Demonstration of an Optical Frequency-Hopping Scheme for Secure Communications

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Abstract: We proposed and demonstrated the optical frequency-hopping system for long distance secure communications. 10.6-Gb/s error-free transmission through 20-km DSF and 40-km SMF was implemented in a 2-frequency-hopping system.

OCIS codes: (060.2360) Fiber optics links and subsystems; (060.2630) Frequency modulation

1. Introduction

Physical layer security is one way of increasing the security of the entire network through very high speed encryption and decryption process. In optical networks, two secure communication systems, i.e., chaotic communication systems [1] and optical code-division-multiplexing-access (OCDMA) systems [2] have been demonstrated. One drawback of these previous systems is that the encrypted signals are analog. As a consequence, their transmission distance is limited due to various impairments in the fiber communication system. In this paper, we propose the optical frequency-hopping scheme, an optical analogy of frequency-hopping system in wireless communications, by adding encryption/decryption equipment at the transmitter/receiver side to implement the secure communication. As shown in Fig.1., every user data hops on different wavelengths at different time slots instead of being fixed at one wavelength all the time. Different users occupy different time-wavelength blocks according to a pre-defined hopping pattern. Any particular user data are thus encrypted by all the other user data. Intruder who looks at one wavelength will fail to understand the mixed and encrypted information. The receiver decrypts the encrypted data using the same encryption hopping sequence. The transmission distance can be very long in this scheme, because the optical signals are digital. In this paper, we demonstrated 10.6-Gb/s data transmission through a 20-km and a 40-km fiber link in a 2-frequency-hopping system.

2. Experimental Setup

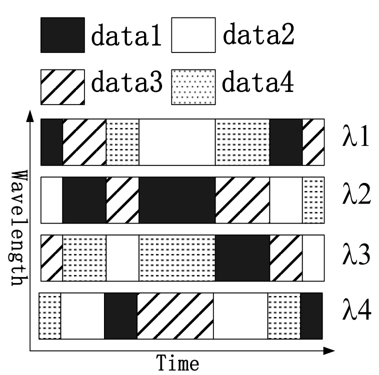

Fig. 1. Optical frequency-hopping scheme

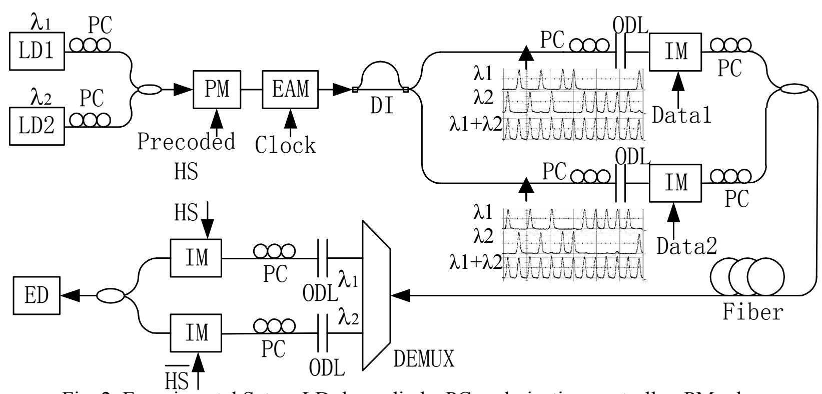

Fig. 2. Experimental Setup. LD: laser diode, PC: polarization controller, PM: phase modulator, EAM: electroabsorption modulator, DI: delayed interferometer, ODL: optical delay line, IM: intensity modulator, ED: error detector, HS: hopping sequence. Insets show the optical frequency-hopping sequence fed to the two users with a timescale of 200ps/div.

Fig. 2 depicts the experimental setup. The optical frequency-hopping sequence was generated by a frequency-shift-keying (FSK) transmitter which consisted of a phase modulator driven by the 10.6-Gb/s differentially precoded hopping sequence and a one-bit delayed interferometer (DI) [3]. With careful wavelength assignment, such a circuit was able to generate, as the insets of Fig.1. illustrates, two constant intensity, complementary FSK signals at each output port of the DI. Then each FSK signal branch was modulated by a 10.6-Gb/s user data with a $LiNbO_3$ intensity modulator and combined together via a 3 dB coupler. The path lengths of the two branches were controlled with optical delay lines (ODLs) to be strictly the same to align the bits of the two branches. The frequency-hopping sequence encrypted data were transmitted through a fiber link and then were decrypted at the receiver. A wavelength demultiplexer at the receiver split the two wavelengths. Two MZI $LiNbO_3$ intensity modulators at different branches were driven by the hopping sequence and the negative hopping sequence, respectively. When the signal on the first wavelength was turned 'on' by the hopping sequence, the second wavelength was turned 'off' by the negative hopping sequence, so the targeted wavelength-time slots was captured by such complementary modulation method. Finally, the two wavelengths were combined together and original user data was reconstructed. The path lengths of the two branches at the receiver were also carefully controlled to be the same to guarantee a good signal quality. In the whole scheme, we used a return-to-zero (RZ) signal by deploying a sinusoidally driven electro-absorption modulator (EAM) to eliminate the interferometric noise at the bit transitions. The hopping sequence used in the experiments was a pseudo random bit sequence (PRBS). However, this PRBS can be replaced by other code systems such as Golden code. The frequency-hopping speed is neither necessarily the same as the user data rate, a submultiple of the user data rate is also applicable in principle.

