Implicit Optical Label Switching System for 1 Gb/s, 2 Gb/s and 5 Gb/s with Frequency-Swept Coherent Detection

Isaac Adjaye Aboagye, *Member, IAENG*, Nii Longdon Sowah, Wiafe Owusu Banahene

***Abstract*—We present the transmission performance of the optical label switching system with coherently detected implicit spectral amplitude code (SAC) labels. Intensity modulation (IM) payloads of 1, 2 and 5 Gb/s with 156 Mb/s four bit SAC labels are considered. The performances of the label and payload bit error rates are assessed and compared by simulation. For the 1 Gb/s payload system, the label/payload received optical power (ROP) is −29.0/-26.8 dBm, and the optical signal to noise ratio (OSNR) is 12.7/11.3 dB, when BER is at 10^{-9}. For the 2 Gb/s payload system, the label/payload ROP is -24.1/-25.2 dBm, and the OSNR is 13.1/12.7 dB when BER is at 10^{-9}. For the 5 Gb/s payload system, the payload ROP is -23.9 dBm, and the OSNR is 15.7 dB when BER is at 10^{-9}. The label ROP is -4.8 dBm, and the OSNR is 25.6 dB for 5 Gb/s when BER is at 10^{-8}. The penalty due to power and the penalty due to OSNR between 1 Gb/s and 40 Gb/s explicit IM payload are 2.3 and 3.2 dB, respectively. The penalty due to power and the penalty due to OSNR between 2 Gb/s and 40 Gb/s explicit IM payload are 7.2 and 3.6 dB, respectively.**

***Index Terms*—Coherent detection, implicit labeling, intensity modulation (IM), optical label switching (OLS), spectral amplitude code (SAC).**

I. INTRODUCTION

THE numerous advances based on all-optical networking have been explored in order to support the scalability of terabit rates packet routing and new streamlined internet protocol (IP) routing [1]. Switching quantities in optical networks are inextricably linked with bandwidth and quality of service. Optical label switching (OLS) enables optical packet routing and forwarding of IP over wavelength division multiplexing networks. Optical label generation is a key technology in the label switching network. It can overcome the problems of optical communication effectively while retaining the high-speed characteristics of optical packet switching. For most promising labeling scenarios, optical code (OC) label switching has attracted much attention because of its high speed and flexibility [2]-[4]. SAC label is one of the realizations of optical labeling [5]. SAC has been applied in OC division multiple access, and OC labeled systems due to its simple structure. The SAC label generation and recognition can be done with a relatively low level of complexity [6]-[8]. Explicit and implicit labeling are both available in a SAC label switching system. In explicit label system, the labels generated occupy different wavelengths as the payload. The main problem associated with explicit labeling is the cost.

The essence of applying implicit labeling is to ensure that: 1. Maximum spectral efficiency is obtained. 2. Payload and label are modulated to the same wavelength and transmitted in the same packet duration. 3. Ensure that the spectrum occupied by the payload in explicit system is removed.

In this paper, we evaluate a novel method for implicit label transmission system of 1, 2 and 5 Gb/s optical label switching system with frequency-swept coherent detection to decode SAC label system. We analyse the factors that influence the received signal qualities of both payload and label.

The remaining parts of the paper are organized as follows: Section II shows the implicit labeling carrying principles. Section III shows the operational principles of our proposed coherent detection. Section IV describes the system model setup. In section V, the simulation result is presented and analysed. Finally, in section VI, we conclude the paper.

II. IMPLICIT LABELING CARRYING PRINCIPLES

Implicit Labeling has the payload and label modulated to the same wavelength and transmitted in the same packet duration. The payload is encoded by the label and the SAC label hides in the payload signal. The payload signal will no longer occupy a separate operating wavelength, but rather is modulated on the available wavelengths of the label. The payload information is encoded on the label's wavelength. The SAC label and payload have the same time interval in the time domain and the payload is encoded by the SAC label. The frequency effectiveness and network magnitude are very high in the implicit SAC-label switching system, since the label and the payload occupy equal wavelength and time in frequency and time domain respectively. The schematic diagram of implicit SAC label packet in the time domain is shown in Fig. 1 below.

