Czech Optical Infrastructure CITAF

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***Summary*—The article describes CITAF, the national optical infrastructure in the Czech republic. It is a non-commercial and open activity focused on the transfer of accurate time and very stable frequency using optical networks.**

Keywords—time transfer; frequency transfer; optical fiber; wavelength division multiplexing.

I. Introduction

Optical links have been more commonly utilized for accurate time and stable frequency transfer in the last decade. It is even dominating technology in densely inhabited areas like Europe. The limiting factor is mainly the availability of optical links in sites that produce or utilize time or frequency. In the last five years, European Commission supported several projects focused on the distribution of time and frequency (TF) as an optical service. An example is CLONETS (Clock Network Services) [1] in years 2017 – 2019. Its follower CLONETS-DS (Design Study) [2] in 2020 – 2022 aims to work around a design study of such European infrastructure. In several European countries, NRENs (National Research and Educational Network) play an important role in optical time and frequency transfer because they operate large optical networks with capacity dedicated to research and science.

There are currently relevant national activities or infrastructures, for example in the Czech Republic, France (REFIMEVE+ [3]) or Poland (OPTIME [4][5]), and the logical next step is to integrate them into the future European infrastructure. Many technologies for time and frequency transfer in optical fiber were developed and deployed in recent years.

II. Czech TF infrastructure

CESNET, the Czech NREN, started building the optical TF infrastructure about 10 years ago as a natural extension to the first time optical transfer between Prague and Vienna [6]. With an increased number of cooperating institutes and organizations, we decided to formalize our activity and to establish CITAF – Czech Infrastructure for Time and Frequency[7].

CITAF is a non-commercial and open activity focused on the transfer of accurate time and very stable frequency using optical network. The infrastructure is operated on top of the CESNET optical network and utilizes its resources. The infrastructure has already reached three neighboring countries, Austria, Poland and Slovakia. The CITAF infrastructure is the result of the research activities of CESNET in cooperation with partners and is further developed. The achieved parameters and potential correspond to similar activities in other countries and allow us to participate in international research in the field of time and frequency metrology.

A. CITAF Goals

The aim of CITAF activity is:

- to be a national platform for cooperation in the research and development of methods of the maximum possible stability and accuracy of time and frequency transfer in optical networks;
- to strive for the establishment of a permanent national optical infrastructure for the transfer of time and frequency with parameters corresponding to the most stable current and developed sources of frequency and for its connection to the follow-up European infrastructure;
- to support joint publishing activities and cooperation in national and international projects and grants;
- to present the results of cooperation and develop an awareness of the possibilities and use of distribution of very accurate time and stable frequency.

B. CITAF Optical Layer

A critical part of the CITAF infrastructure is the optical layer. The majority of its optical paths in CITAF shares fiber with the CESNET data network (which are typically operated 100+ Gbps channels), however compared to unidirectional data channel, the TF channels require bidirectional amplification. Isolation between TF and data channels is made by OADMs (Optical Add-Drop Multiplexors). Generally, the whole CITAF optical layer is highly heterogeneous [11]. It uses preferably bidirectionally lit and amplified dark channel within DWDM (Dense Wavelength Division Multiplexing) telecommunication system for coherent optical frequency transfer. For time transfer, telecommunication lambda services are occasionally used in order to achieve fast service establishment. By the year 2021, the CESNET DWDM backbone undergoes significant upgrade from non-coherent to coherent flex spectrum. During this upgrade, more than 120 OADMs were installed, reserving at least 800 GHz of optical bandwidth for TF and quantum services [12].

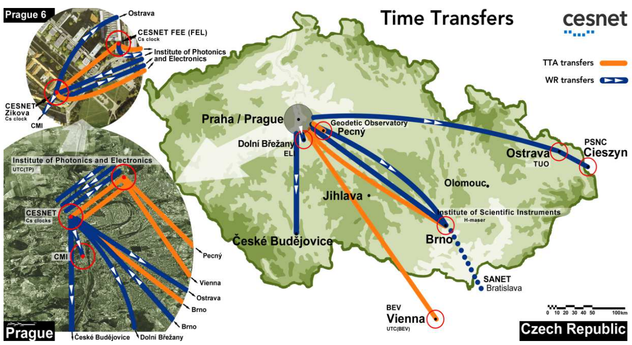

Figure 1 - Time transfer links

III. TIME TRANSFER IN CITAF

Our time transfer in optics started history in 2011, when we set up the first optical link comparison between UTC(TP) and UTC(BEV), the Czech and Austrian national approximations of the UTC time scale. According to our knowledge, it was the world first time transfer optical link between two NMIs (National Metrology Institutes). We operate currently two technologies for time transfer: our own adapters and the White Rabbit system. All time transfer links are shown in Figure 1.

A. Time Transfer Adapters

Time transfer adapters (TTA) were developed in CESNET. They allow comparing of time scales of atomic clocks and are currently utilized in CESNET, the Institute of Photonics and Electronics (Laboratory of the Czech national time and frequency etalon), BEV Vienna (Laboratory of the Austrian national time and frequency etalon), the Institute of Scientific Instruments, the Faculty of Electrical Engineering of the Czech Technical University, and the Research Institute of Geodesy, Topography and Cartography. Adapters are designed to operate in very heterogeneous environment, including multimode fibers, single mode dedicated fibers, telecom lambdas, and passive channels within other WDM systems. The transmission may be performed over both single fiber bidirectional channels and traditional fiber pair setups. More details can be found in [9].

