Long Haul Single Fiber Reamplified-Reshaped White Rabbit Transmission

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***Abstract*— Precise time and ultra-stable optical frequency transfers over fiber networks are deployed often in the present days. When size of such infrastructure for precise time and frequency bidirectional transmission is becoming significant, aspects associated with infrastructure operational costs and time needed for deployment of time and frequency transmission must be considered. First can be decreased via fiber sharing with telecommunication traffic, however spectral allocation must be considered carefully to avoid mutual disturbance of time and frequency transmission versus data, and allow future accommodation of growing demands. In the text, we show and discuss alternative spectral bands to be used for time and frequency transmission. Time to deployment can be quite excessive especially when transmission must be established via multiple networks or network domains, also there is a chance of blocking. In case of precise time and optical radio frequency transmission it is possible to use conversion from optical to electrical and back to optical domain with wavelength change. This possibility removes risk of blocking and reduces time to deployment of such services. We also address possibility to change wavelength, or just to extend reach by using simple re-amplify and reshape approach.**

Keywords*— *precise time, fiber transmission, White Rabbit, regeneration re-amplify, reshape, large infrastructure

I. Introduction

The White Rabbit (WR) system has been designed with the aim to provide time synchronization among large number of sensors, actuators and other devices utilized in very many various experiments within the CERN originally [1]. It combines existing technologies as follows: bidirectional communication in single optical fiber, Synchronous Ethernet (SyncE) and Precise Time Protocol (IEEE-1588) in principle. WR system is the follower of protocols NTP and PTP (IEEE-1588) that also provide time transfer from servers to clients but actually with lower accuracy. White Rabbit requires dedicated hardware in order to provide the accuracy better than 1 nanosecond. Typical feature of White Rabbit is the usage of synchronous Ethernet that effectively distributes frequency from Master to Slave. This way is eliminated by basic frequency drift in protocols NTP and PTP, where the frequency of source is recovered from timestamps of received packets suffering from jitter. White Rabbit transforms the problem to evaluation of phase of received frequency. There have been plenty of studies of precise time and radio frequency transfers using WR and they often address performance comparison between unidirectional and bidirectional transmission, or performance of different WDM multiplexing schemes in case of single fiber bidirectional transmissions, e.g. [2]. Reach extension of WR transmission via bidirectional all optical amplification (e.g. [3]) suffers from noise accumulation especially in long cascades and necessity to rely on fixed wavelengths. Last one becomes a problem especially in multi domain optical networks. There have also been reported long haul WR transmissions deploying 3R regeneration (Reamplify-Reshape-Retime) using WR switches or WR LEN adapters. Such a way might be pricy for some applications with relaxed requirements. In our contribution, we present comparison of all optically amplified single fiber WR transmission and single fiber 2R regenerated (Reamplify-Reshape) WR transmission using affordable 2R regenerators, which could provide extremely affordable extension of precise time transmission over multi hundred kilometers fiber distance with no significantly deteriorated performance compared to previously mentioned scenarios.

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II. EXPERIMENTAL RESULTS

Laboratory setup consists of two WR-LEN devices, configured as grand master and slave, as shown in Fig. 1. The WR system utilizes commercial Small Form Pluggable (SFP) transceivers. Therefore, we have used the pair of 1.25 Gbps SFPs designed for channels 8 and 9 of Dense Wavelength Division Multiplex (DWDM) (wavelengths 1571.24 and 1570.42 nm) featuring extended input sensitivity of -32 dBm and +1 dBm or higher output power.

Fig. 1. Laboratory WR transmission setup

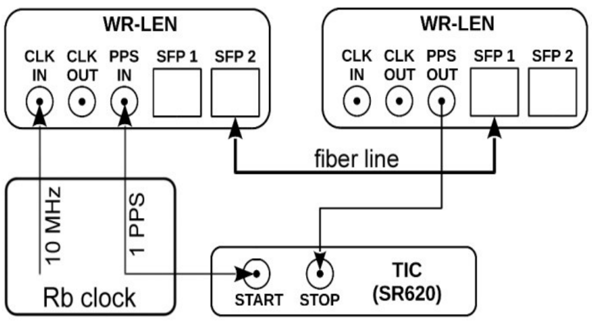
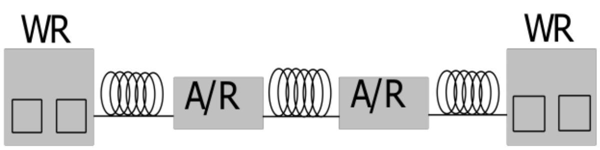
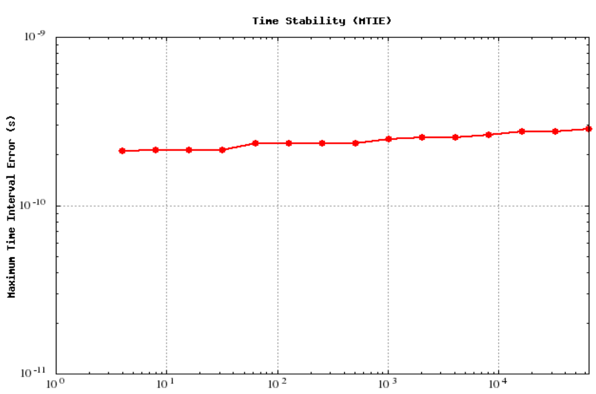


Fig. 2. Fiber line composition



At first, optically amplified setup (similar to [3]) of fiber line according Fig 2. consists of three spans of G.652D spooled fiber, each span with the length of 100 km (two 50 km spools). The attenuation of the line is compensated by two fully bidirectional EDFA amplifiers with single path for signal in both directions placed in between spans. Determined Maximal time interval error (MTIE) is shown in Fig 2.

