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基于超结构光纤光栅的编/解码器的发展和应用:第二部分

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摘要：这篇论文回顾了基于超结构光纤光栅的光学编解码器在保密光通信与光分组交换系统中的应用。基于超结构光纤光栅的光学编解码器能够被当作光学码生成器及解码器件提高光通信的安全性，并且能够被用作光标签生成器及识别器同时生成及识别一组光标签。器件良好的性能使得该器件能够在光通信及信号处理中保证无误差。

关键词：超结构光学光栅；编码/解码技术；保密通信；光分组交换
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Development and applications of superstructured fiber Bragg grating based en/decoders: Part II

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Abstract: In this paper, we review the applications of the superstructured fiber Bragg grating based en/decoders. The devices are used as coding devices in the secure optical communication system and as label generator and recognizer in the optical packet switching system. The device can provide high security in the secure communication system. Besides, the single-input multiple-output device can generate and recognize a group of optical labels simultaneously. The good performance of the device promises the error-free transmission and signal processing.

Key words: Superstructured fiber Bragg grating; encoding/decoding; secure communications; optical packet switching

Introduction

In the previous paper, we introduce the recent development of the superstructured fiber Bragg grating

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(SSFBG) based en/decoding devices[1]. The well-designed SSFBG en/decoder using $\pm\pi/2$-phase-shift can conceal code information in the encoded waveform and improves the security of the coding[2-3]. Besides, the $\pm\pi/2$-phase-shift SSFBG en/decoder can be used together with the conventional $0/\pi$-phase-shift SSFBG en/decoder. Furthermore, the SSFBG en/decoder (SE) can be developed into a single-input multiple-output device[4]. The SSFBG based en/decoding devices have the potential in the field of optical communications.

In this paper, we review the applications of the SSFBG based en/decoding devices. We mainly introduce the applications in the secure optical communication and optical packet switching (OPS) systems.

1 Applications in the secure optical communications

To demonstrate the application of the SSFBG based coding devices in the secure optical communications, we placed the en/decoders in a 2-user on-off keying-optical code division multiple access (OOK-OCDMA) system. The experimental setup is shown in Fig. 1. A mode locked laser diode (MLLD) generated a Gaussian shaped pulse train with the pulse width of 2.3 ps (FWHM) at a repetition rate of 10 GHz, spectrally centered at 1 563 nm. After a 2 km dispersion flattened fiber (DFF) and a 7.5 nm band-pass filter (BPF), the pulse width was compressed to 1 ps. The pulse train was modulated with the 2^{15}-1 pseudorandom bit sequence (PRBS) data by the IM. The modulated pulse train was split into two arms. Two $0/\pi$-SSFBG encoders (CG1 and CG2) or two $\pm\pi/2$-SSFBG encoders (NG1 and NG2) were applied for the encoding. A 20 m single mode fiber (SMF) was added for de-coherence and an attenuator was used to balance the power of the encoded signals in the both arms. Then the encoded signals were combined for decoding. In the decoding section, corresponding decoder was used.

The bit-error-rate (BER) measurement against the received power is illustrated in Fig. 2. Both $0/\pi$-SSFBG and $\pm\pi/2$-SSFBG en/decoders obtain the error-free ($BER<10^{-9}$). Relative to the single-user

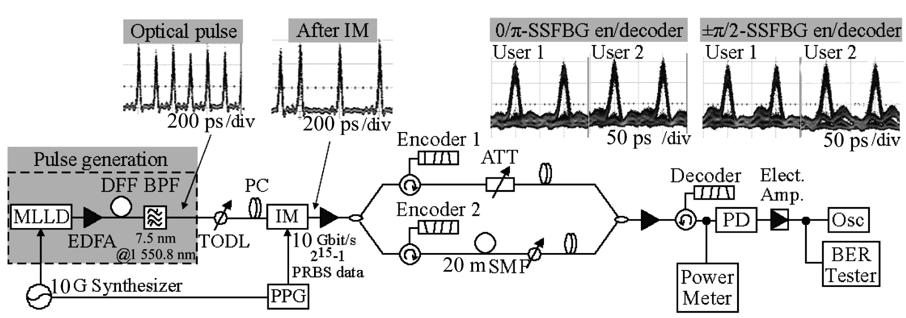

Fig. 1 Experimental setup of 2-user OOK-OCDMA system and measured waveforms and eye diagrams

