FIBER BASED ONE-WAY TIME TRANSFER WITH ENHANCED ACCURACY

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ABSTRACT

To meet the request for access to accurate and reliable time, several time and frequency transfer methods using optical fibers have been developed or are under development. These fiber based techniques will overcome the issues of vulnerability in radio- and satellite solutions; however, they all rely on two-way transmission when variations in transfer time must be compensated for. As an alternative, a one-way transmission over fiber optic WDM-network has been proposed, with estimation of variation in transfer time based on detection of transfer time difference between two co-propagating lightwaves at different wavelengths. The technique was presented previously when the two wavelengths were far apart. Here we present results from an experiment where both wavelengths are within the optical C-band, i.e. within the gain bandwidth of Erbium-doped fiber amplifiers. Thereby it is proven that the technique is usable to a larger extent than previously demonstrated.

INTRODUCTION

The request for better performing time and frequency transfer over baselines longer than 100 km has increased with development of new communication systems. Several transfer methods using optical fibers has been developed or are under development [1-4], using dedicated fibers or already existing fiber networks. The choice of method is often the limiting factor for the performance of the transfer, where the long term stability relies on an accurate estimate of the variations of transfer delay. A common way for high performance transfer is the two-way method, which is an excellent method when the user has easy access to the whole system and when both transmission paths are equal. For the best results both directions in the transfer should operate in the same transmission line to be able to cancel out transmission path delays. The two-way transfer can be implemented very efficiently when operating on existing data traffic [5-6], however when data format or other limitations require that the time and frequency transfer must operate on dedicated communication channels, the technique scales with the number of users and becomes very capacity consuming.

The one-way dual wavelength time transfer technique uses the variations of group velocity between two wavelengths to estimate the delay variation of the timing signal in one of the wavelength channels. The proof-of-concept was previously presented [7] using modulated lasers one at 1310nm and the other at 1550nm. The results showed that it is possible to perform a one-way time and frequency transfer with two wavelengths and, by evaluate these two against each other create a correction signal for compensation for influences along the transmission path. However, to enable long baselines, the optical signal must be possible to amplify and it is desirable to cover both wavelengths inside the optical C-band (1530 – 1560nm). This evaluation is therefore performed with two wavelengths 18nm apart. The presented result shows that the information is possible to extract from these wavelengths, with a 38km fiber link that includes amplification in terms of Erbium doped fiber amplifiers (EDFAs).

BACKGROUND

In a two-way transfer system, in comparison to one-way transfer, all receivers in the communication link transmit and receive timing information. It is based on two counter-propagating one-way transfers between two predetermined nodes to establish the difference between the local and remote clock. The sum of this time difference is the round-trip delay between the two locations. A common assumption is that the delays in paths are evenly distributed between the directions, and if that is a valid assumption, half the round-trip delay in one propagation path should be compensated for. One drawback in two-way time transfer is that the propagation delay in the two directions may be asymmetric, leaving a systematic error in the time transfer result. This error is usually handled by calibrating the asymmetry, still leaving a small added uncertainty.

A schematic of the two-way time transfer between two clocks C_A and C_B is illustrated in Fig. 1. The clocks are compared to each other with two time interval counters (TIC).

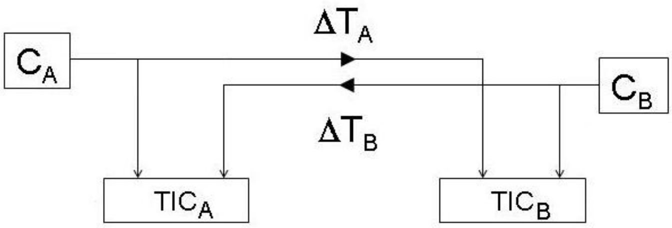

Fig. 1. The figure is a sketch of a two-way time-transfer between clock A (C_A) and clock B (C_B).

