Asymmetric Channel Attack Against Practical Round-Trip Fiber Time Synchronization System

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***Abstract*—Round-trip transmission scheme is one of key scheme for the high-precise fiber time synchronization system. Here an asymmetric channel attack against practical round-trip time synchronization system is proposed and experimentally demonstrated. Using the achieved asymmetric channel attack module, the accuracy of the time synchronization system can be reduced from 90 ps to 538 ps as designed. It shows that channel symmetry assumption in practical applications could be broken by such attack method, and this attack could not be found without single-way-delay monitoring.**

***Index Terms*—time synchronization system, asymmetric attack**

I. Introduction

The synchronization of precis time between different locations plays an important role in today's human life and scientific research, such as quantum internet, deep-space network and antenna arrays [1] [2].Generally speaking, there are two implementation schemes of time transmission based on optical fiber link: round-trip transmission scheme [3] [4] and two-way (bidirectional) transmission scheme [5] [6], where optical fiber links are considered a promising alternative medium for high-stability and long-distance time transmission [7]. However, these time transmission systems are proved vulnerable to spoofing attacks [8]. Because one of the basic assumption of such system is that the transmission delay is symmetrical, that is, the transmission delay required from local end to remote end and from remote end to local end is equal. But once the transmission link is introduced asymmetry by the an adversary, the performance of the system will be greatly affected and hard to be found in round-trip time transmission system. Because the adversary can control the round-trip time to keep it unchanged, which is the only time delay monitoring in the round-trip time transmission system. However, the one-way time can be arbitrarily increased or reduced by the adversary.

In this paper, a method to attack the channel for practical round-trip fiber time synchronization system in an asymmetric way is proposed. First we build a practical round-trip fiber time synchronization system. We theoretically analyze the impact of asymmetric delay on the round-trip fiber time synchronization system. Besides, we designed a method to propose the asymmetric attack. Then we do some experiments to verify the correctness and feasibility of the attack method. These asymmetric attack is controllable by changing the asymmetric optical fiber length. More importantly, these asymmetric attack is undetectable since the attack module introduce the asymmetry without changing the loopback time. Through the asymmetric channel attack given in this paper, the system accuracy with the original system accuracy of 90 ps can be reduced to 538 ps.

II. Practical round-trip fiber time synchronization

The scheme of practical round-trip fiber time synchronization system is shown in Fig. 1. The laser generates continuous light into the AM modulator. The optical signal to be transmitted is modulated by controlling the pulse per second (PPS) signal output by DG645. The modulated optical signal enters through the circulator port 1 and outputs from port 2 to enter the optical fiber link for transmission. After reaching the remote end, the signal is output into the 10:90 BS through the circulator port 1. Part of it is distributed to the PD at the remote end to convert the optical signal into the electric signal, and the other part returns to the optical fiber link again through the circulator. In the link, there will be a time difference between the 1 PPS received at the remote