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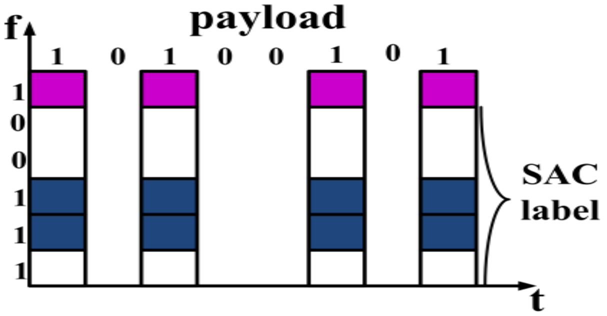

Fig. 1 Implicit SAC labelled packet in time domain.

III. PRINCIPLES OF FREQUENCY SWEPT COHERENT DETECTION

The receiver exploits knowledge of the carrier phase to detect the signal. Labels are encoded in wavelength domain, and recognized by their amplitudes [9]. The structure of frequency swept coherent detection scheme of SAC label is shown in Fig. 2. In this paper, we applied a frequency swept coherent detection as a way of recognizing SAC labels which has been proposed in our previous paper "100 Gb/s PDM-DQPSK Optical Label Switching System with Spectral Amplitude Code Labels"[10]. The SAC Label shown in Fig. 2(a) has 4 bits code of "1111" in wavelength domain. Fig. 2(b) shows the frequency-swept local oscillator (LO) with a swept frequency, which covers the entire SAC label's frequencies. The SAC label and LO are combined by a 3 dB coupler and the hybrid signal is transferred to the baseband electrical signal in time domain after photo- detection (PD). Therefore, the label signals can be recovered by low pass filters (LPF) as shown in Fig. 2 (c).

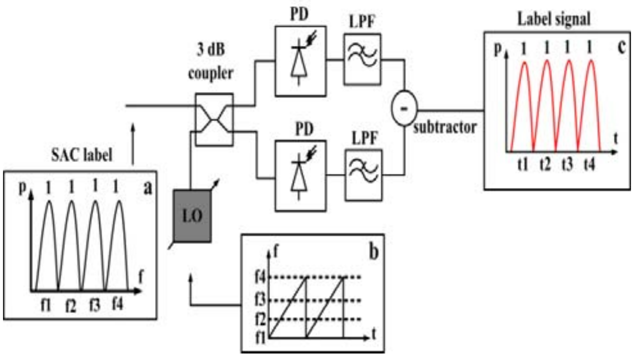

Fig. 2 Frequency-swept coherent detection of SAC label.

IV. SYSTEM MODEL SETUP

Fig. 3 shows the setup for back-to-back (BTB) and fiber transmission for coherently detected implicit label switching system. This is achieved using the VPI Transmission maker 8.3. The SAC label generation is made up of a laser, an optical switch and a pseudo random binary sequence (PRBS) generator. For the generation of SAC label signal, a four-distributed feedback (DFB) laser array and a label encoder were used to generate 2^7-1PRBS label signals at a label bit rate of 156 Mb/s with a 30-dB extinction ratio (ER). The chosen label laser wavelengths are at 1552.92, 1552.96, 1553.00, 1553.04 nm respectively. The frequency

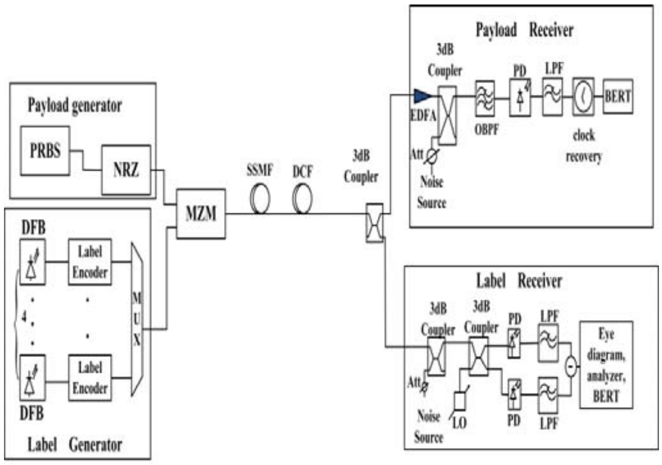

Fig. 3 Simulation setup for implicit SAC label switching system.

