Office for Metrology and Surveying (BEV) in Vienna. Both clocks contribute to the calculation of UTC within the collaboration with the BIPM and thus the 5-day time differences UTC − UTC(k), k = TP, BEV are published monthly in Circular-T **[4]**.

OPTICAL PATH

The optical time transfer utilizes two unidirectional optical channels between IPE and BEV. The whole optical path consists of several segments. The longest part, connecting PoPs in Prague and Brno, utilizes dedicated DWDM (Dense Wavelength Division Multiplexing) channels in Cesnet2 production network. The link between Brno and Vienna University is another DWDM channel in the cross-border link joining CESNET and ACOnet – CENSET is the Czech NREN (National Research and Educational Network), ACOnet is the Austrian NREN. To connect the national laboratories with network points of presence in both metropolises, the rented pairs of dark fiber are used. The total length of the optical path is 550 km and it is equipped with 7 optical amplifiers (EDFA – Erbium Doped Fiber Amplifier). The optical part of time transfer adapter is based on SFP transceivers. Our transmission system uses the same wavelength in both directions – currently, it is 1551.72 nm (i.e. C-band, ITU channel #32). Description of particular segments is summarized in Table 1.

Table 1. Optical path segments.

Segment	Length [km]	Attenuation [dB]	Technology
IPE – Cesnet PoP	16	7.0	dark fiber
Cesnet PoP – Brno University	309	78.6	Cisco ONS (DWDM channel)
Brno University – Vienna University	220	50.0	CzechLight booster/preamp (DWDM channel) **[5]**
Vienna University – BEV	5	1.5	dark fiber

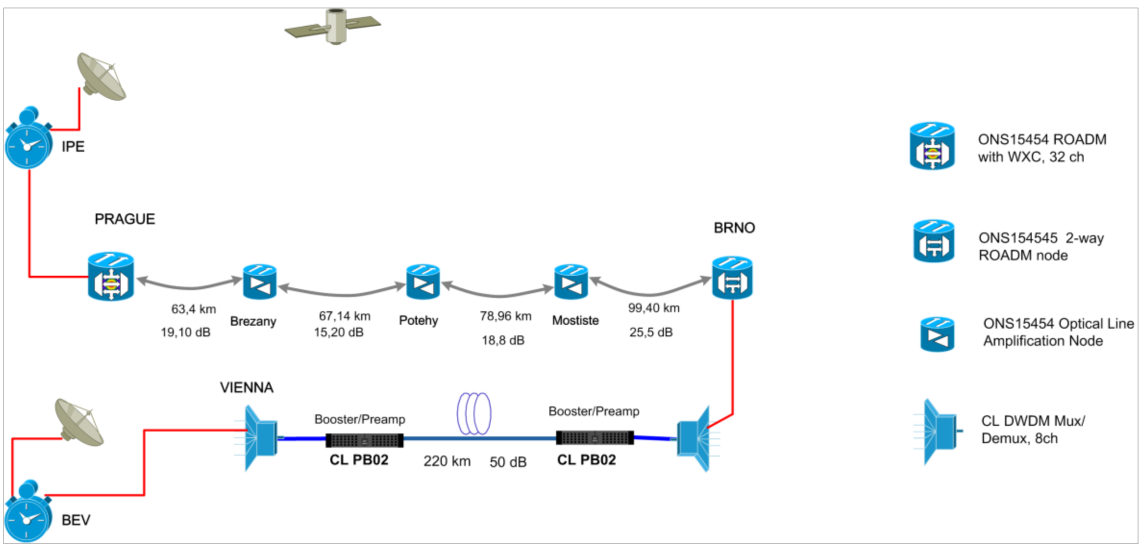

Figure 1. Schematics of the optical path.

ADAPTERS AND EQUIPMENT

ADAPTERS

We designed and manufactured our own time transfer adapters that consist of two main components:

- FPGA chip Virtex 5, which contains all logical circuits;
- SFP (Small Form-factor Pluggable) transceiver, which converts signal between electrical and optical domains.