TTA advantages:

- Smaller phase noise.
- Tolerates lower input power due to lower carrier frequency.

B. White Rabbit System

The second deployed technology is the White Rabbit system which relies on synchronous Ethernet in bidirectional channel [13]. The intention is to use White Rabbit for the operation of a composite atomic time scale based on a local Hydrogen maser and set of remote Cesium clocks.

White Rabbit advantages:

- Reproduction of the source time signal on remote sites.
- Standardized technology with commercial support.

C. TTA and White Rabbit evaluation

We compared the performance of both technologies using a field deployed fiber loop (96 km, attenuation 24.6 dB). According to the White Rabbit specification, the time error should be smaller than 1 ns [14]. We see (Figure 2) that MTIE meets this expectation and the MTIE of TTA system is about two times smaller.

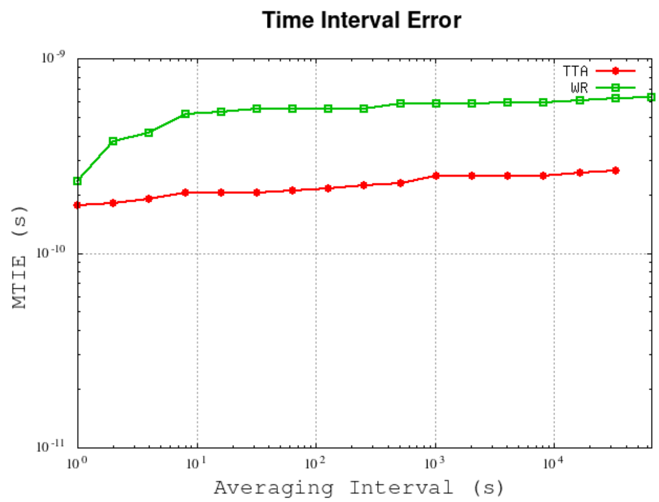

Figure 2 - Maximum Time Interval Error

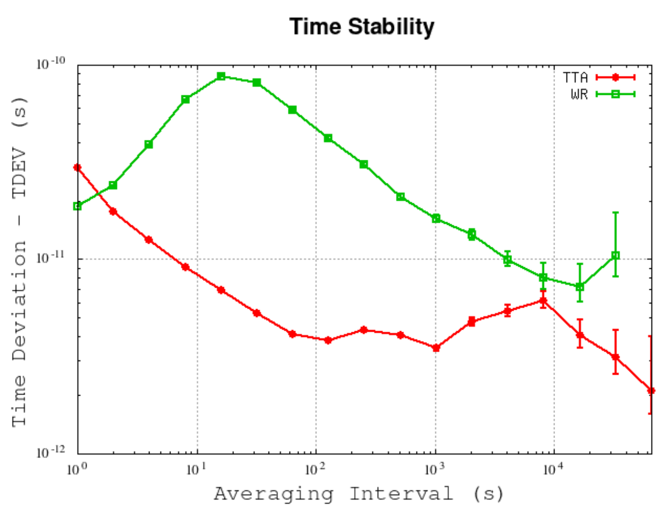

Figure 3 - Time Deviation (TDEV)

Figure 3 provides a comparison of the TDEV of both technologies. We can observe an unexpected peak at about 20 s averaging interval for the White Rabbit system. Such behavior of White Rabbit switches was also reported by other authors [16] and is currently the subject of investigation. TDEV of TTA system is smaller starting 2 s averaging time intervals.

IV. FREQUNCY TRANSFER IN CITAF

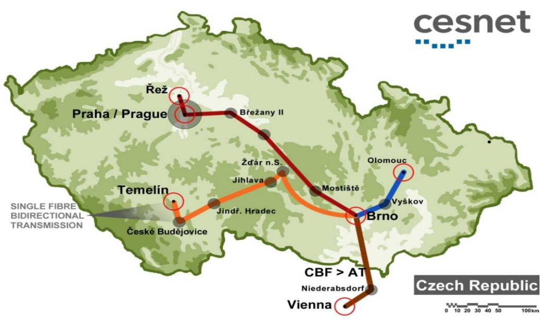

Figure 4 - Frequency transfer links

Frequency transfer links of the CITAF infrastructure are shown in Figure 4. Coherent frequency transfer with active noise cancellation has been operated since 2015 between the Institute of Scientific Instruments (Brno) and CESNET (Prague) on the 307 km long bidirectional channel lit as a service. Channel is amplified by five CzechLight CLAbidi EDFAs [10]. Other links distribute stable frequency to Temelin, Olomouc and Vienna (Austrian time and frequency laboratory BEV). The laser wavelength 1540.5 nm is stabilized by the optical resonator.

Other utilized wavelengths are:

- 1572 nm (Brno to Olomouc)
- 1458 nm (Brno to Olomouc connection of Ca+ optical clock)
- 1542 nm (to BEV)

. Performance of frequency and time transfer in the L-band is very similar to the original one in the C band [17], and we are going to migrate in future to the L-band and keep the C-band for data channels.

V. CONCLUSIONS

CITAF formation is a result of long term informal cooperation between partners. As a national platform, it allows us to formalize cooperation, including expanding the scope and improving the parameters of the national time and frequency transmission infrastructure. We also emphasize cross border connectivity to neighboring countries and cooperation in the range of the European research network GEANT.

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