interval between each label is 5 GHz while the spacing between payload and label is 40 GHz. The average emission power is set at 0 dBm with 1 MHz linewidth. For the transmitter of the payload signal, a 2^{23}-1 PRBS electrical signal generator is used to generate a non-return-to-zero (NRZ) IM payload signal. The payload signal is directly modulated to the label wavelengths through a universal dual-port Mach–Zehnder modulator (MZM) with an ER of 30 dB. By combining the payload and the generated label, we obtain an optical packet of 1 Gb/s, 2 Gb/s and 5 Gb/s NRZ IM payload and 156 Mb/s four-code SAC label. A standard single mode fiber (SSMF) and a dispersion compensation fiber (DCF) are used as the transmission fiber. At the SAC label recognition unit, a frequency swept coherent detection is applied as a way of recognizing SAC labels. A frequency-swept range from 1552.91 to 1553.05 nm is used to cover all the labels available frequencies for the setup and the original SAC label is obtained. The parameters of the LO were optimized at a 1552.05 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 the electrical domain by a balanced photo detection receiver. The electrical label signal was filtered using a 100-MHz dual low-pass filter (LPF) and the original SAC label obtained [13], [14]. The qualities of received label and payload signals are measured using eye diagram, bit error rate (BER), and optical signal-to-noise ratio (OSNR).

V. ANALYSIS AND RESULTS OF THE SYSTEM

A SAC label with four bit codes of "1111" for 5 Gb/s implicit label is shown in Fig. 5.

An eye diagram analyzer and a BER tester were used to measure the received label quality. Eye opening factor (EOF) is used to measure the received quality of SAC label.

Expressed as:

$$EOF = {EA - (\sigma_1 + \sigma_0)} / {EA} \qquad (1)$$

where EA is the eye amplitude, σ_0 and σ_1 are the standard deviations of the sample points of '0' bits and '1' bits within the sample range. The received label eye diagram

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with 1, 2 and 5 Gb/s payload are shown in Fig. 6 (a), (b) and (c). When the payload bit rate increased from 1 Gb/s to 5 Gb/s, the received label quality decreased as shown in Fig. 6 (b) and (c). The label received eye diagram is almost closed with 5 Gb/s payload as shown in Fig. 6 (c). The received label qualities with different payload bit rates are evaluated by BER performance as shown in Figs. 7, 8 and 9.

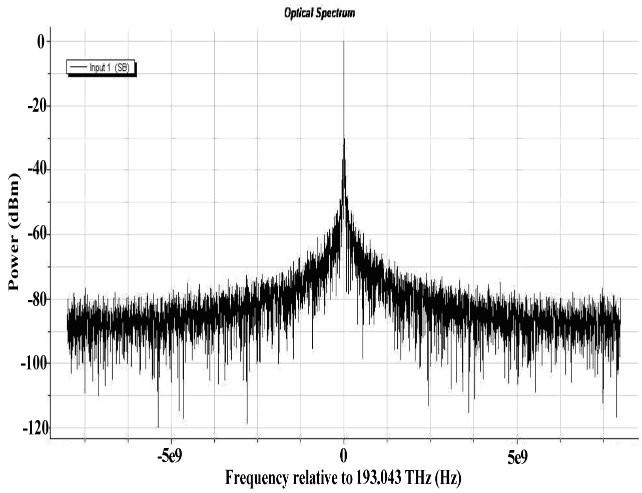

Fig. 4 Optical spectrum of generated local oscillator (LO).