Fig. 3. Optically amplified WR transmission, 3 spans ecah 100km, 2× bidiEDFA CzechLight: Maximal time interval error (MTIE)



Next, bidirectional optical amplifiers in setup on Fig. 2. have been replaced by two simple protocol agnostic repeaters S-4GPT-DSFP declared for speed ranging from 155 Mbps to 4.25 Gbps, which are equipped with two SFP shafts each. Two additional pairs of SFP transceivers have been added, the ones for channels 8 and 9.

Fig. 4. Electrically regenerated WR transmission, 3 spans each 100km, 2× speed and protocol agnostic repeaters: Maximal time interval error (MTIE)

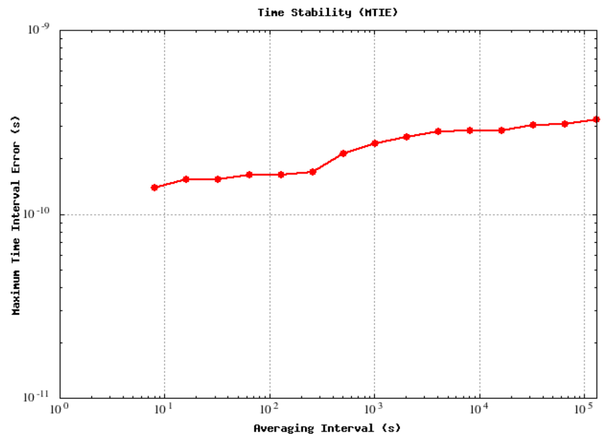


Fig. 5. Electrically regenerated WR transmission, 3 spans each 20 dB, 2× speed and protocol agnostic repeaters: Maximal time interval error (MTIE)

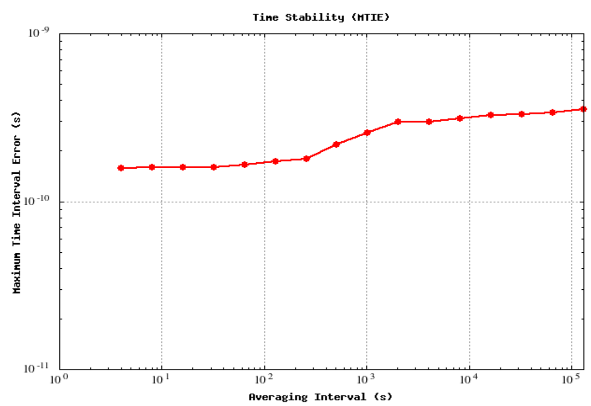
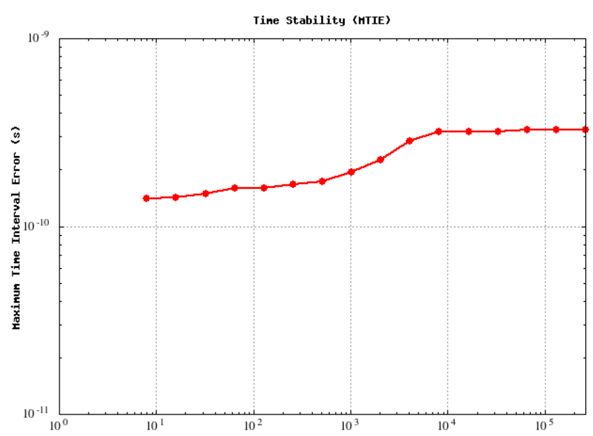


Fig. 6. Electrically regenerated WR transmission, 4 spans each 20 dB, 3× speed and protocol agnostic repeaters: Maximal time interval error (MTIE)



Determined Maximal time interval error (MTIE) is shown in Fig 3. In order to confirm own influence of 2R repeaters the setup was changed in that way the 100km fiber segments have been replaced by 20 dB attenuators. We expected the change should extinct influence of chromatic dispersion and other in fiber aroused noises.As shown in Fig. 4, MTIE significantly after approximately 2000 s of averaging time similarly to the previous case. To confirm this trend for longer chains of repeaters, we extended this setup to total four repeaters and totally five spans where each one is represented by 20 dB attenuator. Fig 5. shows MTIE for this line setup.

III. CONCLUSION

Measured results show that proposed target of WR - sub ns stability should be possible to be fulfilled using simple 2R regenerators instead of fully 3R performing WR devices, at least for chains with small number of regenerators. And thus the possibility to deploy these repeaters for reach extension or wavelength conversion of WR transfers. However, we can clearly see that TDEV increases for approximately 2000 s averaging time. As our measurement still continuous we are planning to verify behavior over real fiber loops buried in ground.

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