Photonic Services for Time and Frequency Transmission in the Czech Republic

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Abstract. In every country exists a time and frequency laboratory that operates a certain set of atomic clocks with goal to provide national approximation of UTC time scale. Generally, higher number of these interconnected clocks (Caesium primary standards and Hydrogen masers) might improve accuracy and stability of the time scale. The term "interconnection" in this context means that we have to transfer time between them despite of their location at geographically distant places – the common method is a dedicated two-way satellite link or a GPS based system, however utilization of fibre links constantly increases. And present all-optical networks allow stable transmission of information. However to increase stability specific measures are necessary. Contribution summarizes the reasons for building of infrastructure dedicated to transfer of accurate time and frequency in the Czech Republic. It shows achieved results and indicated necessary steps for further stability improvements.

Introduction

Transmission capacity of present Dense Wavelength Division Multiplex (DWDM) is increasing still; in experiments it reaches tens of Tbit/s [1]. Such capacities are achieved by to simultaneous data transmission of hundreds of wavelength channels and continuous increase in channel transmission rate. Systems are also evolving from a fixed channel bandwidth to a state where the bandwidth of a channel can be dynamically allocated with very fine steps and channel capacity can be adjusted based on channel quality and requested reach. The optical modems with adaptive transmission capacity [2] will also be able of adaptation to traffic load and minimal energy consumption. Majority of present data transmission is packet oriented and typically it is processed by networks non-deterministically. However, once time constraints are not guaranteed and a problem arises for real-time applications. This fine step of allocation approach also allows creation of channels with all optical processing and without jitter caused by packet transport. The variable bandwidth of channels excellently suits for the real time transmissions that offering adaptive transmission rate and especially guaranty of time limits. In following paragraphs this type of new multi-domain, end-to-end network service will be referred as Photonic service. We proved the concept of photonic services on a specialized metrology application comparison of time scales.

Field Implementation

CESNET operates national research network using DWDM technology and also is involved in Time and Frequency (TF) metrology applications and cooperates with Czech national time and frequency laboratory in Institute of Photonics and Electronics (IPE). Both organizations are also participants of European research project NEAT-FT [3] aimed at time and frequency transfer using optical fibre links.

The usage of dedicated dark fibre for long haul transmission of TF is challenging from economic reasons. Because of it, we decided to use all optical lambdas. Following several experiments, CESNET started to operate time comparison of time scales between Czech and Austrian national time and frequency laboratories IPE in Prague, and Bundesamt für Eich - und Vermessungswesen in Vienna (BEV) in August 2011[4]. In principle, we measured time offset between atomic clock with uncertainty of about 10^{-10} s (i.e., 100 ps). The photonic path has total length of two times 550 km. It passes through dark fibres in local loops and mixture of two transmission systems, according Figure 1.

During three months of measurement, very good correlation between optical transfer and standard GPS Common View method, i.e. method when signal from the same satellite is received in both sites, has been achieved. Good correlation with published so called Circular-T, the official documents evaluating time offset between UTC time scales and its national approximations, has been achieved. See Figure 2. Time stability of all three methods in terms of Time Deviation (TDEV) is visualized in Figure 3. It confirms our observation that optical time transfer has smaller noise than both GPS based methods. We can identify the white phase modulation noise for optical transfer 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. Figure 4 shows difference between optical transfer and GPS carrier phase method (PPP) smaller then ± 0.5 ns during about 20 day interval.

