Calibration of Fiber-Optic Time Synchronization System Over 800km

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***Summary*—Due to the excellent performance in accuracy and stability, fiber-optic time synchronization is becoming a key technology in the field of time-frequency metrology. And the accuracy of fiber-optic time synchronization system mainly depends on asymmetry calibration. Here we study the calibration of time synchronization system over 800km laboratory fiber link. Asymmetry caused by chromatic dispersion, bidirectional EDFAs, sending and receiving devices are investigated. After calibration, the residual of clock difference between two sites is 56.80ps, and the timing jitter is 33.91ps. By further optimizing the whole system and the method of calibration, a system with accuracy better than 50ps over thousands of kilometers fiber link is expected to be obtained in the future.**

Keywords—time synchronization system; fiber link; asymmetry calibration; accuracy

I. INTRODUCTION

Due to the excellent performance in accuracy and stability, fiber-optic time synchronization is becoming a key technology in the field of time-frequency metrology [1]. And in fiber-optic time synchronization, asymmetry has always been a concern of researchers. To figure out the problem of calibration introduced by transmission asymmetry, some schemes have been proposed, such as automatic calibration algorithm [2], new structure of symmetry EDFA [3], and so on. This paper mainly discusses the calibration of time synchronization system over 800km fiber link, in which asymmetries of this system and fiber link are measured and compensated to some extent. After calibration, the residual of clock difference between two sites is 56.8ps, which means the system has achieved high accuracy synchronization. By further optimizing the whole system and the method of calibration, a system with accuracy better than 50ps over thousands of kilometers fiber link is expected to be obtained in the future.

II. METHODS

The fiber-optic time synchronization system based on bidirectional time transfer is shown in Fig. 1. In local site, the time signal(1PPS, one-pulse-per-second) is modulated by a phase modulator over an optical carrier with a wavelength of λ_L, and transmitted to remote site along fiber link. The transmitted signal is demodulation by Michelson interferometer and photodetector in remote side, same as described in [4]. And the 1PPS signal generated in remote site is transmitted back to the local site in the same manner except that the wavelength of optical carrier is λ_R. The time interval between the 1PPS signal generated and the pulse signal received is measured by time interval counters(TICs) in two sites.

This paper is based on 800km fiber link in laboratory which is consists of ten 80km-fiber-spools. Between each two fiber spools, a bidirectional EDFA is employed to compensate the loss. With the intention to avoid the effects of backscattering on SNR, EDFAs amplifies optical signals in separated directions, as shown in Fig. 1. Dispersion compensated fiber(DCF) is used as well, but the total length of DCF do not match with the length of the fiber link strictly.

The asymmetry of forward and backward transmission directly affects the accuracy of clock synchronization. By analyzing the forward and backward transmission path of optical signal, the asymmetry mainly comes from three aspects:

- Asymmetry comes from chromatic dispersion(CD).
- Asymmetry caused by the different path of forward and backward transmission inside the bidirectional EDFAs.
- Asymmetry introduced by the sending and receiving devices in local and remote sites.

And all of these asymmetries could be calibrated by well-designed experiments. CD of fiber spools can be measured by self-developed platform, which is believed to have an accuracy of better than ±3ps/nm. And the calibration of asymmetry comes from every single bidirectional EDFA also have an accuracy about ±3ps. Asymmetry introduced by the sending and receiving devices in different sites is pre-calibrated by back-to-back(BTB) experiment, and the accuracy is a little bit worse.

Through the measurements, the CD coefficient of compensated fiber link is 751.30ps/nm, and the wavelength difference between λ_L and λ_R is 2.40nm, which means the asymmetry came from CD is 1,803.12ps. There are 9 EDFAs along the fiber link, the asymmetry caused by them is about 23,049.63ps by calibrating them one by one. Asymmetry introduced by the sending and receiving devices in local and remote sites is -11,510.40ps. The value is negative because of pre-defined method of calculating the clock difference. Finally, the total asymmetry can be obtained by summing the above three terms. And it can be compensated by adjust the delay of programmable delay line in remote site.