TIC_A is measuring C_A compared to C_B including the propagation delay for its transmission path and TIC_B is measuring C_B compared to C_A including the corresponding propagation delay for its transmission path. The conclusive clock comparison equation is presented in (1) with the addition of a factor F(t) taking a possible time varying differential path delay between ΔT_A and ΔT_B into account.

$$C_A - C_B = \frac{TIC_A - TIC_B - F(t)}{2}. \quad (1)$$

This method is valid for any two-way transfer, performed in free space, coaxial or fiber cables. In general this is a good method for comparing clocks with each other, but it has some disadvantages such as the use of two different paths for transmitting and receiving for the cable based transfer. This will result in an unmodeled asymmetry F(t) in (1) that can be difficult to make corrections for. This asymmetry is due to many components such as ageing, connector connections and different length in the transfer paths and equipment in and between the nodes. With this classic transfer method as reference point, this paper will discuss a different method based on a single path that will be able to circumvent previous mentioned disadvantage.

For a common one-way time transfer, as illustrated in Fig. 2, there is a time varying part associated with ΔT_A as also is included in (2). Even though the average transfer time can be calibrated for, the time varying part will pose as an uncertainty unless it continuously is measured and compensated for.

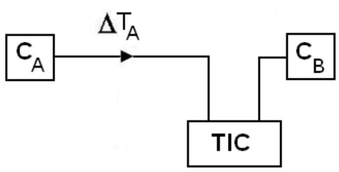

Fig. 2. The figure is a sketch of a one-way time-transfer between clock A (C_A) and clock B (C_B).

$$C_A - C_B = TIC - \Delta T_A(t). \quad (2)$$

The proposed solution to solve for $\Delta T_A(t)$ is by transmitting two wavelengths in the same fiber and detect the propagation delay differences between these [8-11]. Development of this one-way transfer method with enhanced stability should result in transfer quality comparable with well established two-way methods. Furthermore, it should be operating within the C-band of commercial DWDM networks for distances >100km. The reason for using the C-band is that the commonly used EDFA have a gain spectrum in this region, close to 1550nm. Previously presented results showed proof of concept [7]. Those experiments however used two wavelengths 240nm apart as indicated in Fig. 3, whereas this paper presents an evaluation of the information in two wavelengths 18nm apart. The wavelengths for this evaluation are plotted as blue peaks in Fig. 3.

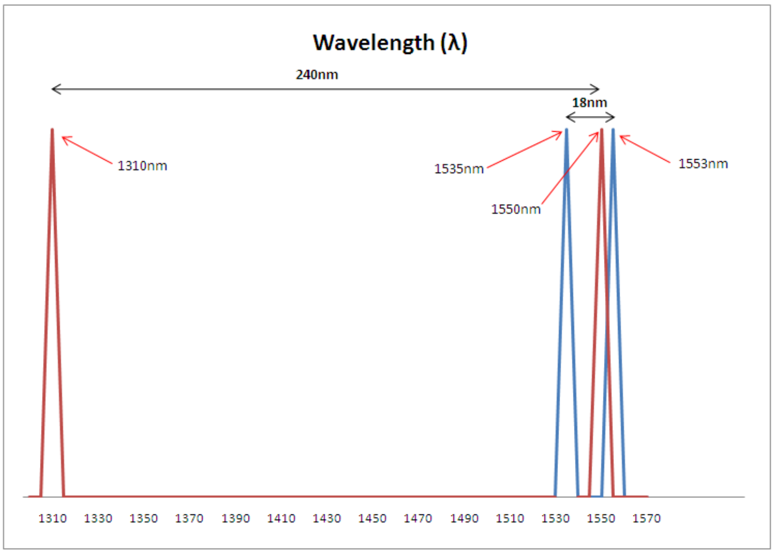

Fig. 3. Previously used wavelengths with this one-way transfer method are plotted in red and the wavelengths for this evalutaion is plotted in blue.

EXPERIMENTAL SETUP

The proposed one-way transfer method for time and frequency is based on a single mode optical fiber SMF28 connected between two passive optical splitters/combiners. In this experimental setup, as shown in Fig. 5, the drive current to two laser diodes (emitting light at 1535nm and 1553nm, respectively) are directly modulated from a 10MHz reference oscillator.