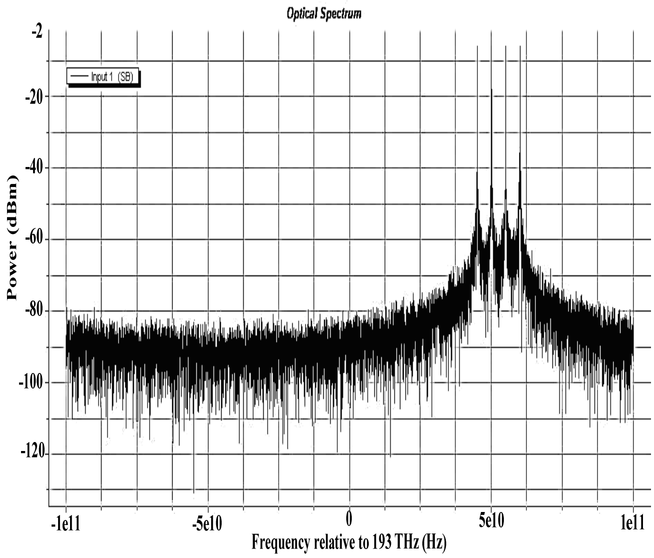

Fig. 5 Four bit codes for implicit SAC labelled packet in time domain.

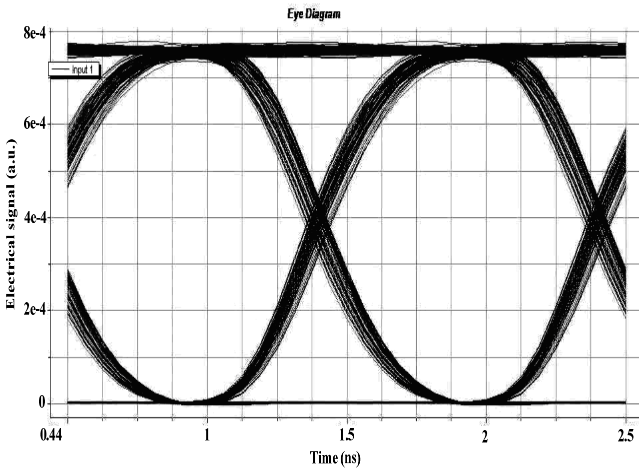

Fig. 6 (a) Received eye diagrams of implicit SAC label with 1 Gb/s payload.

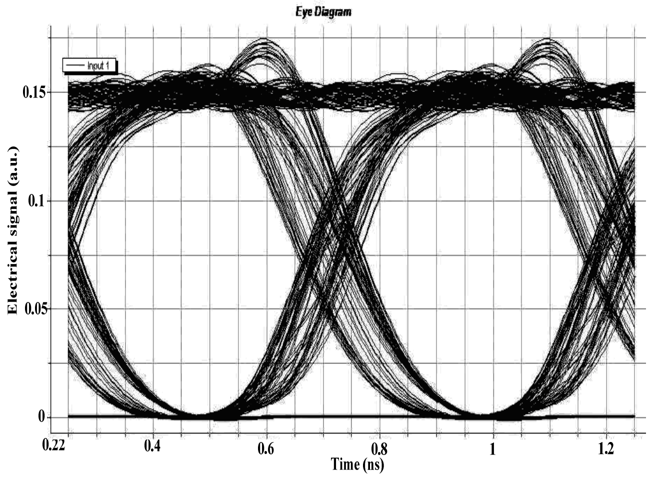

Fig. 6 (b) Received eye diagrams of implicit SAC label with 2 Gb/s payload.

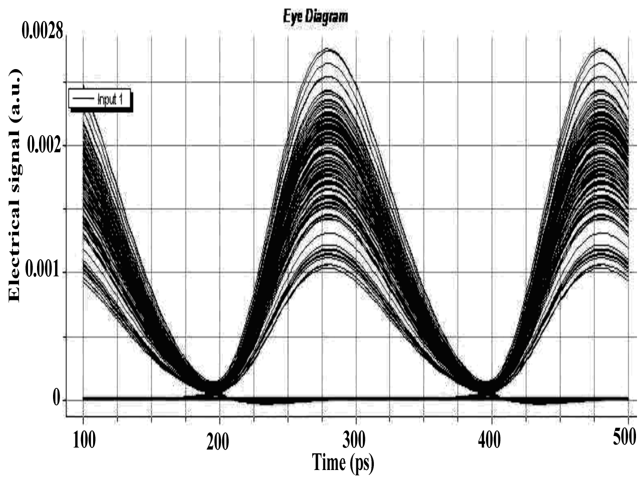

Fig. 6 (c) Received eye diagrams of implicit SAC label with 5 Gb/s payload.

