Frequency-swept coherently detected spectral amplitude code for flexible implicit optical label switching

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A new optical label switching system with coherently detected implicit spectral amplitude code (SAC) labels is proposed in this letter. The implicit SAC labels are recognized using a frequency-swept local light source oscillator. Intensity modulation payloads of 625 Mb/s and 1.25 Gb/s are considered. Label and payload bit error rate (BER) performances are assessed and compared by simulations. The results reveal that, at a BER value of 10^{-9}, -32.4-dBm label received power can be obtained. In addition, 8.3-dB optical signal-to-noise ratio (OSNR) is obtained when carrying a payload of 625 Mb/s. The label BER value hardly reaches 10^{-9} if the payload bit rate is at 1.25 Gb/s; however, a high payload bit rate only has little influence on received payload quality at a BER value of 10^{-9}. Finally, a payload of 1.25 Gb/s could obtain -28.2 dBm received power and 9.5-dB OSNR.

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Optical label switching (OLS) enables optical packet routing and forwarding in IP over wavelength division multiplexing networks. OLS allows high bit rate payloads to be switched and routed transparently while applying low-speed electronic label processing[1]. Currently, optical code (OC) label switching has attracted much attention, and it is considered as one of the most promising labeling scenarios because of its high throughput, high speed, and potential flexibility[2−4]. Although OC label can be encoded in time, phase, wavelength and polarization domains, spectral amplitude code (SAC) is an attractive implementation, which has been applied in OC division multiple access and OC-labeled systems due to its simple structure and because label generation/recognition can be done with a relatively low level of complexity[5−7].

For an SAC-labeled switching system, explicit labels and implicit labels are both available. Explicit labels occupy independent wavelengths and are generated, recognized, and extracted by simple procedures; however, more frequency resources will be costly. For an implicit SAC-labeled system, labels and payload are modulated to a same wavelength and transmitted in the same packet (burst) duration. The maximum spectral efficiency could be obtained by applying implicit labels, and the transmitter structure can be significantly simplified[8,9]. The schematic diagram of explicit and implicit SAC-labeled packets in time domain is shown in Fig. 1.

For the implicit system, an SAC label "hides" in the payload signal, and payload is "encoded" by the label (Fig. 1). The spectrum occupied by the payload in the explicit system is removed in the implicit scenario[10].

To simplify the SAC label recognition unit, a frequency-swept coherently detected explicit SAC label switching system has been demonstrated in our previous work; this system has 156-Mb/s labels and a 40-Gb/s intensity modulation (IM) payload[11,12]. In this letter, we propose a novel implicit SAC-labeled switching system with a coherently detected SAC label recognition unit. We demonstrate the system performance of this proposal by simulating a 4-code 156-Mb/s label as well as 625-Mb/s and 1.25-Gb/s IM payload signals. The qualities of received label and payload signals are measured using eye diagram, bit error rate (BER), and optical signal-to-noise ratio (OSNR).

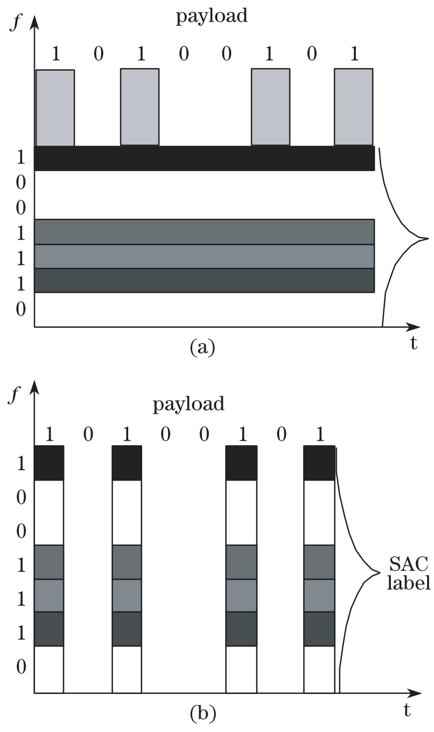

Fig. 1. Schematic diagrams of SAC-labeled packets in time domain: (a) explicit SAC-labeled packet; (b) implicit SAC-labeled packet.