3. Results and Discussions

10.6-Gb/s data transmission was experimentally demonstrated through two fiber links. One was a 20-km dispersion shifted fiber (DSF), and the other was a 40-km standard single mode fiber (SMF) with an 8-km dispersion compensating fiber (DCF). Decryption was performed on user data1. Fig.3. shows the BER curves of the decrypted user data without transmission, after 20-km DSF, and after 40-km SMF and 8-km DCF. The eye-diagrams of these decrypted signals are also shown in the figure. Error-free results were obtained for all the cases. The sensitivity at a BER of 10^{-9} for the without transmission experiment was -17.9 dBm. The 2.5-dB power penalty compared with the base line arose mainly from the interferometric noise at the transmitter when the two branches were combined. An additional 1-dB and 1.3-dB power penalties were introduced by the 20-km DSF transmission and the 40-km SMF transmission respectively as a result of dispersion-induced signal walk off which could be regarded as timing jitter at the receiver. Consider a general multi-frequency-hopping case, the maximum walk off among the different wavelengths can be expressed as $\Delta T=\Delta\omega\Sigma\beta_2 L$, where β_2, L, and $\Delta\omega$ represents the fiber dispersion, fiber length and the maximum frequency difference, the sum runs over all the fiber sections. The maximum walk off should be much less than the pulse width to ensure an opening eye. In our experiment, the two carriers were 1.6 nm spaced, a 3-ps timing jitter in the 20-km DSF and a 10-ps timing jitter in the 40-km SMF was induced by dispersion. Because the dispersion will accumulate, per-wavelength based dispersion compensation scheme should be used in order to further extend the transmission distance. The synchronization of frequency-hopping sequence between the transmitter and the receiver was achieved by manually adjusting a fiber delay line in the current experiment. In practical use, a dedicated synchronization wavelength or synchronization searching algorithm can be used.

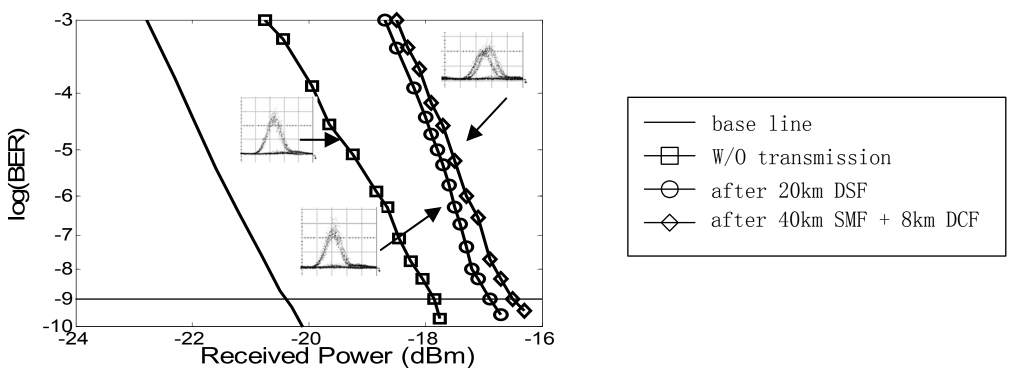

Fig. 3. The measured BER performance of the decrypted signals. Insets show the corresponding eye-diagrams, time scale is 20ps/div

4. Conclusions

We proposed and demonstrated the optical frequency-hopping system for long distance secure communications. 10.6-Gb/s data was transmitted in a 2-frequency-hopping system with a frequency-hopping speed of also 10.6 Gb/s. Error-free transmission through a 20-km DSF and a 40-km dispersion compensated SMF verified the efficacy of the system. In this first experiment, we have only demonstrated a 2-frequency-hopping system, however, in principle, the number of wavelengths involved can be upgraded to support more users and to further improve the security.

References

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