Optical Time Transmission Over Dual 100 GHz-Grid Optical Channels in the Czech Republic

Sarbojeet Bhowmick[1], Radek Velc[1], Lada Altmannova[1]
[1]Optical Networks Department
CESNET
Prague, Czech Republic
radek@cesnet.cz

***Summary*—This work explains the White Rabbit Network system using a single-mode fiber of 400 km over a dual 100 GHz-grid optical channel in CESNET. The work highlights especially the alternative spectral bands use for time transfer and the infrastructure operational costs and time can be reduced.**

Keywords— White Rabbit; network; single-mode; fiber; optical channel; spectral bands; time transfer; infrastructure

I. INTRODUCTION

White Rabbit (WR) system by CERN [1] generally provides a time synchronization facility. The bidirectional transmission in single-mode fiber [2] and Precise Time Protocol (IEEE-1588) combination follows in this experiment. Typically, WR-LEN devices are dedicated to transmitting frequency from Master to Slave [3]. WR needs precise measurement to provide time >1 nanosecond. WR for long-distance bi-directional transmission typically gets noise accumulation for optical amplification to be on fixed wavelengths [4,5]. For the reduction of this noise accumulation issue for long-distance systematic improvisation has been used in this experiment to make regeneration of timestamps over long-distance fiber links [6].

II. MATHEMATICAL EXPRESSION

For long-distance, WR transmission fiber delay asymmetry coefficient occurs. An optical fiber delay asymmetry originates by chromatic dispersion affecting the velocity of light in the fiber depending on the wavelength of the light. Fiber delay asymmetry in long-distance WR transfers recommends maintaining the spacing between ∂_{MS} and ∂_{SM} as small as possible [7].

WR transmission method is a two-way time transfer that comprise a pair of WR devices, optical fibers, and optical amplifiers in this work. WR devices are composed of a WR master, and the other is a WR slave. WR devices effectuate over a single fiber, using one wavelength for forwarding data from master to slave λ_{MS} and, the other wavelength λ_{SM} for slave to master, to evade significant delay between the forward and reverse path of the two-way time transfer. The wavelengths are picked distinctly from each other to avoid false measurements of the round-trip time (rtt) from back-reflected signals [8]. To transfer precise time packets and recover the original WR master timestamps at the WR slave side, the one-way propagation latency in the link is measured from a rtt measurement.

Calibration of fiber delay asymmetry formed over-performing two delay measurements in which the forward wavelength λ_{MS} and reverse wavelength λ_{SM} exchanged.

WR convention corrects the 1PPS output signal of the WR slave to compensate for the path delay from the master to slave. The required correction is half of the measured round-trip-time from master to slave and back to master. This means that if the fiber delay from master to slave ∂_{MS} for wavelength λ_{MS} equals the fiber delay from slave to master ∂_{SM} for wavelength λ_{SM}, the 1PPS output from the WR slave would be aligned with the 1PPS output from the WR master. And, vice versa, if ∂_{MS} is smaller than ∂_{SM}, the applied delay correction from the WR protocol is more than the actual ∂_{MS} and therefore, the output 1PPS of the WR slave is a bit ahead of the 1PPS output from the WR master [9].

The fiber delay asymmetry parameter, α, which is available in the WR system for the delay difference and is defined by:

$$\alpha = \frac{\partial_{MS} - \partial_{SM}}{\partial_{SM}} \quad \dots (1) \qquad [10]$$

Here, α can be determined as the corrected rtt measurement for the long-distance WR links.

III. METHOD AND RESULTS OF THE EXPERIMENT

This project set-up exists with two WR-LEN devices configured as master and slave where we have used a pair of 1.25 Gbps Small Form Pluggable (SFP) transceivers with channel 8 and channel 9 of Dense Wavelength Division Multiplexing (DWDM) wavelengths 1571 nm and 1570 nm as shown in Fig.1.

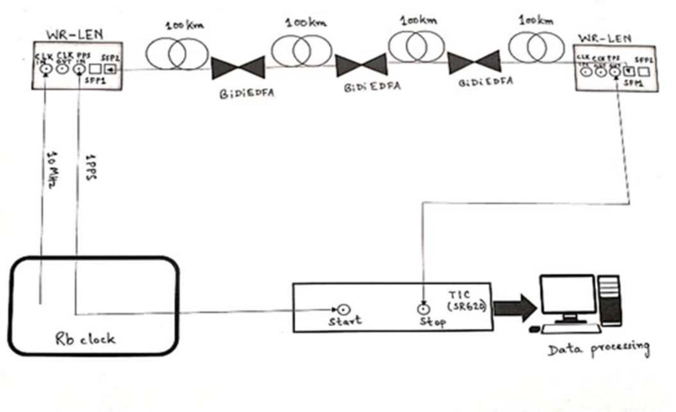

Fig.1. Experimental line set-up using WR-LEN devices and EDFAs

The 400 km fiber line is attenuated by three L-band (long band) BiDi (bidirectional) Erbium-Doped Fiber Amplifier (EDFA) in a single path for bidirectional transmission in fiber