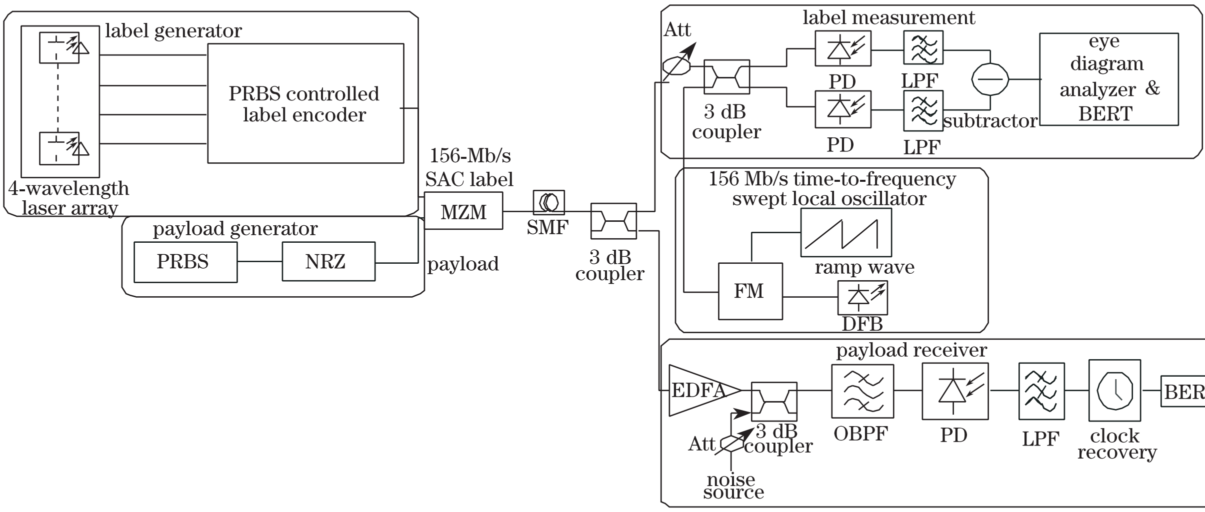

Fig. 2. Simulation setup of coherently detected implicit SAC label switching system. SMF: single mode fiber.

The back-to-back simulation setup of our proposed coherently detected implicit SAC label switching system is shown in Fig. 2. The software VPI Transmission Maker 7.5 was used for simulation purposes.

A group of typical and optimized parameters were chosen for this letter (Fig. 2)[10,11]. A four continuous-wave (CW) laser array and a label encoder were used to generate 2^7-1, pseudorandom binary sequence (PRBS) label signals, with a 30-dB extinction ratio (ER) at a label bit rate of 156 Mb/s. The chosen label wavelengths were at 1,552.83, 1,552.86, 1,552.89, and 1,552.92 nm, and the average emission power was 0 dBm with 1 MHz linewidths. For the transmitter of the payload signal, a $2^{23}-1$ PRBS electrical signal generator was used to generate a non-return-to-zero (NRZ) IM payload signal; however, there was no optical source in the payload transmitter, and the payload signal was directly modulated to label wavelengths through a universal dual-port Mach–Zehnder modulator (MZM) with an ER of 30 dB[10,11].

A frequency-swept distributed feedback (DFB) CW laser was simulated using an optical frequency modulator (FM) driven by a ramp wave generator. The frequency-swept range was from 1,552.82 to 1,552.93 nm to cover all the label available wavelengths. The parameters of this local oscillator (LO) were demonstrated and optimized at a 1,552.93-nm wavelength with 1 MHz linewidth and 0 dBm emission power[11,12]. The SAC labels were combined with the frequency-swept LO by a 3-dB coupler, after which the combined signal was transferred to electrical domain by a balanced photodetection receiver. The electrical label signal was filtered using a 120-MHz dual low-pass filter (LPF). An eye diagram analyzer and a BER tester (BERT) were used to measure received label quality. The following materials were used for the payload signal measurement: an erbium-doped fiber amplifier (EDFA) with a fixed output power of 0 dBm, an optical band-pass filter (OBPF) at 1,552.83 nm with a 2-GHz bandwidth, a photodiode (PD) with p−i−n structure and 1 A/W responsibility, an LPF with a 1-GHz bandwidth, a clock recovery module, and a BERT. Two attenuator (Atts) are employed in label and payload receivers to estimate the received responsibility.