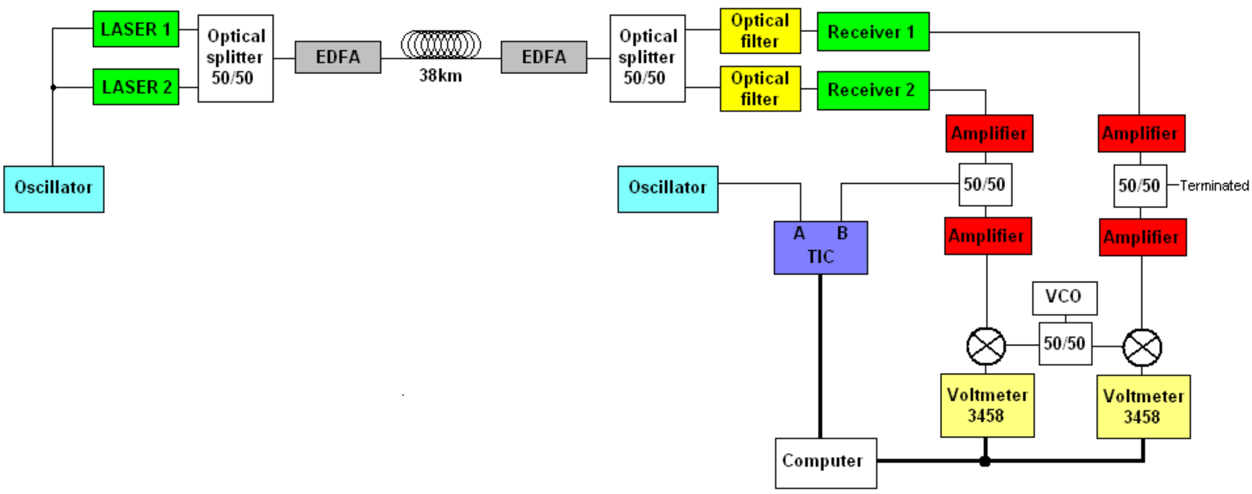

Fig. 4. Schematics of the equipment used for the one-way frequency transfer.

Most of the equipment is housed in a laboratory with controlled environment, except the spools of SMF28 which is placed outdoors for emulation of an actual environmental condition. The total sum of fiber length is measured with an OTDR (optical time-domain reflectometer**)** to be 38km as shown in Fig. 5 Included in this length is 188m of transfer fiber between the lab and the outdoor fiber spools. The fiber path starts and ends in the laboratory for evaluation. The use of several fiber spools instead of one creates a similar case to a commercial link, which will be assembled of multiple fibers spliced by connectors, and there is no possibility to know the age or ageing of all optical fiber along this. An OTDR measurement also measures the attenuation of the fiber, shown as the slope of the trace, and the reflections at each connector, which appears as the peaks.

Fig. 5. OTDR measurement of the whole fiberlength including transfer fiber between the laboratory and the outdoors spools.

The optical filters that are used separates two wavelengths, since the optical splitter will divide both wavelengths to both fibers equally. Measurement equipment detects the two 10MHz sine waves after propagation through the fiber link, amplifies and compares with a reference signal, as shown schematically in Fig. 6.