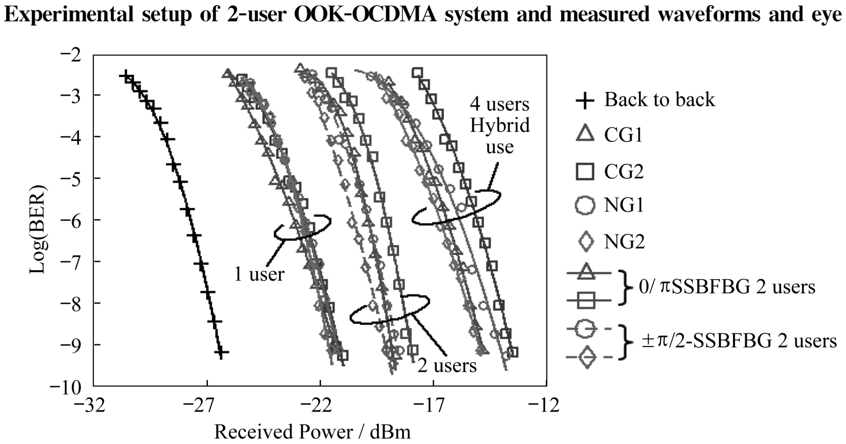

Fig. 2 BER performance of the $0/\pi$-SSFBG and $\pm\pi/2$-SSFBG en/decoders in the OOK-OCDMA system

OOK-OCDMA system, the 2-user system has about 3 dB power penalty, which is resulted from the multiple access interference(MAI). Compared to the 0/π-SSFBG en/decoder, ±π/2-SSFBG en/decoder has equally good performance in the system.

2 Hybrid use of 0/π- and ±π/2-SSFBG based en/decoder

To investigate the hybrid use of the 0/π-SSFBG and ±π/2-SSFBG en/decoders in the same system, we modified the experimental setup as shown in Fig. 3. Two 0/π-SSFBG encoders and two ±π/2-SSFBG encoders were simultaneously utilized for the encoding. The encoded signals were multiplexed to generate the 4-user OOK-OCDMA signals, which exhibited as noise-like waveforms, as shown in the inset Fig. 3(i). In the receiving side, four decoders were used one by one to decode the multiplexed signal. When the decoder matched the encoder, the target signals were recovered into the high intensity peaks and the signals from other users resulted in the MAI noise, as illustrated in the inset Fig. 3(ii). To restrain the interference from other users, the supercontinuum(SC) based optical thresholding was adopted, which was composed of an amplifier, a 2 000 m DFF and a 5 nm BPF with the center wavelength of 1 554 nm. The MAI was efficiently removed by the optical thresholding(see inset Fig. 3(iii)). Clear eye diagrams for four users could be observed. The BER of four users is also describe in Fig. 2. Compared to the single-user system, the four-user system causes about 7 dB power penalty at the BER of 10^{-9}. The 10^{-9} BER of four users confirms the feasibility of the hybrid use of the 0/π-SSFBG and ±π/2-SSFBG en/decoders.