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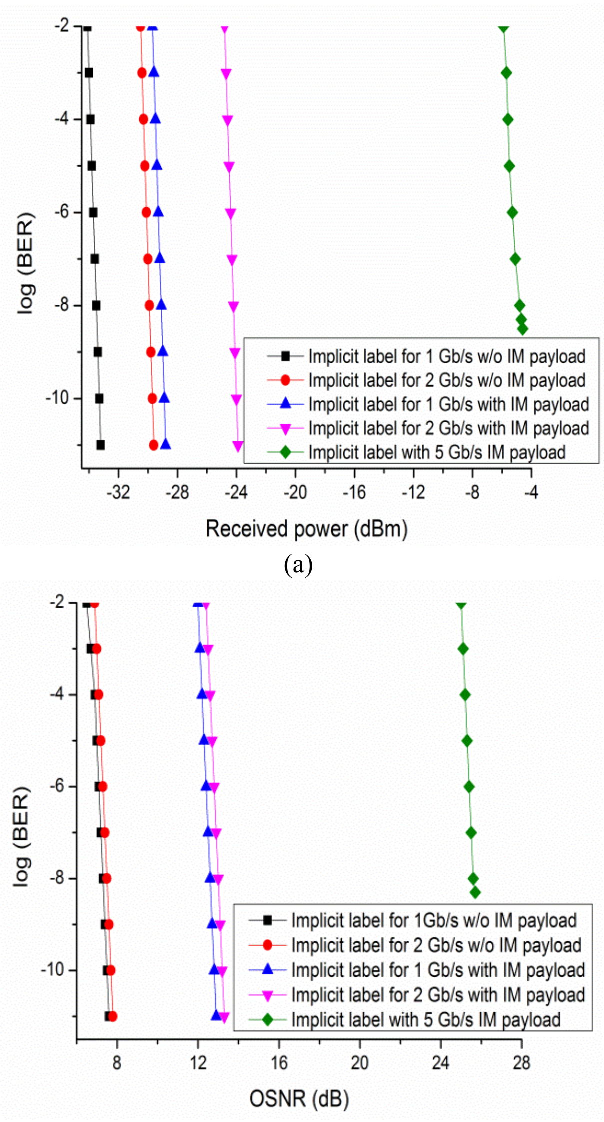
For implicit labels of 1 and 2 Gb/s IM without payloads, at a BER of 10^{-9} the label ROP and OSNR are -33.4 dBm and -28.8 dBm for received power and 7.4 dB and 7.6 dB for OSNR respectively. In carrying 1 and 2 Gb/s implicit label with payloads at a BER of 10^{-9} the label ROP and OSNR are -29.0 dBm and –24.1 dBm for received power and 12.7 dB and 13.1 dB for OSNR respectively. There is a 4.4 dB power penalty and a 5.3 dB OSNR penalty between 1 Gb/s system without/with payload and 4.7 dB power penalty and a 5.5 dB OSNR penalty between 2 Gb/s system without/with payload respectively. In carrying a 5 Gb/s payload, the label BER value could not reach 10^{-9}. At a BER of 10^{-8}, the label received power is -4.8 dBm and the OSNR is 25.6 dB. If high bit rate payload thus 5 Gb/s and above is applied, the frequency-swept LO is unable to recognize the correct label signals. This is because the label spectrum is widely extended by the payload. Although the 5 Gb/s payload is available, very large power penalty and OSNR penalty must be produced to obtain an eligible received label quality. This is shown in Fig.7 (a) and (b).