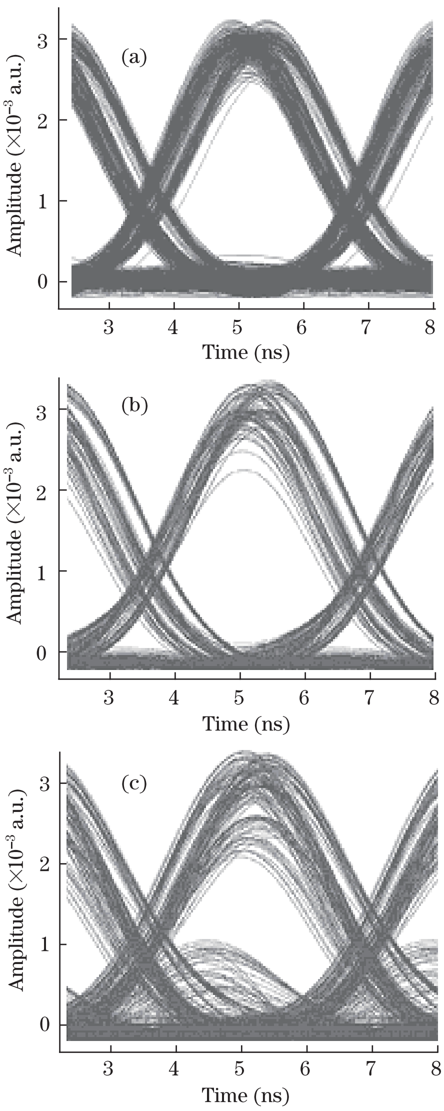

Fig. 3. Received eye diagrams of implicit SAC label: (a) without payload; (b) with 625-Mb/s payload; (c) with 1.25-Gb/s payload.

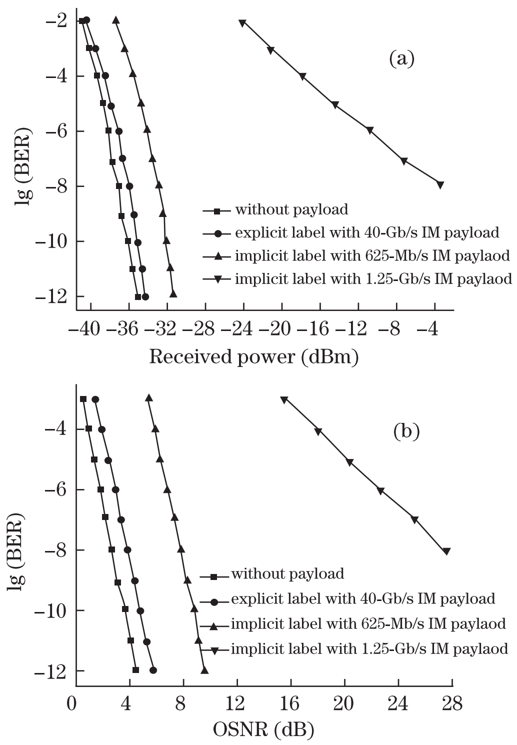

Fig. 4. BER performances of implicit SAC label with different payload bit rates: (a) BER versus received power; (b) BER versus OSNR.

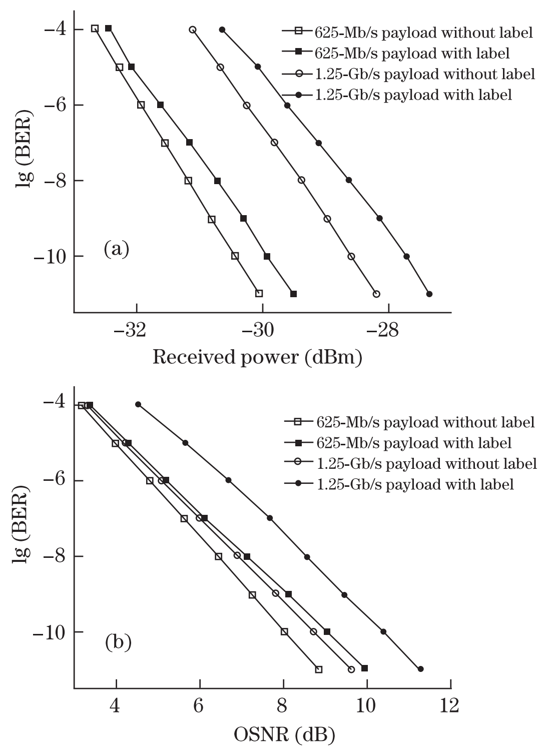

Fig. 5. Payload BER performances with different bit rates: (a) BER versus received power; (b) BER versus OSNR.