These adapters encode 1PPS signal from the clock and transport it to the remote site through one of the fibers. Signal from the second fiber is decoded in the adapter and 1PPS referring to the remote clock is provided. Adapter structure is described in **[3]**.

TIME INTERVAL COUNTERS

In the IPE site, we use Pendulum CNT-91 counter having basic resolution ≈50 ps, while BEV is equipped with Stanford Research System SR-620 with resolution of ≈20 ps.

GPS RECEIVERS

Both laboratories are equipped with different GPS time transfer receivers: GTR50 (Dicom) in IPE and TTS-2 (PikTime Systems) in BEV. Both receivers generate CGGTTS data, thus the Common-View comparison using the GPS code measurements could be done. Unfortunately, comparison using GPS carrier phase measurements couldn't be performed because of the lack of the carrier phase data in the TTS-2 receiver.

RESULTS

Our measurements started on August 2, 2011 (MJD 55775), and the data collected until November 26, 2011 (MJD 55891) are presented here. We measured the UTC(TP) and UTC(BEV) time offset every second using the optical method. We are going to present these data and compare them with Common-View GPS and with Circular-T values.

The graph at Figure 2 provides general overview of all results: red points represent optical measurement data, green points are GPS data, and the blue line shows the time offset between UTC(TP) and UTC(BEV) according to Circular-T. The graph also shows missing optical measurement data for the interval from September 30 (MJD 55834) to October 6 (MJD 55840) – the origin was a bad coaxial cable connector between adapter and counter.

In order to directly compare GPS and optical time transfer, we also processed optical measurement data the same way as CGGTTS does: by calculating the linear regression over interval of 780 s. Figure 3 shows detailed comparison for a 5-day period – we can see that optical measurement contains less noise than CV GPS. Time stability of both methods in terms of Time Deviation (TDEV), which is visualized in Figure 4, confirms the observation from Figure 3. The Time Deviation of the optical transfer is about 130 ps, while the TDEV of GPS transfer is ≈800 ps at 780-s averaging interval. The optical time transfer is more stable up to averaging interval of about 50000 s.

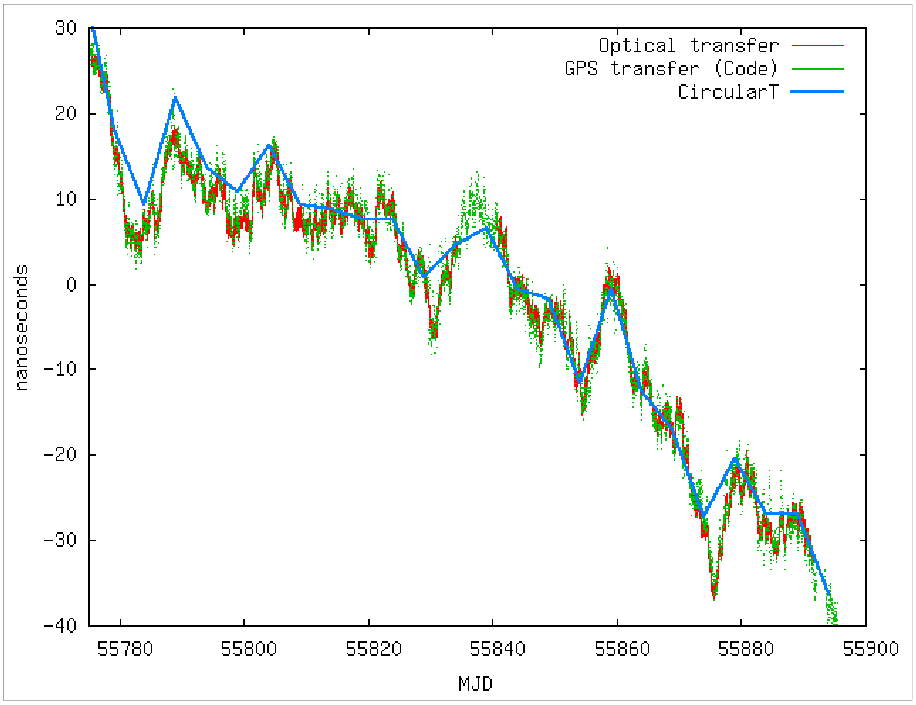

Figure 2. Time difference UTC(TP) − UTC(BEV) measured using optical link (red), via GPS (green) and from BIPM Circular-T (blue).