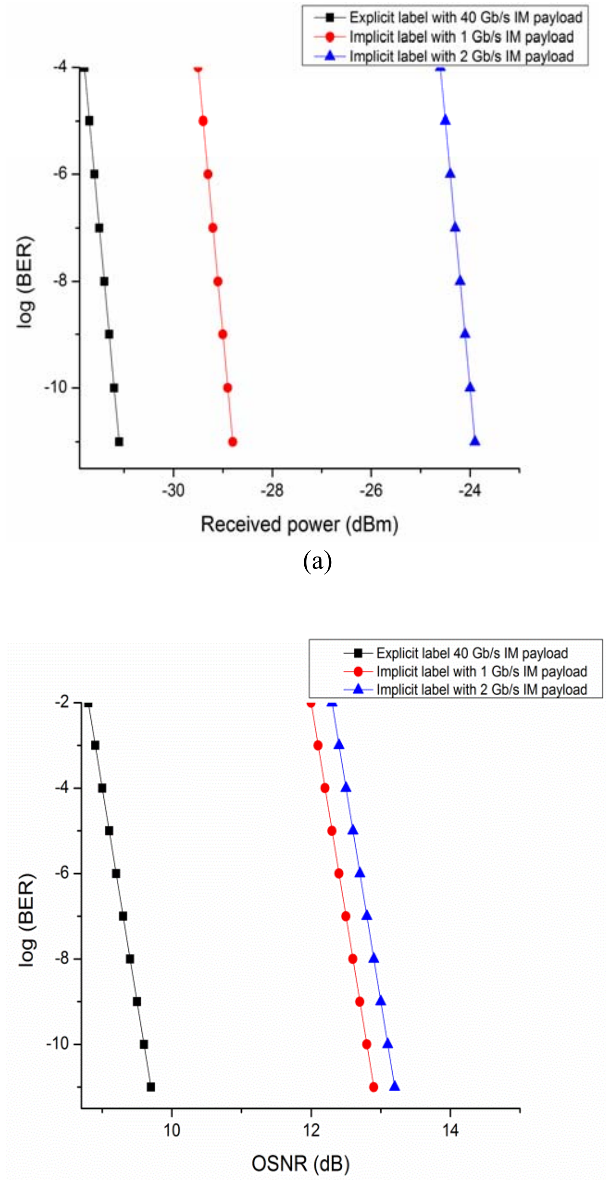


(a)

(b)

Fig. 7 BER performances of implicit SAC label with different payload bit rates: (a) BER vs received power; (b) BER vs OSNR.

The penalty due to power and the penalty due to OSNR between 1 Gb/s and 40 Gb/s explicit IM payload are 2.3 and 3.2 dB, respectively. The penalty due to power and the penalty due to OSNR between 2 Gb/s and 40 Gb/s explicit IM payload are 7.2 and 3.6 dB, respectively. This is shown in Fig. 8.



(a)

(b)

Fig. 8 BER performances of 40 Gb/s explicit and 1 and 2 Gb/s implicit SAC label payload: (a) BER vs received power; (b) BER vs OSNR.

The received payload BER performances with different bit rates are shown in Fig. 9.

At a BER of 10^{-9}, the received powers of 1, 2 and 5 Gb/s payloads without labels are -27.5, -25.8 and -24.3 dBm, respectively, and the OSNRs are 10.7, 11.9 and 14.3 dB, respectively. The received powers of 1, 2 and 5 Gb/s payloads with labels are -26.8, -25.2 and -23.9 dBm, respectively, and the OSNRs are 11.3, 12.7 and 15.7 dB, respectively. There is a 0.7 dB power penalty and a 0.6 dB OSNR penalty between 1 Gb/s payload without/with label, 0.6 dB power penalty and a 0.8 dB OSNR penalty between 2 Gb/s payload without/with label and 0.4 dB power penalty