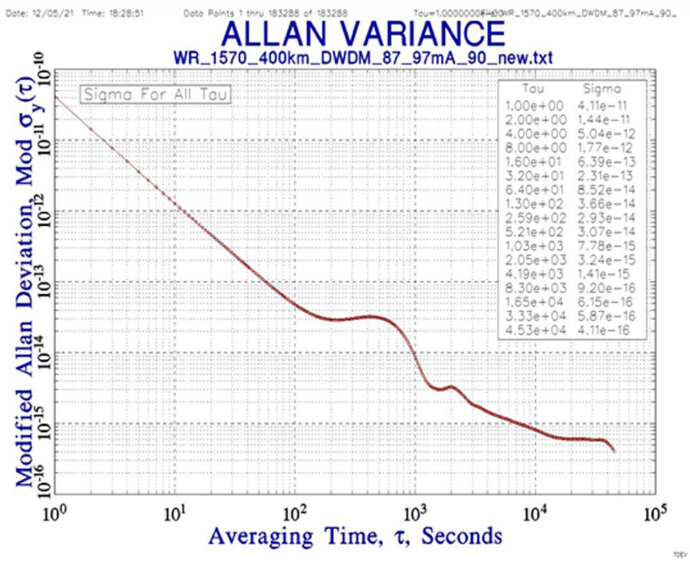

Fig.2. MADEV plot for 400 km fiber at 1570 nm wavelength

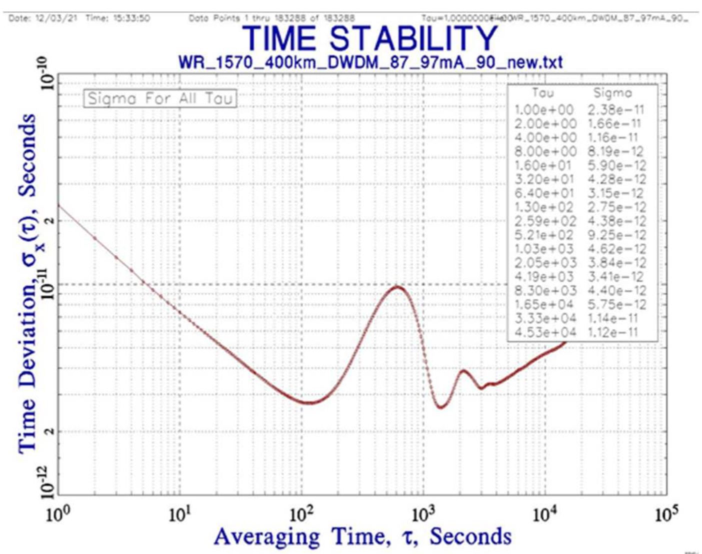

Fig.3. TDEV plot at 1570 nm wavelength

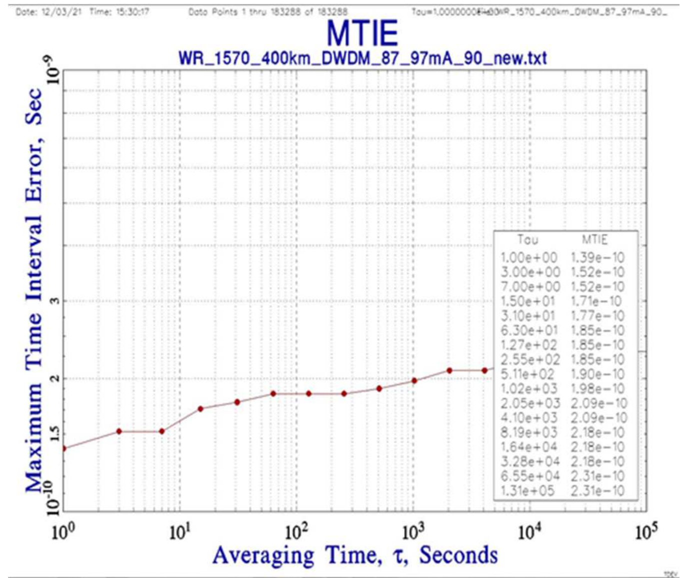

Fig.4. MTIE for 400 km fiber line

Modified Allan Deviation (MADEV) in Fig.2., Time Stability (TDEV) in Fig.3., and Maximal Time Interval Error (MTIE) in Fig.4. have been realized in this experiment.