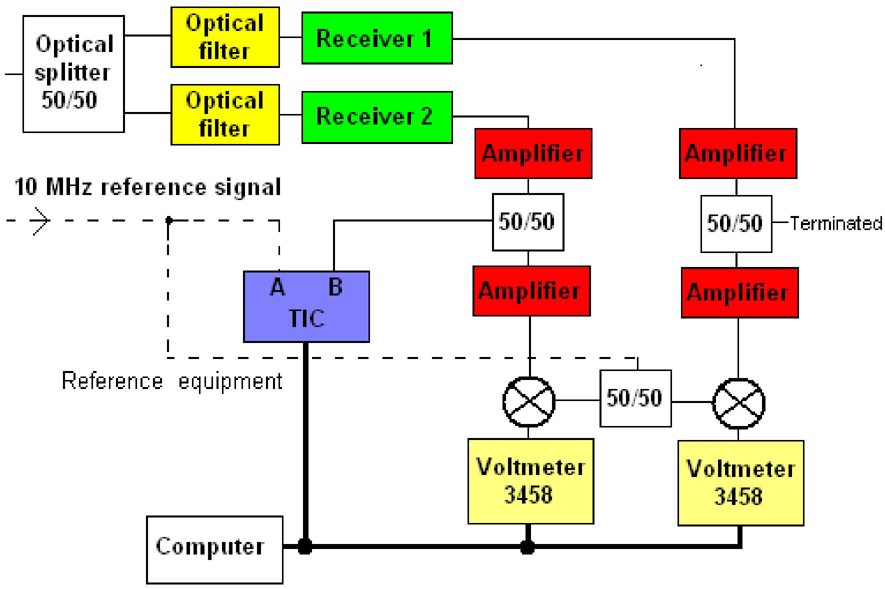

Fig. 6. Schematics of the receiver and reference signal placed in the laboratory. The reference signal is used to evaluate the information in the transmitted wavelenghts.

The equipment in the setup at the receiving end are commercial 10Gbit PIN receivers that convert the optical signals into electrical. Due to rather weak optical power of the signal, electrical amplifiers must be inserted, and both signals are connected into the RF-inputs of two double-balanced mixers. The LO-ports are connected to the 10MHz reference oscillator of the transmitting side, thus the output voltage of the mixers will be proportional to the cosine of the transmission delay. The use of the reference from the transmitter will be replaced with a local solution, but during this study it was used to verify the characteristics of the fiber. The outputs from the mixers are fed into high precision voltmeters (HP3458), and a computer connected to the TIC and voltmeters collects the data and timestamps the measurements.

RESULTS

A graph displaying the raw data of the TIC and voltage measurements during six days are shown in Fig. 7. The large steps at day 4 are due to the phases of the transmitted modulations varies more than the modulation period of 100ns.

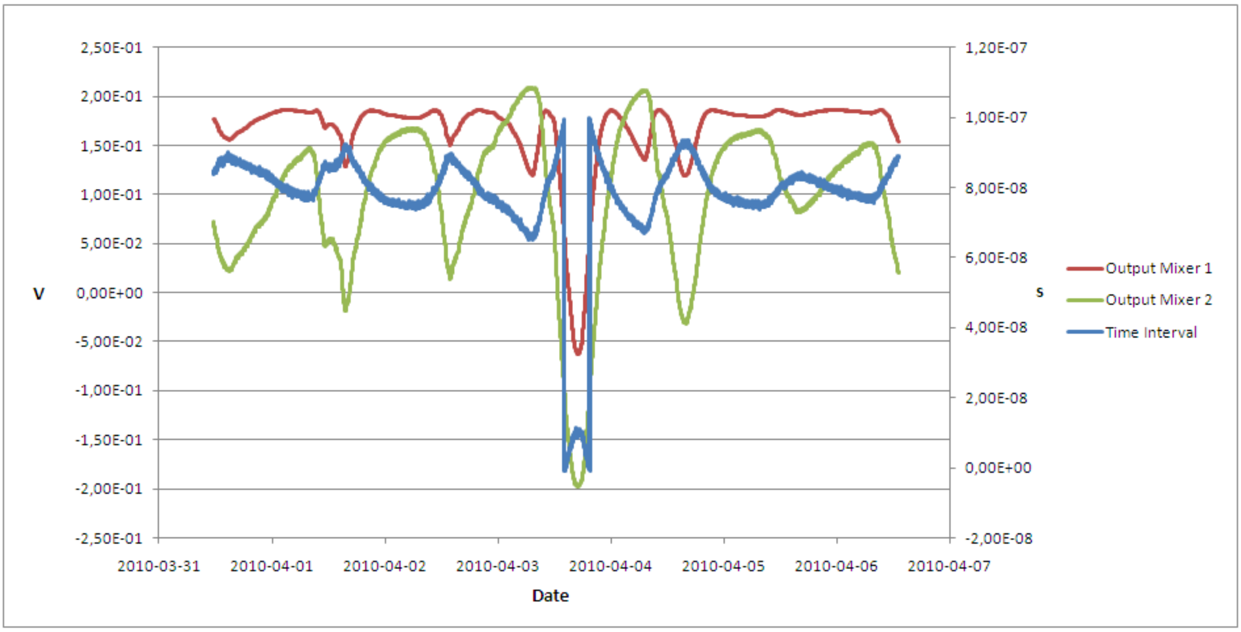

Fig. 7. Outputs from the mixers and the time interval represented by the reference TIC is plotted from raw data during six days of measurement