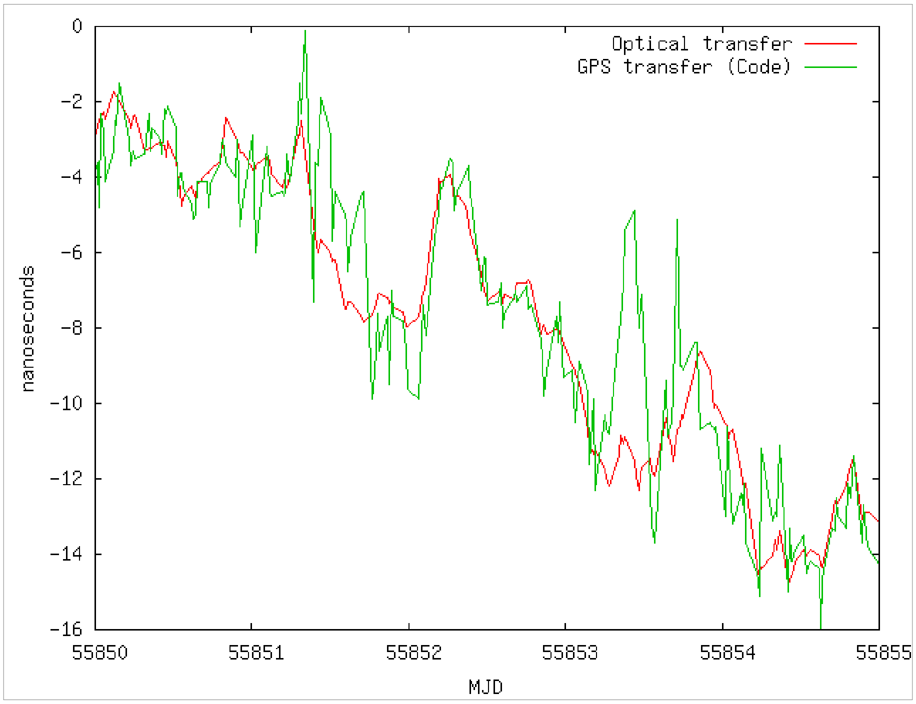

Figure 3. Detail of the time difference calculated from 780-s interval averages obtained from optical measurements (red) and measured using GPS (green).

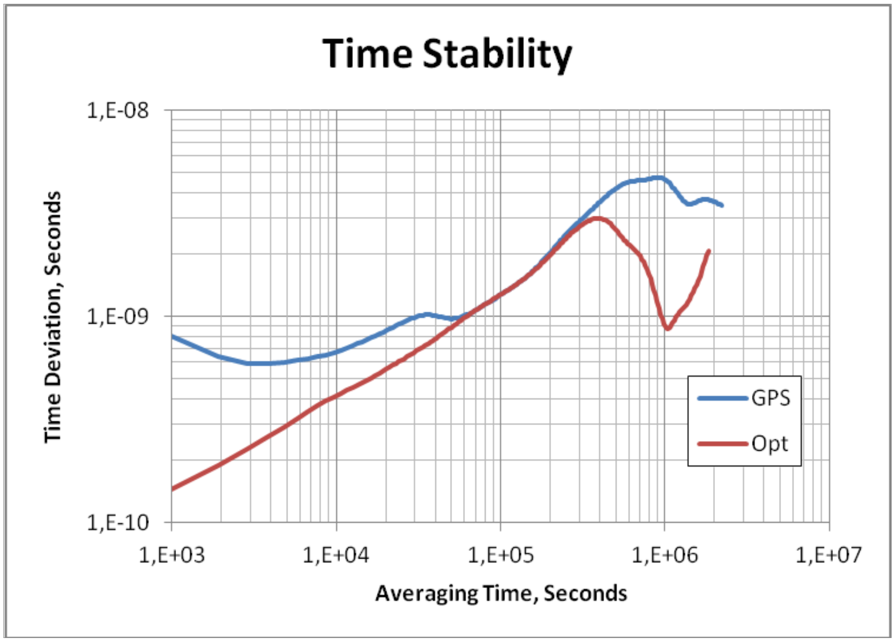

Figure 4. Time stability of the optical (red) and GPS (blue) time transfer.