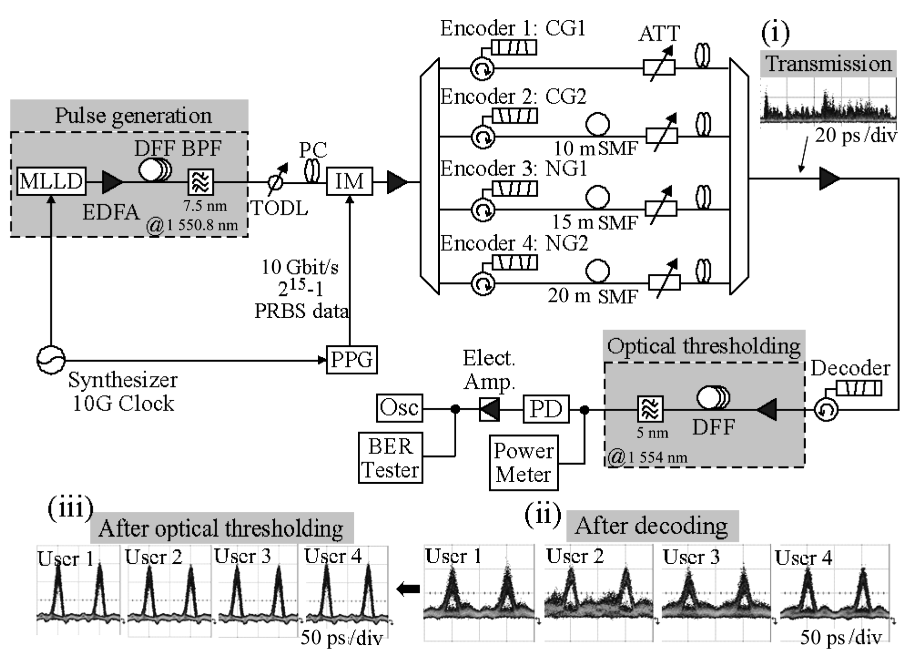

Fig. 3　Experimental setup of 4-user OOK-OCDMA system with hybrid use of en/decoders and measured waveforms and eye diagrams

3 Applications in the OPS networks

In an optical packet switching(OPS) network, the data packets are routed at the switching nodes in the optical domain. Therefore it could provide a very high throughput with good flexibility and fine granularity that is suitable for Internet protocol (IP) traffic. In addition, OPS show a lower power consumption, lower cost, and higher integration with respect to electronic switches. Therefore, OPS technique is expected to be a potential evolution to the next-generation backbone optical network.

In an OPS system, the optical label is an identifier of the payload data attached and carries the routing information. Optical labels available contain wavelength, optical code (OC), and subcarrier. Between them, the OC label, specifically the coherent time-spreading (TS) OC, has obtained lots of interests because it could provide an in-band routing function. Therefore, the OC processing is the key technique. A lot of different coding schemes have been proposed, particularly, in coherent TS coding scheme, the OC is generated by spreading the coherent optical pulses in time, and the phase of the optical carrier is changed according to a specific bipolar signature pattern. Therefore, the optical pulses are coherently interfering with each other during the signal processing is required for controlling the optical paths in the order fractions of optical wavelength, however, SSFBG can satisfy this critical requirement and have been applied as en/decoder. And the SSFBG that has also been successfully applied in optical code(OC) division multiple access(OCDMA) as encoder/decoder has the advantages of high compactness, polarization-independent performance, low cost for mass producing, and most importantly, the potential to generate ultra-long OC with very low insertion loss[5-6].

Figure 4 describes the architecture of an optical-code based OPS network. In the network, many routers switch optical packets to different destinations. An optical packet consists of an optical label and an optical payload. Optical codes are used as the optical labels. In this network there are three kinds of routers. Ingress routers generate and assign an optical label to the optical packet entering the core network and pass the optical packet to the core network by a certain route. Routers inside the core network separate the optical label and the optical payload. Based on the information of the label, the routers generate and assign a new label to the payload to form an optical packet. Then, the optical packet is switched to another router by a designated route. When an optical packet leaves the core network, it passes through an egress router. The egress router separates the label and payload and selects a certain route to transmit the payload.