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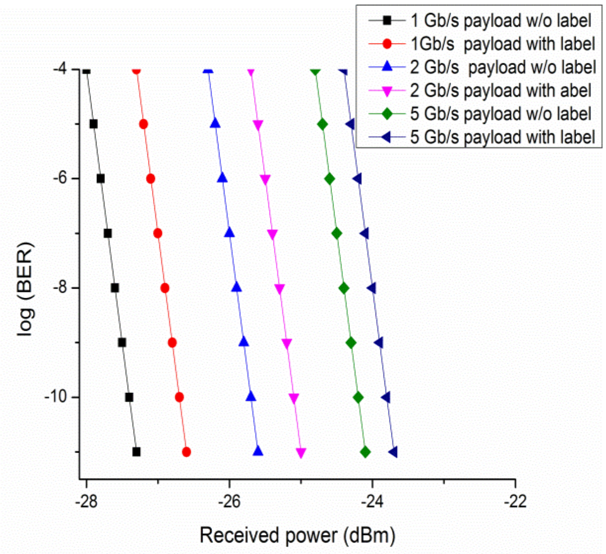
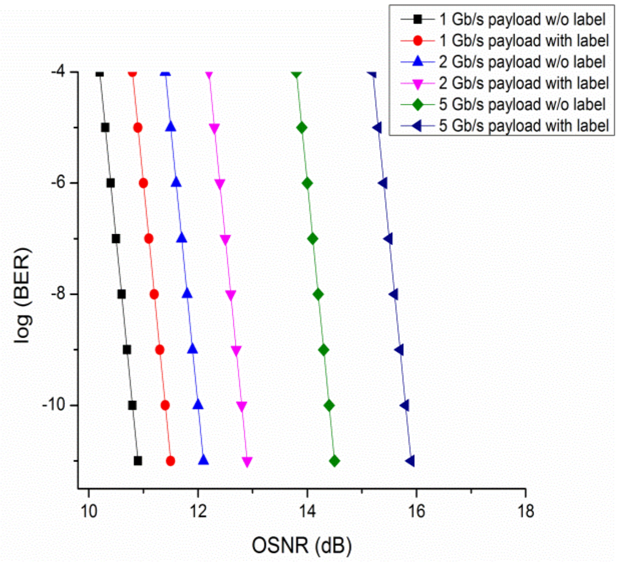
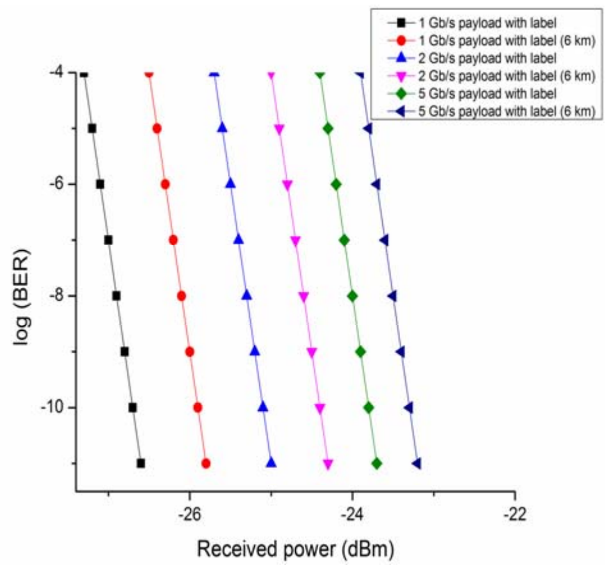


(a)

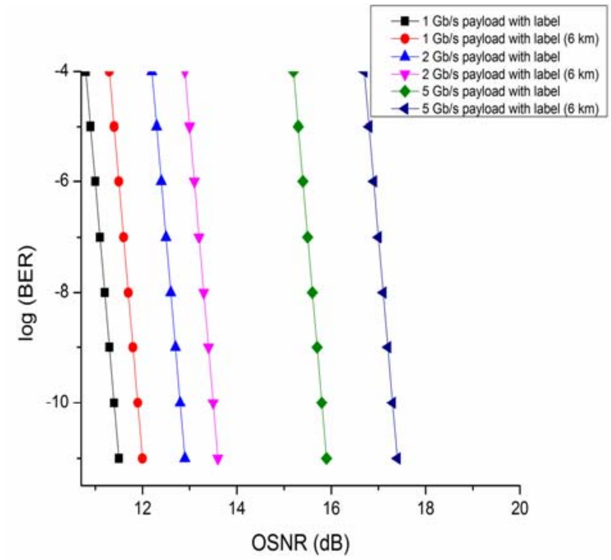


(b)

Fig. 9 Payload performances with different bit rates: (a) BER versus received power (b) BER versus OSNR.



(a)



(b)

Fig.10 Payload performances with different bit rates after 6 km: (a) BER versus received power (b) BER versus OSNR.

and a 1.4 dB OSNR penalty between 5 Gb/s payload without/with label. There is a 0.3 dB power penalty and a 0.8 dB OSNR penalty between the 1 Gb/s system and 5 Gb/s system. Also a 0.2 dB power penalty and a 0.6 dB OSNR penalty between the 2 Gb/s system and 5 Gb/s system. This shows that a higher payload bit rate only has a slight influence (not larger than 2 dB) on received payload quality. 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.