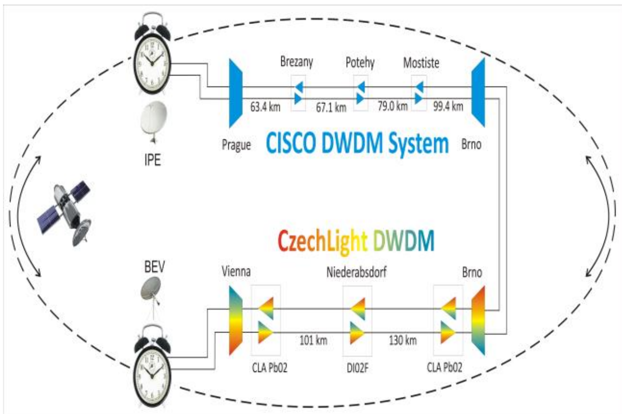

Figure 1. Schematic of photonic path

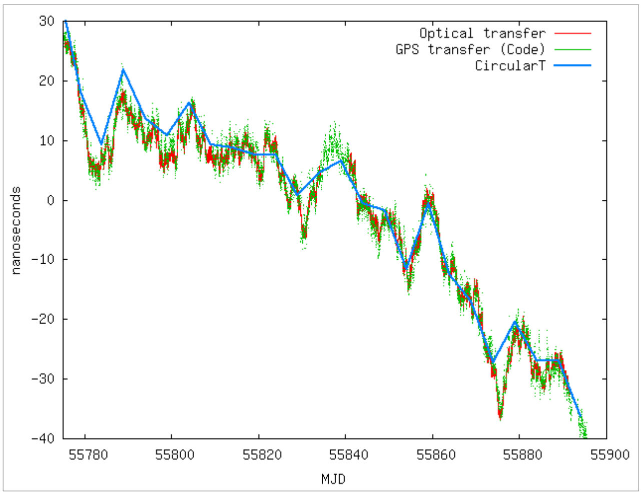

Figure 2. Time difference UTC(TP) – UTC(BEV)

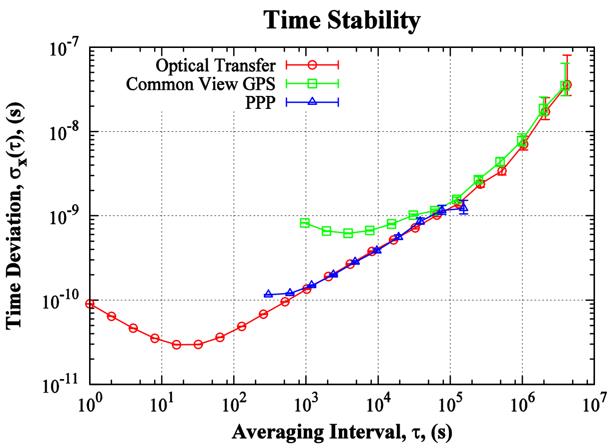

Figure 3. Time transfer stability

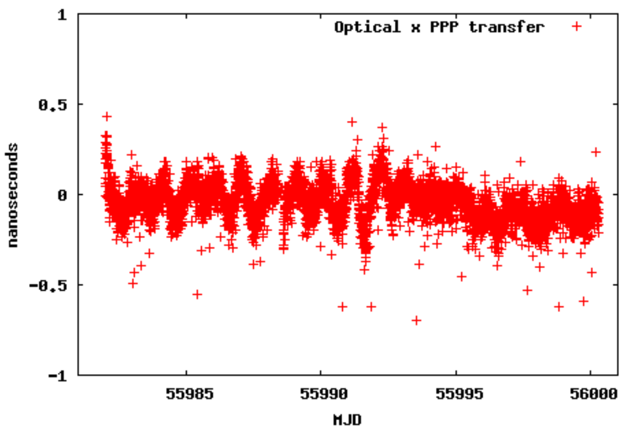

Figure 4. Difference between optical transfer and GPS PPP methods

TF Transmission Infrastructure

Based on these achievements we start building of national TF infrastructure with following goals:

- Transfer time from existing Caesium primary standard to Czech national time and frequency laboratory in IPE.
- Compare national approximation of UTC with that one in neighbouring countries.
- Distribute accurate time and stable frequency to users.

Figure 5 shows the first phase of actually built TF-infrastructure at the map of Czech Republic. The TF-infrastructure physical topology is a star with centrum in CESNET, the transport layer topology is a star having centrum in IPE. The dark fibre between these two localities is currently used for time transport IPE – BEV only, but we are going to install there a DWDM system providing at least 16 channels. Links between CESNET and involved organizations utilize available technology, in most cases it is a combination of commercial and open DWDM transmission systems:

- Pair of channels (with the same wavelength in both directions) in a standard DWDM system.
- Pair of DWDM channels with different wavelengths in single fibre bidirectional DWDM system.
- Pair of DWDM channels (both uni- and bi-directional) in experimental links, e.g. testbeds.
- Dark fibre – usually last mile in the urban area.