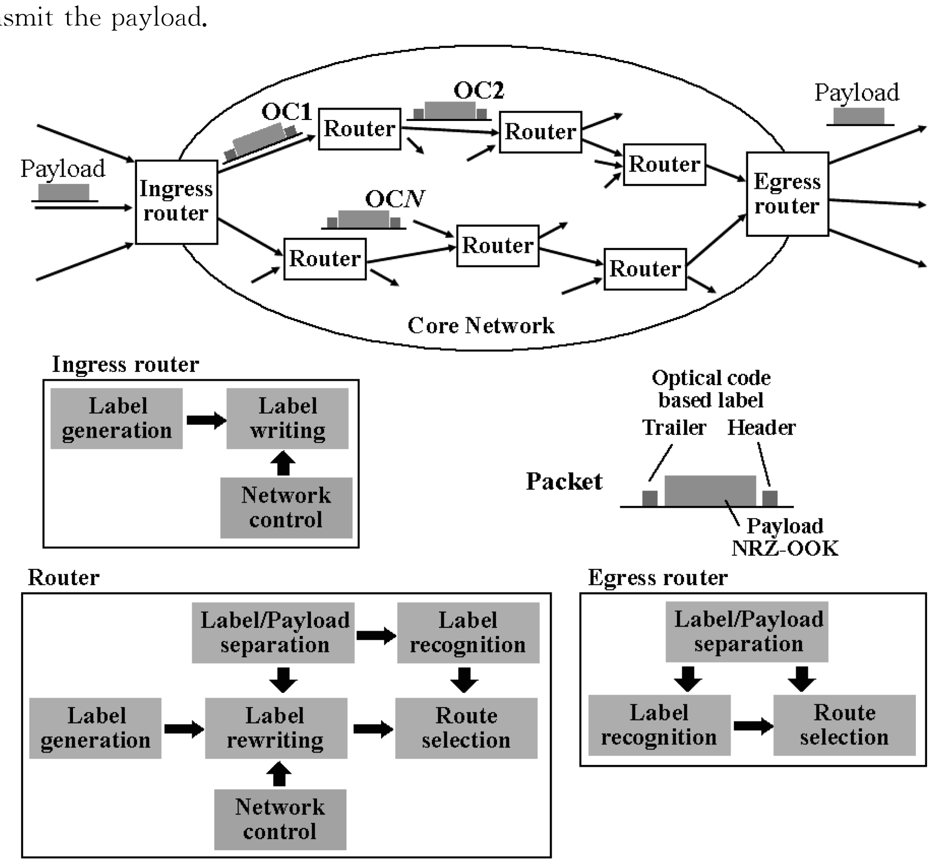

Fig. 4 Architecture of optical-code based OPS network and the functions of different routers

Figure 5 shows the experimental setup of the OPS system. We demonstrated the key functions of the routers including payload generation, label generation, label writing, label and payload separation, label recognition and packet selection and switching.

In this experiment, four payloads are generated by intensity modulation of a continuous-wave (CW) light with a 10 Gbit/s NRZ signal. The payload duration is 3 ns and there is a time slot of 200 ps between the two adjacent payloads for inserting optical labels. The data rate and the length of payloads can be much higher and longer and it does not affect the label processing. The waveform of Payload 3 is shown in Fig. 6(a). To generate optical labels, including headers and trailers, a 10 Gbit/s optical pulse train is modulated by an intensity modulator with a specified data pattern and input into the SIMO encoder. The four optical labels are generated simultaneously from the SIMO encoder and inserted into the time slots of the payloads, as shown in Fig. 6(b). The optical labels only have two data bits, but still contain sufficient routing information. The packet rate is 312.5 MHz. The spectrum of the optical packet is shown in Fig. 6(a). The spectra of the payloads and labels are overlapped together to efficiently use the optical spectrum.