The received label eye diagrams, including those with no payload, those with 625-Mb/s payload and those with 1.25-Gb/s payload, are shown in Fig. 3.

When the payload bit rate increases to 1.25 Gb/s, the received label quality decreases (Fig. 3). As can be seen, label received eye diagram is almost totally closed if applying a 2.5-Gb/s payload. For discussion and analysis, received label qualities with different payload bit rates were evaluated by BER performance. The results are shown in Fig. 4.

Figure 4 further demonstrates the phenomena presented in Fig. 3. In carrying a 625-Mb/s payload at a BER of 10^{-9}, the label received power is −32.4 dBm, and the OSNR is 8.3 dB. There is a 4.2-dB power penalty and a 5.2-dB OSNR penalty between the 625-Mb/s system and a system without payload. The power penalty and the OSNR penalty are 3.2 and 4 dB, respectively, between the 625-Mb/s payload system and the 40-Gb/s explicit IM payload system. In carrying a 1.25-Gb/s payload, the label BER value could not reach 10^{-9}. Even if the BER is at 10^{-8}, the label received power is −3.5 dBm, and the OSNR is 27.7 dB. The power penalties and the OSNR penalties between the 1.25-Gb/s payload system and those without/explicit payload are more than 30 and 20 dB, respectively.

The above results reveal that in our proposed frequency-swept implicit SAC label switching system, if overly high bit rate payload (over 1.25 Gb/s) is applied, then the frequency-swept LO is unable to recognize the correct label signals because the label spectrum is widely extended by the payload. Although the 1.25-Gb/s payload is available, very large power penalty and OSNR penalty must be produced to obtain an eligible received label quality. The received payload BER performances with different bit rates are shown in Fig. 5.

At a BER of 10^{-9}, the received powers of 625-Mb/s and 1.25-Gb/s payloads are −30.2 and −28.2 dBm, respectively, and the OSNRs are 8.1 and 9.5 dB, respectively (Fig. 5). There is also a 2-dB power penalty and a 1.4-dB OSNR penalty between the 625-Mb/s system and the 1.25-Gb/s system. This means a higher payload bit rate only has a slight influence (not larger than 2 dB) on received payload quality. By comparing this with the systems with and without the label, the power penalty and OSNR penalty obtained are 1.6 and 0.8 dB, respectively.

On the other hand, for a coherently detected explicit SAC with a payload of 40-Gb/s IM, the power penalty and the OSNR penalty between systems with and without the label are 1.1 and 0.6 dB, respectively[11]. Although the payload bit rate in the implicit system is much lower than that in the explicit system, the power penalty and OSNR penalty increased. This phenomenon reveals that, for the implicit SAC label system, the interference between label and payload is increasing because the label "hides" in the payload signal.

To the best of our knowledge, we proposed what we think is a novel method of frequency-swept coherently detected implicit SAC-labeled system. The operation principle of this approach has been demonstrated using computer simulation. A 156-Mb/s SAC label with a payload signal scheme of 625-Mb/s and 1.25-Gb/s IM has also been examined. For the 625-Mb/s payload system, the label/payload received power is −32.4/−30.2 dBm, and the OSNR is 8.3/8.1 dB, when BER is at 10^{-9}. For the 1.25-Gb/s payload system, the payload received power is −28.2 dBm, and the OSNR is 9.5 dB when BER is at 10^{-9}. The label received power is −3.5 dBm, and the OSNR is 27.7 dB when BER is at 10^{-8}. This means the frequency-swept LO is unable to recognize the correct label signal if the payload bit rate is over 1.25 Gb/s. This is because the label spectrum is widely extended by the high-speed payload.

By comparing with the systems with and without the label, the payload power penalty and the OSNR penalty obtained are 0.8 and 1.6 dB, respectively. These values are slightly higher than those in a coherently detected explicit SAC with a payload of 40-Gb/s IM. For the implicit SAC label system, the interference between label and payload is increasing because the label "hides" in the payload signal.

In conclusion, this proposal provides the basic information and proof of a coherently detected implicit SAC-labeled system. The simulation results reveal that the 625-Mb/s payload scheme shows good BER/OSNR performances with reduced complexity and high spectral efficiency; such results indicate its potential application in future all-optical switching networks.

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