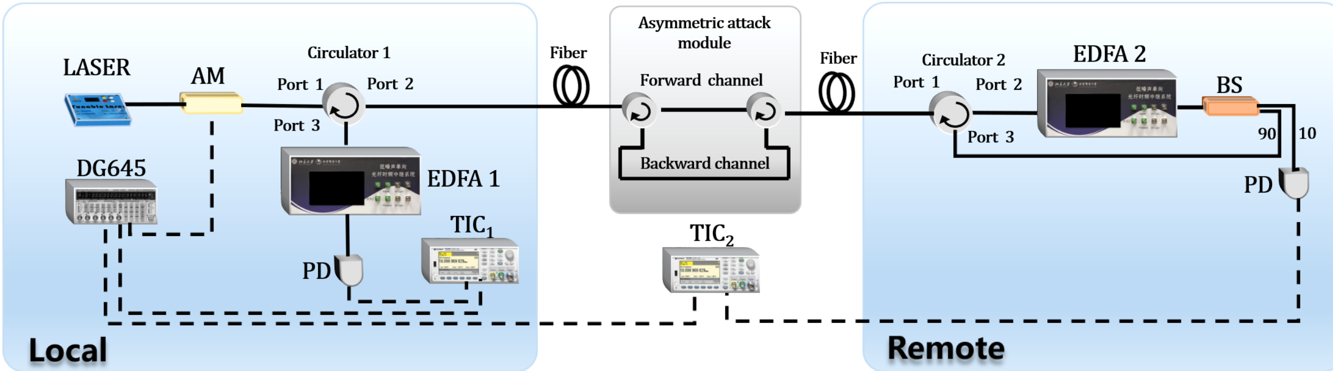

Fig. 1: Experimental setup of practical round-trip fiber time synchronization system. AM: amplitude modulator; TIC: time interval counter; EDFA: erbium doped fiber amplifier; PD: photo detector; BS: beam splitter with the splitter ratio of one to nine. An asymmetric attack module is used to replace a part of fiber with length l. In the asymmetric attack module, the length of the forward channel is $l-\Delta l$. The length of the backward channel is $l+\Delta l$. The round-trip time remains unchanged. However, there is an asymmetry between the forward channel and the backward channel.

end and the local time scale τ. Technically, the time system is designed to deal with this time difference. 1 PPS signal is sent repeatedly every second. If the local signal generates an additional delay (1- τ) during transmission, the nth PPS which remote end receive will synchronize with the (n + 1)th PPS which the local end send.

In the system, TIC_1 measures the round-trip time of the whole system. In order to better measure the time difference between the local end and the remote end, a time interval measuring instrument is added between the remote end and the local end, which is TIC_2. This data measures by TIC_2 and reflects the time synchronization accuracy of the whole system. And TIC_2 is not existed in a real round-trip fiber time synchronization system. T_{LC} is the time delay from AM modulator to the circulator output, T_{LR} is the optical fiber transmission delay from local to remote, and T_{CR} is the transmission delay from the remote circulator to the remote PD. T_{RC} is the delay of return optical path, T_{RL} is the optical fiber transmission delay from the remote end to the local end, and T_{CL} is the transmission delay from the circulator to the local PD. When calculating the time difference by round-trip fiber time synchronization method, there is an assumption that the optical fiber link is symmetrical, that is, $T_{LR} = T_{RL}$.In the system, T_L is the local initial time and T_R is the remote time. T_{LC} is the time delay from AM modulator to the circulator output, T_{LR} is the optical fiber transmission delay from local to remote, and T_{CR} is the transmission delay from the remote circulator to the remote PD. T_{RC} is the delay of return optical path, T_{RL} is the optical fiber transmission delay from the remote end to the local end, and T_{CL} is the transmission delay from the circulator to the local PD. Therefore, the time difference ΔT between the local end and the remote end is:

$$\begin{aligned}\Delta T &= T_R - T_L \\ &= \frac{TIC_1}{2} + \frac{T_{LR}-T_{RL}}{2} + \frac{T_{LC}+T_{CR}-T_{CL}-T_{RC}}{2}\end{aligned} \tag{1}$$

When calculating the time difference by round-trip fiber time synchronization method, there is an assumption that the optical fiber link is symmetrical, that is, $T_{LR} = T_{RL}$. Therefore, the above formula can be expressed as:

$$\Delta T = (TIC_1)/2 + (T_{LC} + T_{CR} - T_{CL} - T_{RC})/2 \tag{2}$$

Since the devices used are not completely symmetrical, there is a time delay caused by the asymmetry of the devices used in the system in the formula:($(T_{LC} + T_{CR} - T_{CL} - T_{RC})/2$. It can be compensated by certain compensation before the system starts operation.

III. The principle of the asymmetric channel attack

The time difference ΔT between the sending end and the remote end is:

$$\Delta T = \frac{TIC_1}{2} + \frac{T_{LR}-T_{RL}}{2} + \frac{T_{LC}+T_{CR}-T_{CL}-T_{RC}}{2} \tag{3}$$

Once we introduce asymmetry into the system, which means $T_{LR} \neq T_{RL}$, the time difference ΔT between the local end and the remote end can be expressed as:

$$\Delta T = (TIC_1)/2 + (T_{LR} - T_{RL})/2 \tag{4}$$

That is, the synchronization accuracy of the round-trip fiber time synchronization system will be affected by the asymmetry. In practical application, even a small change in the asymmetry of the transmission link will have a great impact on the accuracy of the system. Due to the length difference between the forward channel and the backward channel in the module, the time from the remote end to the local end and from the local end to the remote end are different, so as to realize the asymmetric attack. During an attack, the optical fiber link sent from the local end to the remote end can be reduced by Δl meters, and the optical fiber link returned from the remote end to the local end can be lengthened by Δl meters, so the