Time deviation of the optical transfer (raw data, no linear regression) is shown at Figure 5. We can identify the white phase modulation noise in averaging intervals 1–20 s and the white frequency modulation noise in averaging intervals $2 \cdot 10^1$–$3 \cdot 10^5$ s. The lowest noise in terms of Time Deviation observed is 30 ps at 20-s averaging interval. Time deviation values for averaging intervals over $3 \cdot 10^5$ are influenced by the insufficient number of points used for the calculation.

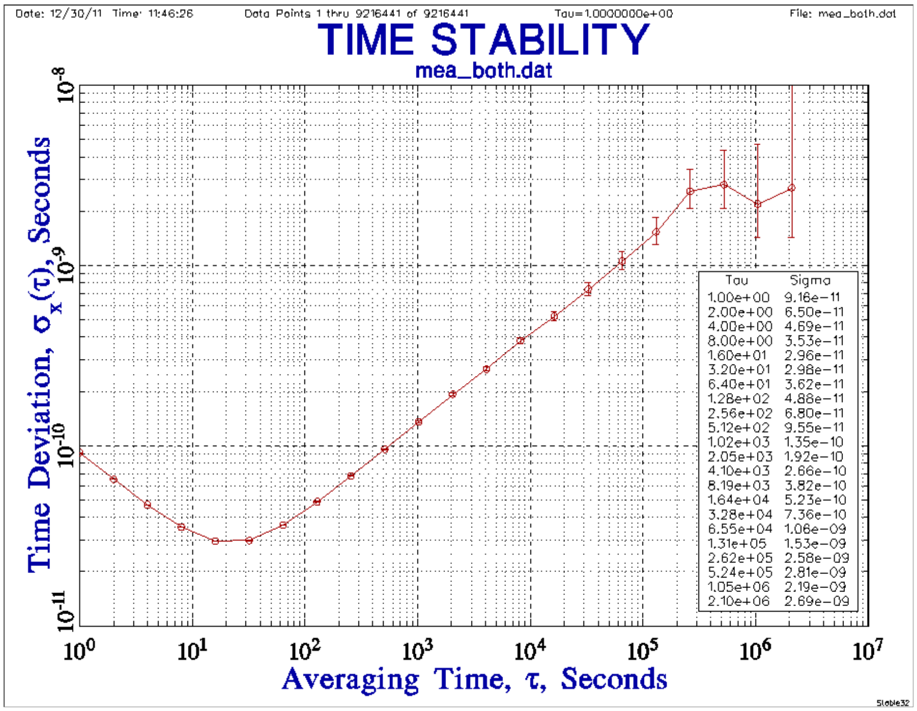

Figure 5. Time Transfer Stability.

Temperature-dependent propagation delay is the important issue of the optical fiber. The dominating effect is caused by the thermal change of the group refraction index, which is about 36 ps / (ºC · km) **[6]**. The environmental temperature influence depends on physical installation of optical cable. We utilize fiber thread in commercial telecommunication cables which are buried typically 1 m under ground, however part of the technology, namely coils of fiber compensating chromatic dispersion, are installed in technological rooms, usually air-conditioned. To describe the delay changes, it is important to distinguish diurnal and seasonal variations. Figure 6 shows the results of our measurement – only the data between October 7, 2011 (MJD 55841) and November 26, 2011 (MJD 55891) are displayed, because large seasonal influence was observed in August and September. We see the diurnal delay changes of 4–7 ns and the total delay difference is 210 ns during the 177 days of measurement. It represents $7.5 \cdot 10^{-5}$ of the average propagation delay 2788 μs.

