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Chaos synchronization over 1040-km fiber relay transmission using hybrid amplification

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Abstract–Limited by chaos synchronization, chaotic optical communication is faced with a problem of long-haul fiber transmission. Here, we propose a scheme of long-distance chaos synchronization using fiber relay transmission with hybrid amplification of erbium doped fiber amplifiers (EDFAs) and distributed fiber Raman amplifiers (DFRAs). Assisted with the low-noise Rama amplification, the fiber channel impairments of amplified spontaneous emission and self-phase modulation can be suppressed, which helps to improve the synchronization distance. Numerical and experimental results show that a 1040-km chaos synchronization can be achieved by cascaded relay of EDFAs and DFRAs over eight 130-km single-span fibers comprised of standard single-mode fibers and dispersion compensation fibers.

1. Introduction

Since the first field demonstration in the metropolitan area network of Athens [1], chaotic optical communication (COC) has shown great potential in securing data transmission and aroused great interests. Much effort has been devoted to improving the rate of COC to match that of the conventional fiber transmission [2-5]. But less attention is paid to increasing the COC's transmission distance which is still below 200km. This impedes the COC from possible applications in a communication network with a larger scale, such as 1000-km interurban network.

For the 1000-km transmission, compensating power loss in the transmission path is necessary, and a way to take it for granted is optical relay using erbium doped fiber amplifiers (EDFAs). However, as is widely known, the EDFA with a high gain will introduce serious channel impairments including amplified spontaneous emission (ASE) noise and self-phase modulation (SPM) [6-8]. These impairments can be even accumulated after cascaded relay and greatly deteriorate chaos synchronization which is the prerequisite of COC, thus limiting the transmission distance.

Here, we propose a scheme of long-distance chaos synchronization using the hybrid amplification of EDFAs and distributed fiber Raman amplifiers (DFRAs). The DFRA has a low noise figure and can help to reduce the effects of ASE noise and SPM, and resultantly the long-distance chaos synchronization can be expected. Numerical and experimental results show that 1040-km chaos synchronization can be achieved by cascaded relay of EDFAs and DFRAs over eight 130-km single-span fibers.

2. System setup

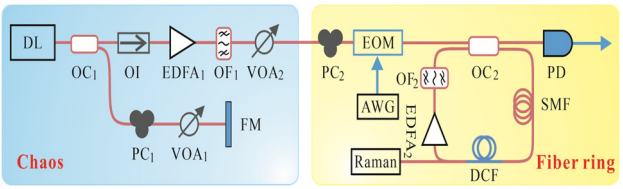

Fig. 1. System setup of fiber relay transmission with hybrid amplification.

It is noted that one usually uses semiconductors with mutual coupling or common injection to establish chaos synchronization. But, from the point view of long-distance transmission, the latter shows a greater potential than the former due to the way of common injection has a higher tolerance to the system asymmetry. For the way of common injection, the key of establishing long-distance chao synchronization is to keep a high fidelity of the drive signal injected into response lasers after the long-haul relay transmission, and Figure 1 shows the proposed system setup. Optical chaos generated from a semiconductor laser (DL) subject to mirror optical feedback is used as the drive signal. To imitate the scenario of long-haul transmission, the drive signal is delivered to an optical fiber loop composed of optical coupler (OC_2), standard single-mode fiber (SMF), dispersion compensation fiber (DCF), and transmitted within it repeatedly. The DFRA comprised of Raman laser with fiber, and the $EDFA_2$ are arrange d in the fiber loop to hybrid-amplifying the drive signal, and the OF_2 is used to suppress the out-of-band ASE noise. The drive signal after *N*-circle transmission and that before launching into the loop are recorded for cross-correlation calculation to evaluate the fidelity.

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3. Results

Firstly, we ascertained the pumping wavelength of Raman laser using VPIphotonics software. Figure 2 shows the DFRA gain as increasing the wavelength of Raman laser under different pumping powers. It can be seen that a large gain is achieved within a wavelength range from 1445nm~1455nm, which underlies the selection of Raman laser used in experiment.

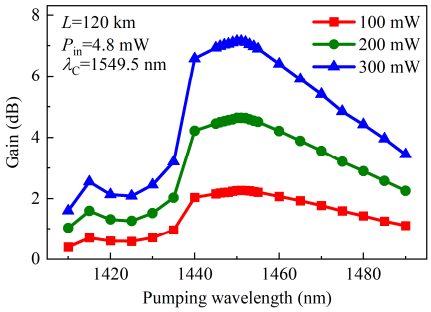

Fig. 2. DFRA gain as function of pumping wavelength of Raman laser under different pumping powers.

We further simulated the transmission scenario of drive signal over a 120-km single-span fiber. Figure 3(a) shows the fidelity with increasing the drive signal's power launched into fiber at different gain ratios. The gain ratio is defined as the ratio of gain from DFRA and that from EDFA, i.e., G_{DFRA}/G_{EDFA}. For a fixed gain ratio, as the power increases, the fidelity increases with a reducing rate, and starts to decrease after reaching an extreme value at the optimal power. Note that, there is also an optimal gain ratio that yields the highest fidelity of drive signal. Figure 3(b) further depicts the drive signal's fidelity after relay transmission of multi-span fibers, and each span has a length of 120km, 130km, and 150km. With increasing the number N, the fidelity decreases monotonically. To induce high-quality chaos synchronization with a cross correlation not below 0.90, the fidelity of drive signal should not be lower than 0.92. It is found that a maximum transmission distance of 1040km can be achieved with 8-span 130km fibers while keeping the fidelity as 0.92.

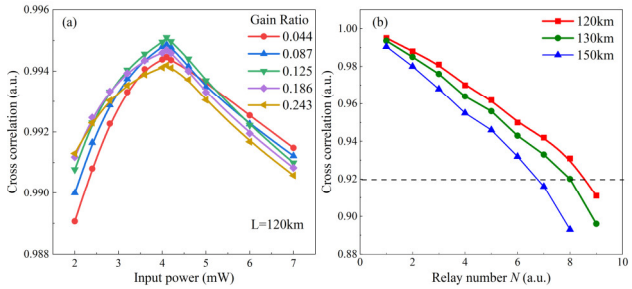

Fig. 3. Fidelity of chaotic drive signal as a function of (a) signal power launched into fiber under different gain ratios; (b) relay number N with single-span fiber length of 120 km, 130 km, and 150 km.

Based on our theoretical finds, we experimentally established a system of long-distance chaos synchronization induced by the common drive signal. In this system, the transmission link is replaced with 8 spans of 130km fiber with CD well compensated. By optimizing the power of drive signal launched into fiber and the gain ratio DFRA and EDFA, a high-quality chaos synchronization over 1040-km fiber relay transmission is achieved, which will be discussed in detail in our next paper.

4. Conclusion

In conclusion, a scheme of long-distance chaos synchronization based on fiber relay transmission with hybrid amplification of EDFAs and DFRAs is proposed and demonstrated in this paper. Theoretical and experimental results show that, by optimizing the pumping wavelength of Raman laser, drive signal power launched into fiber, and gain ratio of DFRA and EDFA, the chaotic drive signal can be transmitted with a fidelity not below 0.92 over eight 130-km single-span fibers. Driven by this chaotic signal, a 1040-km high-quality chaos synchronization is finally achieved. This scheme provides an alternative of constructing long-distance chaos synchronization in optical domain, and paves the way of high-speed long-haul COC.

Acknowledgments

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