Despite this heterogeneous physical layer, the transport layer provides parameters required for accurate time (resp. frequency) transfer. Currently, channels for time transport are amplified by the same unidirectional amplifiers that are used for standard data channels. Recently, we develop own bidirectional amplifiers (in scope the project CzechLight), that will be dedicated only for time transfer. In future, we plan to install these new amplifiers even in the backbone.

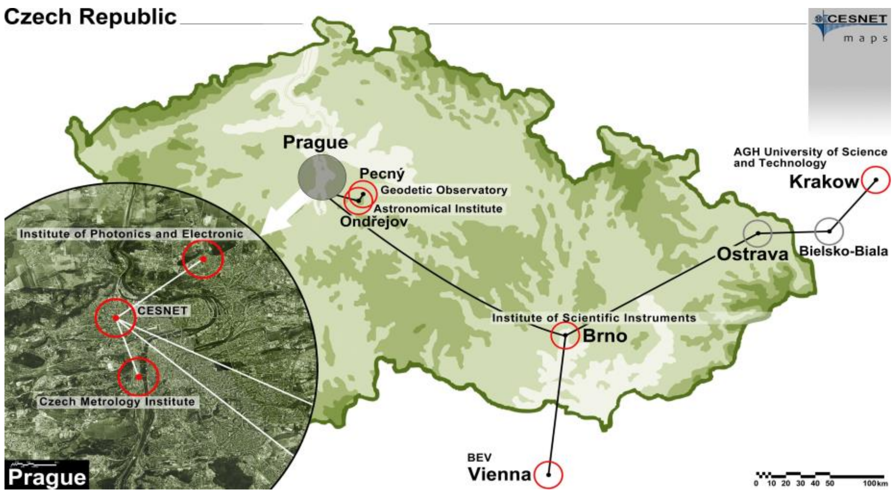

Figure 5. TF-infrastructure

Laboratory experiments

The developed transfer system [6] implements a two-way transfer method and actually over two unidirectional channels [5]. Time transfer is disturbed especially by change of propagation delay. The most important factor for long paths comes from temperature dependent length change. By these temperature changes suffers mainly fibres which are not buried, e.g. hanged fibre lines, spare fibres or fibre based chromatic dispersion compensating units outside air-conditioned rooms. To mitigate influence of these relatively slow thermal processes, it is possible to deploy bidirectional transmission within the single fibre. This method performs well and it is relatively simple for short distance without optical amplification. However when amplification needs to be deployed, the issue must be solved. The principle of optical Erbium Doped Fibre Amplifier (EDFA) is naturally bidirectional. But due to high gain of EDFA (typically 20-30dB) and reflections together with backscattering returning from fibre, EDFA must be equipped with isolators to limit unwanted lasing [7]. And these isolators prevent EDFA from bidirectional operation. During the laboratory experiments we have deployed simple setup using bidirectional EDFA (without isolators) and passing over 2 times 100km of standard single mode fibre according specification G.652 - see Figure 6. Transmission was directionally split and performed on wavelengths 1472.72 nm and 1546.12 nm.

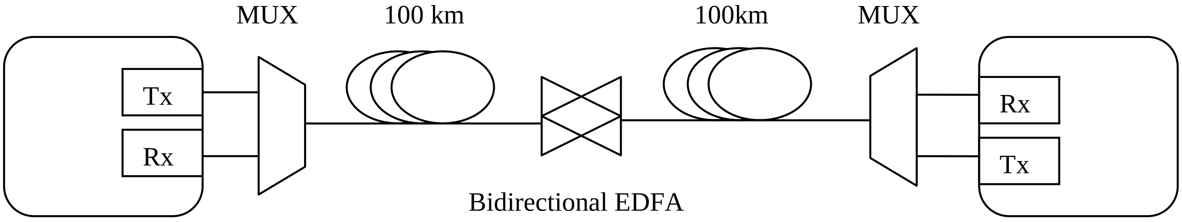

Figure 6. Schematic of laboratory experiment

Conclusions

We achieved better transfer stability of time transfer compared with both GPS based methods over 2x550km all optical path using regular unidirectional all-optical lambdas. In actually tuned TF infrastructure we will improve time stability by establishing bidirectional channel.

Acknowledgements

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