CONCLUSIONS

We implemented optical time transfer system that allows long term time transfer between IPE and BEV and thus provides comparison between UTC(TP) and UTC(BEV). According to the data collected in first four months of the system operation, the stability of the implemented optical time transfer method in terms of Time Deviation is better than Common View GPS time transfer. The lowest noise is 30 ps at 20-s averaging interval. We are going to evaluate seasonal influence to the time transfer accuracy once data of the whole year are available.

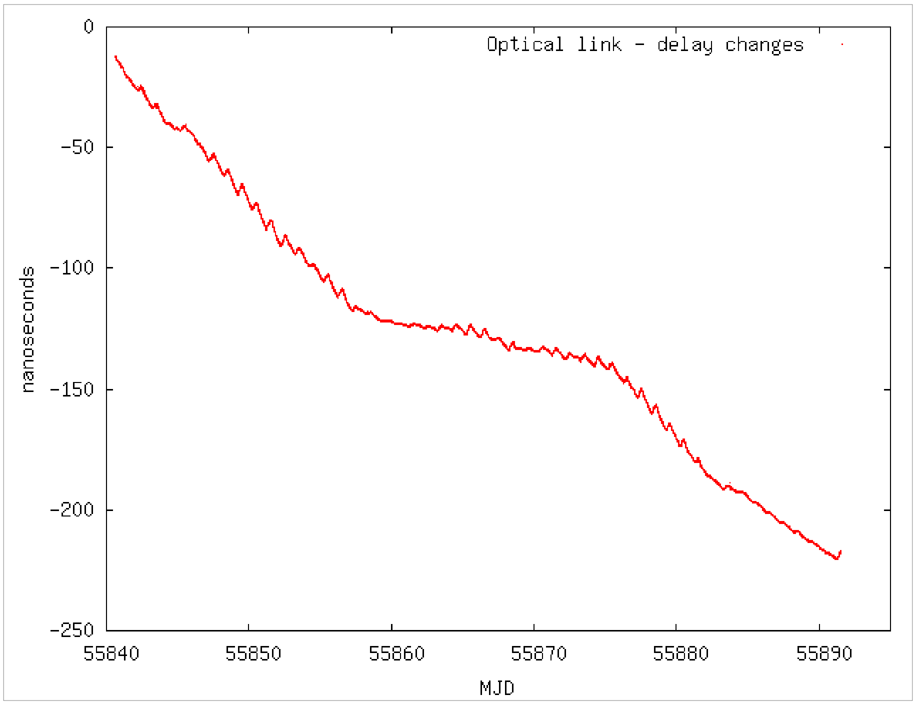

Figure 6. Diurnal and seasonal variations in the optical path delay.

REFERENCES

[1] S.C. Ebenhag, P.O. Hedekvist, P. Jarlemark, R. Emardson, K. Jaldehag, C. Rieck, and P. Lothberg, 2010, *"Measurement and Error Sources in Time Transfer Using Asynchronous Fiber Network,"* **IEEE Transactions on Instrumentation and Measurement, IM–59**, 1918–1924.

[2] S.C. Ebenhag, P.O. Hedekvist, and K. Jaldehag, 2010, *"Single-way Fiber-based Time Transfer with Active Detection of Time Transfer Variations,"* in Proceedings of the 42nd Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 15–18 November 2010, Reston, Virginia, (U.S. Naval Observatory, Washington D.C.), pp. 413–426.

[3] V. Smotlacha, A. Kuna, and W. Mache, 2010, *"Time Transfer in Optical Network*," in Proceedings of the 42nd Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 15–18 November 2010, Reston, Virginia, (U.S. Naval Observatory, Washington D.C.), pp. 427–436.

[4] BIPM, *"Circular-T ,"* at *http://www.bipm.org/jsp/en/kcdb_data.jsp.*

[5] Cesnet, 2009, *"CzechLight Amplifier devices,"* at *http://www.optokon.com/datasheets/C-Active_devices_for_optical_network/C8-EDFA/ACT_01-07_EN-EDFA.pdf.*

[6] L. G. Cohen and J. W. Fleming, 1979, *"Effect of Temperature on Transmission in Lightguides,"* **Bell System Technical Journal**, **Vol. 58**, No. 4, 945–951.