III. Discussion

Fig. 2 shows the evaluation about the jitter and calibration result of the time synchronization system, which is measured by TIC-3 in Fig. 1. The timing jitter of original data is 33.91ps, and the mean value, as well as the calibration residual, is 56.80ps. Such a result tells that there is still a room for improvement. Considering the source of calibration residual, here are some analyses. The inaccuracy of wavelength difference between λ_L and λ_R is a factor, but the value of it is always about picometers. Combined with the CD coefficient, the effect is not significant. In contrast, the error accumulation of bidirectional EDFA asymmetry calibrations, picoseconds for each, is a possible source of calibration residual. And we also conclude that the largest error comes from the BTB measurement for asymmetry introduced by the sending and receiving devices, as mentioned before.

Besides calibration residual, time variations of asymmetry in the evaluation data are still of concern. So the original data is processed by moving average filter to degrade the effects of random error in measurements, as well to further display the trend of the clock difference fluctuations over time. It is shown as the red solid line in Fig. 2, which vary around the calibration residual of long term measurement. This phenomena of clock difference fluctuations is consistent with previous research in [5]. It is considered to be asymmetry fluctuations caused by environment, such as temperature. And the peak-to-peak value in red solid line is 78.37ps. The main factor of such a big peak-to-peak value is believed that the cumulative length of asymmetric transmission path inside the EDFAs is too long to make the EDFA-related asymmetry sensitive to temperature fluctuations, which degrade the fiber-optic time synchronization accuracy as well. Therefore, for directionally separated bidirectional EDFAs, some necessary temperature control methods need to be adopted to optimize the accuracy in the future.

IV. Conclusions

Fiber-optic time synchronization system shows outstanding performance on high accuracy and stability. By using directionally separated bidirectional EDFAs to avoid the effects of backscattering on SNR, the system can be easily extended to thousands kilometers. The calibration in this paper shows that the accuracy of such a system can achieve tens of picoseconds. Based on above results, further research on optimizing the key components in the system and method of asymmetry calibration needs to be carried out. And we believe a system with accuracy better than 50ps over thousands kilometers fiber link is expected to be obtained in the future.

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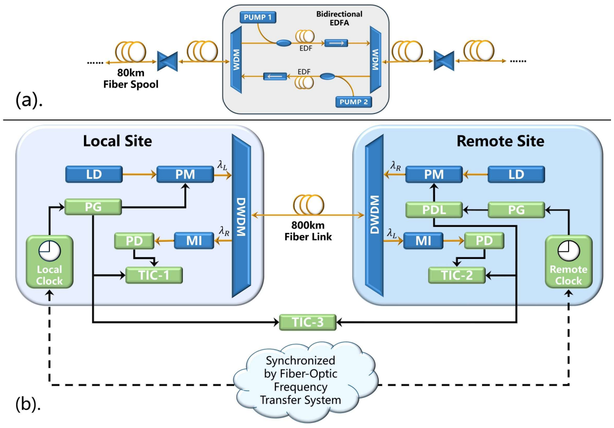

Fig. 1. (a). The composition of 800km fiber link. (b). Principle scheme of fiber-optic time synchronization system. LD, laser diode; PM, phase modulator; PG, pulse generator; MI, Michelson interferometer; PD, photodetector; TIC, time interval counter; PDL, programmable delay line.

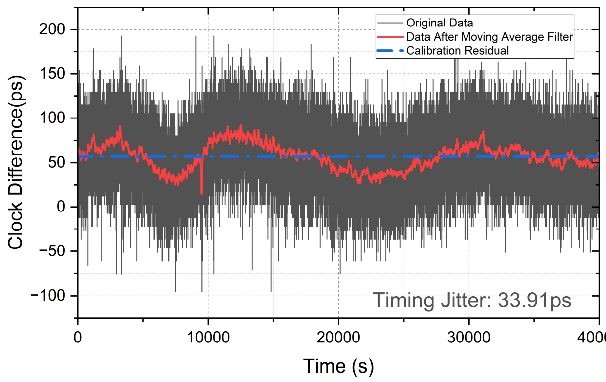

Fig. 2. The evaluation of time interval between local site and remote site, which shows the synchronization accuracy between two sites.