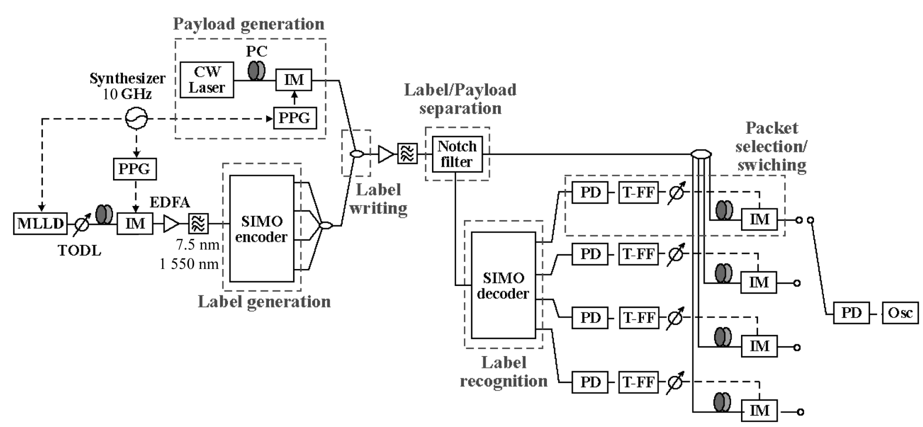

Fig. 5　Experimental setup of the OPS system

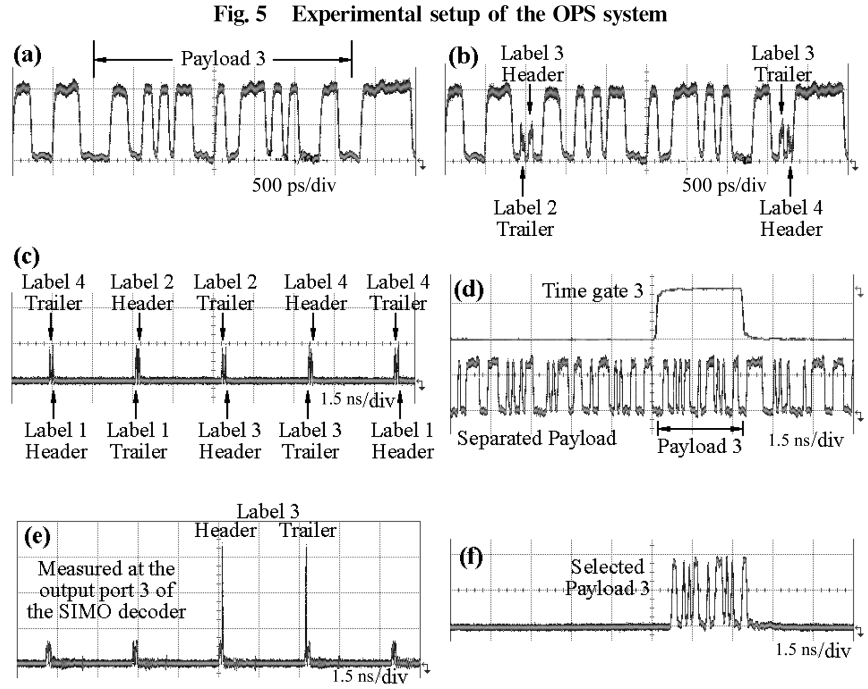

Fig. 6　Waveforms of (a) the payloads, (b) insertion of the optical labels into the payloads, (c) the separated optical labels, (d) the generated electrical time gate and the separated payloads, (e) the recognized optical labels, and (f) the selected payload

To separate the labels and the payloads, a spectral notch filter with 3 dB bandwidth of 0.6 nm is used. The waveforms and spectra of the separated payloads and labels are illustrated in Figs. 6(c), 6(d) and 6(b). The separated optical labels are input into the SIMO decoder for label recognition. The recognized labels are output simultaneously from the four output ports of the SIMO decoder. In the each output of the SIMO decoder, only the target label is recovered into a high-intensity optical pulse, as shown in Fig. 6(e). Then, the recognized labels are converted into electrical signals to generate a time gate by using a T flip-flop. The generated time gate is used to drive an intensity modulator to select the target payload from the separated payloads. The selected payload is shown in Fig. 6(f). The payload selection can also be realized all-optically by using optical time gating techniques so as to achieve all-optical packet switching.

The BER performance of the optical packet switching system is illustrated in Fig. 7. All selected payloads are error-free. Compared with the original generated payload, the selected payload has only about 2 dB degradation.

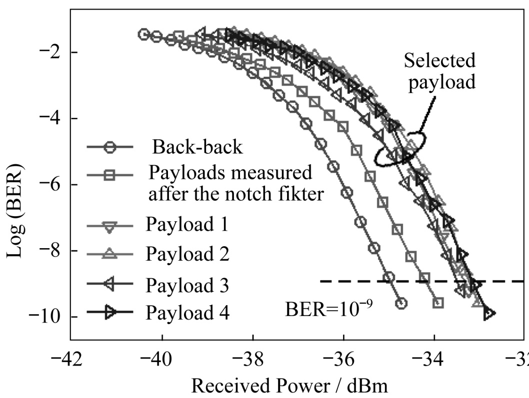

Fig. 7 The BER performance of the OPS system

4 Conclusions

In this paper, we overview the applications of the SSFBG based coding devices. The devices are demonstrated in the secure optical communication and optical packet switching systems and present very good performances. The coding features and many advantages including low cost and high stability of the SSFBG based coding devices make them good candidates in the many potential applications, such optical communications and optical signal processing.

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