IV. CONCLUSIONS

Results from the experiment reflect our achievement of using the regeneration technique to eliminate noise accumulation. TDEV plot shows the increasing rate for time averaging >2000 s. Hence, this technique has the possibility to deploy in live network infrastructure and ease the operational cost and time [11].

ACKNOWLEDGMENT

This work is partially supported by Ministry of Education, Youth and Sport of the Czech Republic by the project "E infrastructure CESNET-modernization", reg. no. CZ.02.1.01/0.0/0.0/16 013/0001797 and in part by the TiFOON 18SIB06 Project through the EMPIR Programme co-financed by the participating states.

REFERENCES

[1] T.Włostowski. Precise time and frequency transfer in a White Rabbit network [Master's thesis]. https://ohwr.org/project/white-rabbit/wikis/Documents/Tom's-Master-thesis

[2] Vojtech, J., Havlis, O., Slapak, M., Kundrat, J., Bhowmick, S., Smotlacha, V., Velc, R., Altmannova, L., Horvath, T., Hazlinsky, M., Pecka, T., Kubernat, V., Cizek, M., Hrabina, J., Hucl, V., Pravdova, L., Rerucha, S., & Cip, O. (2021). Active bidirectional precise time transmission outside the telecommunication bands over 200 km of single mode fiber. Proceedings of the 52nd Annual Precise Time and Time Interval Systems and Applications Meeting. https://doi.org/10.33012/2021.17775

[3] Vojtech, J., Havlis, O., Bhowmick, S., Slapak, M., Munster, P., Horvath, T., Velc, R., Kundrat, J., Altmannova, L., Vohnout, R., Skoda, P., & Smotlacha, V. (2020). White rabbit single fibre bidirectional transmission of precise time using unconventional wavelengths. 2020 Joint Conference of the IEEE International Frequency Control Symposium and International Symposium on Applications of Ferroelectrics (IFCS-ISAF). https://doi.org/10.1109/ifcs-isaf41089.2020.9234815

[4] P. Moreira, J. Serrano, and T. Wlostowski, "White Rabbit: Sub-Nanosecond Timing over Ethernet" ISPCS 2009 International IEEE

Symposium on Precision Clock Synchronization for Measurement, Control and Communication.Brescia, Italy, October 2009.

[5] Vojtech, J., Havlis, O., Slapak, M., Smotlacha, V., Horvath, T., Altmannova, L., Velc, R., Kundrat, J., Vohnout, R., Bhowmick, S., Hazlinsky, M., Cizek, M., Hrabina, J., Pravdova, L., Cip, O., & Roztocil, J. (2021). Long haul single fiber reamplified-reshaped white rabbit transmission. 2021 Joint Conference of the European Frequency and Time Forum and IEEE International Frequency Control Symposium (EFTF/IFCS). https://doi.org/10.1109/eftf/ifcs52194.2021.9604245

[6] Smotlacha, V., & Vojtech, J. (2020). White rabbit in the Czech time and frequency transfer infrastructure. 2020 Joint Conference of the IEEE International Frequency Control Symposium and International Symposium on Applications of Ferroelectrics (IFCS-ISAF). https://doi.org/10.1109/ifcs-isaf41089.2020.9234900

[7] Dierikx, E. F., Wallin, A. E., Fordell, T., Myyry, J., Koponen, P., Merimaa, M., Pinkert, T. J., Koelemeij, J. C., Peek, H. Z., & Smets, R. (2016). White rabbit precision time protocol on long-distance fiber links. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 63(7), 945-952. https://doi.org/10.1109/tuffc.2016.2518122

[8] Grzegorz Daniluk. (2012). White Rabbit PTP Core the sub-nanosecond time synchronization over Ethernet [Master's thesis]. https://ohwr.org/project/white-rabbit/wikis/Documents/Greg's-Master-thesis

[9] Jansweijer, P., & Peek, H. (2019). Insitu determination of the fiber delay coefficient in time-dissemination networks. 2019 IEEE International Symposium on Precision Clock Synchronization for Measurement, Control, and Communication (ISPCS). https://doi.org/10.1109/ispcs.2019.8886632

[10] Erik Dierikx, Yan Xie. White Rabbit Good Practice Guide (15SIP04_TIMEFUNC_D3). VSL, EMPIR MSU. https://www.vsl.nl/sites/default/files/rtf/WR_Good_Practice_Guide.pdf

[11] Stanislav Sima. Economical analysis, dark fibre usage cost model and model of operations. CESNET | CESNET, zájmové sdružení právnických osob.

https://www.cesnet.cz/wp-content/uploads/2012/10/POS-D3.2_Economical_analysis.pdf