Time Synchronization Over Cascaded Backbone and Access Fiber-Optic Links

Faxing Zuo[1], Kunfeng Xie[1], Liang Hu[1], Jianping Chen[1,2] and Guiling Wu[1,2]

[1]State Key Laboratory of Advanced Optical Communication System and Networks, Department of Electronic Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

[2]Shanghai Key Laboratory of Navigation and Location Based Services, Shanghai 200240, China

E-mail: wuguiling@sjtu.edu.cn

***Abstract*—We experimentally demonstrate a high-precision time synchronization system over a fiber-optic network with an equivalent 2400 km backbone link and a 60 km urban access link. Time signals aligned with the master station can be available at arbitrary station over the backbone and access links. Moreover, link calibrations are not required, which decreases the operation and maintenance cost significantly. The high-precision, easy-to-implement and telecom-network-compatible time synchronization system demonstrated here opens up a possibility to providing synchronized time signals to multiple users over the public telecom fiber networks.**

***Index Terms*—fiber-optic, time synchronization, cascaded backbone and access links**

I. Introduction

Recently, we presented a multi-access time dissemination scheme with bidirectional optical-electrical-optical (BOEO) nodes based on bidirectional time division multiplexing transmission over a single fiber with the same wavelength (BTDM-SFSW) and the performance is initially evaluated over the main fiber link up to 350 km [1]–[3]. The results confirm that the scheme has a negligible effect on the performance of telecommunication data and link calibrations are not required. In this scheme, however, only time differences with respect to the master station are obtained for users instead of synchronized time signals, which may not meet the requirements where aligned time signals are required. The system performance exploring worse signal-to-noise ratio (SNR) and more serious fiber temperature fluctuation and mechanical disturbance over the ultra-long haul and urban fiber link is also not investigated.

II. Experiment

In this paper, we demonstrate a fiber-optic time synchronization system over a cascade 2400 km backbone link and 60 km access link (see Fig.1 and Fig.2). The equivalent 2400 km backbone link is implemented by recirculating the time signals 6 laps in a 400 km fiber loop consisting of four BOEO stations in the lab [4]. The access network is composed of a 60 km urban fiber link that extends underground along the city then returns to the lab [5]. At the slaver station, access station and each BOEO station, a voltage controlled oscillator (VCO) is dynamically served based on the calculated time differences [6]. Thus, time signals (1PPS, one pulse per second) aligned with the main clock at the master station are available at arbitrary station over the backbone and access links. The time synchronization performance is evaluated by measuring the time difference between the PPS from the master clock and the output one from each station.

III. Results

The measured time differences with synchronization and the corresponding time stabilities in terms of time deviation (TDEV) for the 2 m short fiber, 2400 backbone link, 2460 km cascade backbone and access links are shown in Fig. 3 and Fig. 4, respectively. The back-to-back measurement over 2 m fiber can be considered as the noise floor of our experiment apparatus with the mean time difference of 12 ps and the time stability of 14.9 ps/s and 1.4 ps/1000s. Without any link calibration procedure, the time synchronization system is implemented in the 2400 km backbone link, and a mean clock difference of 58 ps and a time stability of 15.1 ps/s and 2.1 ps/1000s can be achieved. The time stability performance is slightly worse on the 2460 km cascade backbone and access links, however, it is still better than 20.9 ps/s and 6 ps/1000s and a mean time difference of 10 ps can be obtained.

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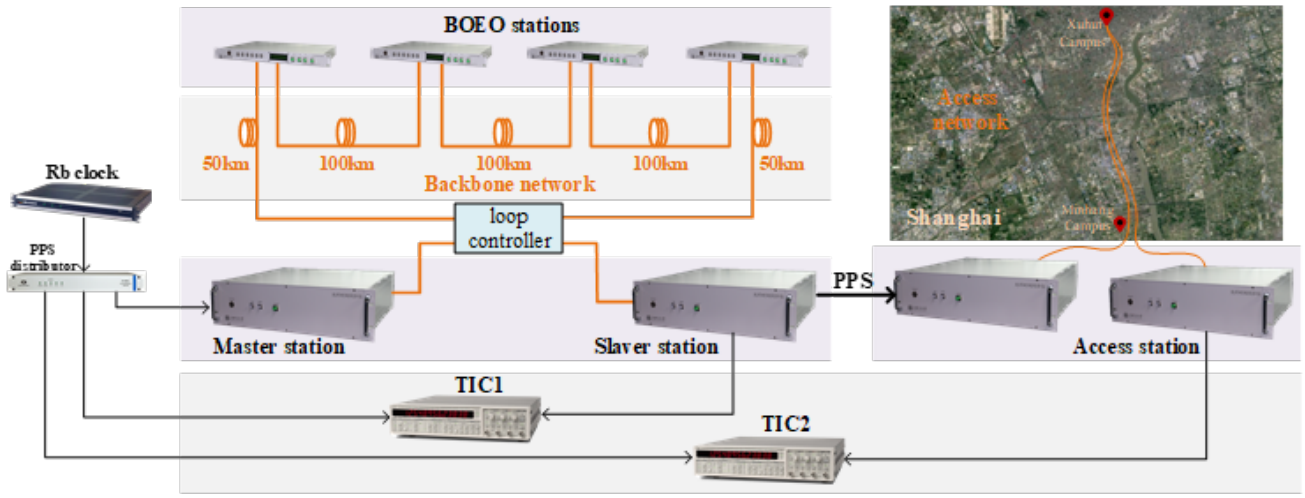

Fig. 1. Experiment structure of the fiber-optic time synchronization over the cascaded backbone and access links. BOEO: bidirectional optical-electrical-optical station, PPS: one pulse per second, TIC: time interval counter.

Fig. 2. The photo of the fiber-optic time synchronization system.

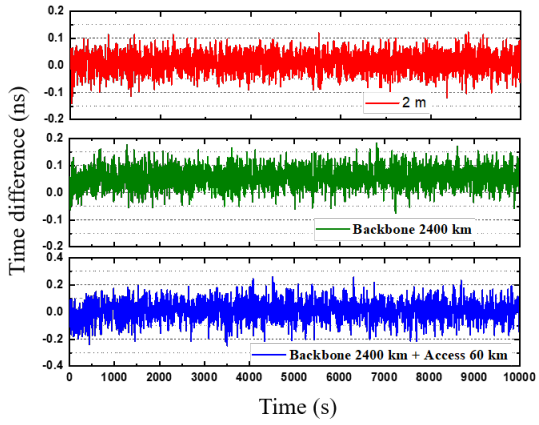

Fig. 3. Measured time differences for the 2 m, 2400 km backbone and the 2400 backbone + 60 km access fiber link.

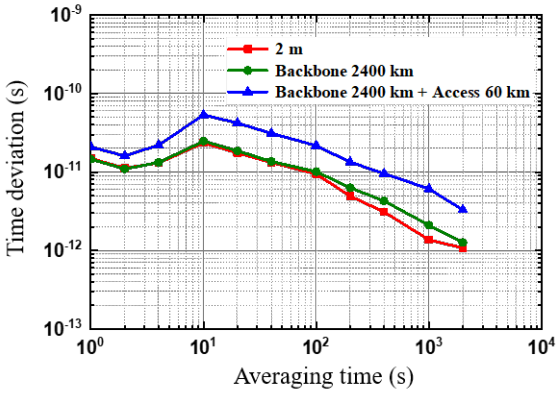

Fig. 4. Measured time stabilities in terms of time deviation.