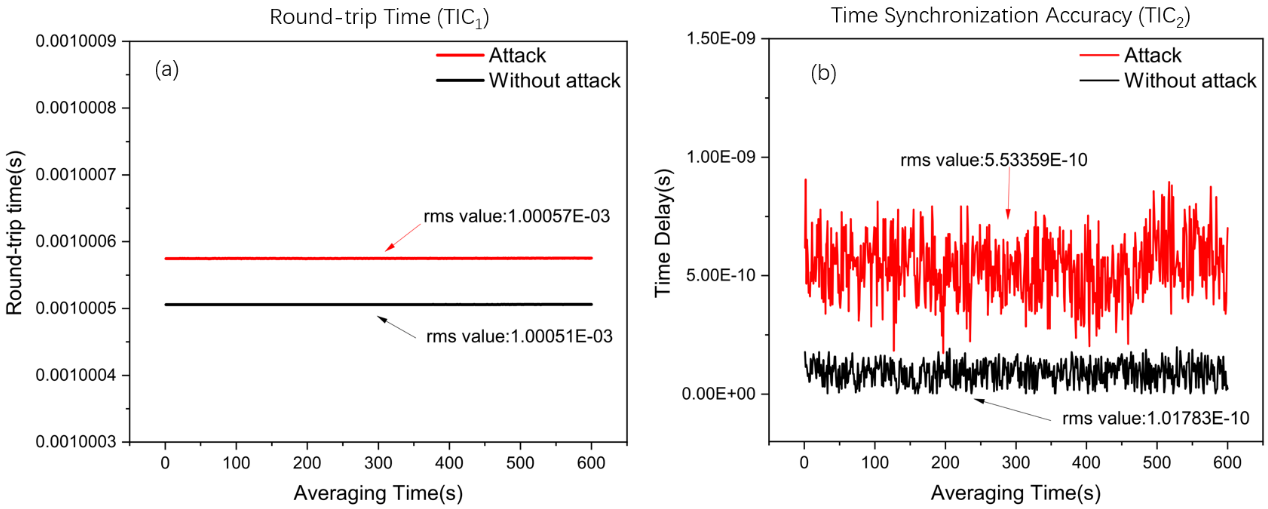

Fig. 2: Measured transfer delay and round-trip time of round-trip fiber time synchronization system. The red line represents the system with 100 km fiber and attack module. The black line represent the system with 100 km fiber. (a) The round-trip time of the whole system. (b) The system accuracy of round-trip fiber time synchronization system.

round-trip time of the system monitored at the local end will remain unchanged, which makes it difficult for the local end and the remote end to detect the attack, but in fact, there will be a large error in the system compensation time is:

$$T_{err} = \Delta l/(3 \times 10^8/1.5) = \Delta l/2 \times 10^{-8} \quad (5)$$

The attack scheme is as shown in the Fig. 1. Due to the length difference between the forward channel and the backward channel in the module, the time from the remote end to the local end and from the local end to the remote end are different while the round-trip time is unchanged, so as to realize the asymmetric attack.

IV. Experimental Results and Discussions

Firstly, we connect 100 km optical fiber into the system and test the time difference between the remote end and the local end. According to the data within 10 minutes, without asymmetric attack, our system accuracy can be stabilized at an average of 90 ps with 100 km optical fiber. After that, we add the asymmetric attack module in the optical fiber link between the systems and test again. In this experiment, the attack module can make the round-trip optical path have an optical path difference of 500 ps. And the system delay decreases to an average of 538 ps. The results are shown in Fig. 2.

From Fig. 2, in practical application, even a small change in the asymmetry of the transmission link will have a great impact on the accuracy of the system. At the same time, the reading of TIC_1 shows that the round-trip time of the system does not change much before and after accessing the module. It can be determined that the asymmetric attack on the round-trip time system is feasible.

In conclusion, an asymmetric attack on the round-trip fiber time synchronization system is carried out. Two circulators are used to change the length of the round-trip channel, so as to introduce asymmetry. When there is an optical path difference of 500 ps in the round-trip optical path, the accuracy of the system decreases to 538 ps. These experiments and results put forward some potential for the way of system attack and improving the security of the system.

Acknowledgment

This research was supported by the National Natural Science Foundation of China under Grants 62001044, the Fund of State Key Laboratory of Information Photonics and Optical Communications under Grants IPOC2021ZT02, and the Fundamental Research Funds for the Central Universities of China under Grants 2021RC11.

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