Fig. 10 below shows fiber transmission after 6 km for 1, 2 and 5 Gb/s. At a BER of 10^{-9}, the received powers of 1, 2 and 5 Gb/s payloads with labels are -26.0, -24.5 and -23.4 dBm, respectively, and the OSNRs are 11.8, 13.4 and 17.2 dB, respectively. There is a 0.8, 0.7 and 0.5 dB power penalty for 1, 2 and 5 Gb/s payload system with label/after 6 km respectively. There is a 0.5, 0.9 and 0.1.5 dB OSNR penalty for 1, 2 and 5 Gb/s payload system with label/after 6 km respectively. To the best of our knowledge, we proposed what we think is a novel method of frequency-swept coherently detected implicit SAC-labeled system with a payload of 5 Gb/s and fiber transmission after 6 km. The operation principle of this approach has been demonstrated using computer simulation.

Apparently much research has not been done on implicit fiber transmission. Cao Yongsheng et al. have done a research but only on back-to-back (BTB) transmission. Their results reveal that, at a BER of 10^{-9}, -32.4 dBm is obtained for label received power and 8.3 dB for OSNR when carrying a payload of 625 Mb/s. Their label BER value hardly reached 10^{-9} if the payload bit rate is at 1.25 Gb/s. A payload of 1.25 Gb/s could obtain -28.2 dBm received power and 9.5 dB OSNR. By comparing the payload and label performance to that of Yongsheng Cao et al., it is observed that our simulation has a better performance and for the first time, a distance of 6 km was transmitted using 5 Gb/s implicit SAC label.

VI. CONCLUSION

A 156 Mb/s SAC label with a payload signals scheme of 1 Gb/s, 2 Gb/s and 5 Gb/s IM has been examined. For the 1 Gb/s payload system, the label/payload received power is −29.0/-26.8 dBm, and the OSNR is 12.7/11.3 dB, when BER is at 10^{-9}. For the 2 Gb/s Gb/s payload system, the label/payload received power is -24.1/-25.2 dBm, and the OSNR is 13.1/12.7 dB when BER is at 10^{-9}. For the 5 Gb/s payload system, the payload received power is -23.9 dBm, and the OSNR is 15.7 dB when BER is at 10^{-9}. The label received power is -4.8 dBm, and the OSNR is 25.6 dB when BER is at 10^{-8}. The frequency-swept LO is unable to recognize the correct label signal if the payload bit rate is over 5 Gb/s because the label spectrum is widely extended by the high-speed payload. By comparing implicit labels of 1 Gb/s and 2 Gb/s without/with payloads, at a BER of 10^{-9}, the label received power and OSNR, there is a 4.4 dB power penalty and a 5.3 dB OSNR penalty between 1 Gb/s system without/with payload and 4.7 dB power penalty and a 5.5 dB OSNR penalty between 2 Gb/s system without/with payload respectively. By comparing implicit payload of 1 Gb/s, 2 Gb/s and 5 Gb/s IM without/with labels at a BER of 10^{-9}, the payload receive power and OSNR, there is a 0.7 dB power penalty and a 0.6 dB OSNR penalty between 1 Gb/s system without/with payload, 0.6 dB power penalty and a 0.8 dB OSNR penalty between 2 Gb/s system without/with payload and 0.4 dB power penalty and 1.4 OSNR penalty between 5 Gb/s system without/with payload respectively. There is a 0.3 dB power penalty and a 0.8 dB OSNR penalty between the 1 Gb/s system and 5 Gb/s system. Also a 0.2 dB power penalty and a 0.6 dB OSNR penalty between the 2 Gb/s system and 5 Gb/s system. The power penalty and the OSNR penalty between 1 Gb/s and 40 Gb/s explicit IM payload are 2.3 and 3.2 dB, respectively, while The power penalty and the OSNR penalty between 2 Gb/s and 40 Gb/s explicit IM payload are 7.2 and 3.6 dB, respectively. For the implicit SAC label system, the interference between label and payload increased because the label “hides” in the payload signal. The simulation results reveal that the 1 Gb/s and 2 Gb/s payload scheme show good BER/OSNR performances with reduced complexity and high spectral efficiency. Also the results indicate that the payload and SAC label are compactible. Such results indicate its potential application in future all-optical switching networks.

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