The retrieved raw data is processed with respect to the 100ns modulation, and the data of the mixer output voltages is used to predict the variation in TIC-measurement. The simplest model that can be matched to the change in time, T_{change}, with respect to the starting value, is given by:

$$T_{change\_estimated} = (\arccos(\frac{(V_1 - V_2)}{\max(V_1 - V_2)})) \times A + B \qquad (3)$$

Where $T_{change\_estimated}$ is the outcome of the model, V_1 and V_2 are the two measured voltages, and A and B are calibration coefficients, that must be determined empirically for each individual setup. When applying this equation on a six day dataset, and compare it with the actual variation in transfer time, the result is as shown in Fig. 8. It is apparent that there is a good correlation between the one-way method and the time interval measurements, when the coefficients A = 1,58e-8 and B=1,71e-9. With these values, the mean value of the difference between T_{change} and $T_{change\_estimated}$ is less than 1ps, and the rms is below 1ns.

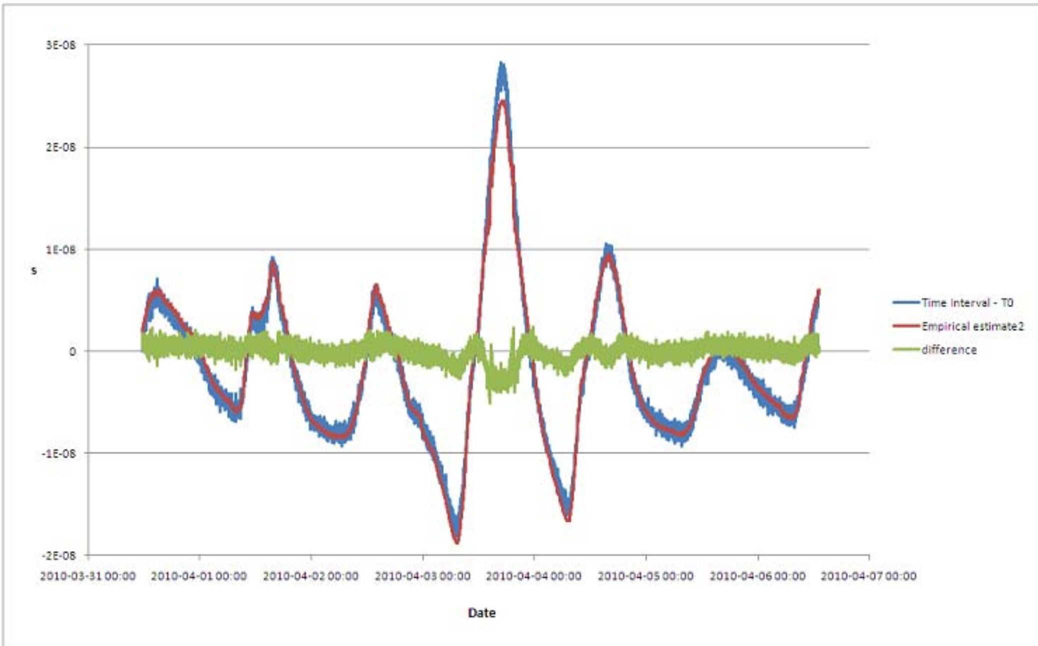

Fig. 8. The result from six days of measurement with both TIC and one-way measurment showing an rms diffrence of less than 1n and a mean value of less 1ps reached with the estimate described in eq. (3).

CONCLUSION

It is experimentally verified that it is possible to perform a one-way time and frequency transfer of optical single mode fiber with continuous estimate of delay variations. The technique is based on transmission over two wavelengths, separated by 18nm, and by evaluating the phase of these two create a correction signal which can be used to compensate for the inevitable variations along the transmission path.

This experiment has shown proof of concept, and future work includes development of a physical correction component at the end of the link that incorporates the steering signal based on the measured difference between the arriving signals at the two wavelengths.

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