Transmission performance of implicit optical label switching system with coherently detected spectral amplitude code labels*

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(Received 13 March 2013)

A new optical label switching system with coherently detected implicit spectral amplitude code (SAC) labels is proposed in this paper. The implicit SAC labels are recognized using a frequency-swept local light source oscillator. An explicit SAC-label switching system with 40 Gbit/s intensity modulation (IM) payloads and 156 Mbit/s label and an implicit SAC-label switching system with 2.5 Gbit/s IM payloads and 156 Mbit/s label are both considered. Label and payload bit error rate (BER) performance is assessed and compared by simulations. The results reveal that after 80 km transmission and at the BER of 10^{-9}, the received optical power (ROP) values of label and payload are -8.3 dBm and -23.5 dBm in implicit SAC-label switching system, respectively, while those are -18.2 dBm and -18.6 dBm in explicit SAC-label switching system, respectively. As a result, the payloads of 40 Gbit/s and 2.5 Gbit/s in explicit/implicit SAC-label switching system have little influence on the received payload quality at the BER of 10^{-9} after 80 km transmission. Finally, a payload of 40 Gbit/s can obtain 12.5 dB optical signal-to-noise ratio (OSNR) after 80 km transmission.

Document code: A **Article ID:** 1673-1905(2013)04-0297-4

DOI 10.1007/s11801-013-2413-z

Recently, there is an increasing concentration on developing optical packet-switched networks to overcome future bottlenecks in transport and access networks. As a transition, researchers pay more attention to optical label switching (OLS) system[1]. However, for commercial optical communication system, there are still several challenges, for example, how to accomplish fast label recognition, simple label switching node with low cost and all optical buffering[2,3].

To solve above problems and achieve an available OLS system, different optical label generation and recognition technologies have been proposed, for example, amplitude-shift-keying (ASK) labels[4,5], frequency-shift-keying (FSK) labels[6,7], sub-carrier modulated (SCM) labels[8], orthogonal modulation labels[9,10] and so on. However, since optical code (OC) was firstly demonstrated as a control signal for a photonic switch in 1987, it has been applied in OC division multiple access (OCDMA) and OC label switching system. Due to its simple structure, OC label generation and recognition can be done with relatively low complexity. For current OC label recognition technology, it needs 1×N splitter, N correlators, N photodiodes (PDs) and N filters. As a result, it has large splitting lost, complex structure and high cost. So a new method of recognizing spectral amplitude code (SAC) by using frequency-swept coherent detection has been proposed and used in explicit SAC-label switching system, which not only has the advantages of OC label but also can overcome the disadvantages of its recognition technology[11,12]. However, more frequency resources must be used.

In this paper, an implicit SAC-label switching system, whose labels and payloads are modulated to the same wavelength and transmitted in the same packet duration, is proposed. The maximum spectral efficiency can be obtained by using implicit encoding method, and the transmitter structure can be simplified significantly. Fig.1 shows the schematic diagrams of explicit and implicit SAC-labeled packets in time domain.

In order to research the transmission performance of implicit SAC-labeled switching system, the bit error rate (BER) analysis on 156 Mbit/s label and 2.5 Gbit/s intensity modulation (IM) payload is presented after back to back (B2B), 40 km and 80 km transmission. And the BER analysis on 156 Mbit/s label with 40 Gbit/s IM payload in explicit SAC-labeled switching system is also

* This work has been supported by the National Natural Science Foundation of China (No.61205067), the Fundamental Research Funds for the Central Universities (No.ZYGX2010J007), and the Open Fund of State Key Laboratory of Information Photonics and Optical Communications in Beijing University of Posts and Telecommunications.

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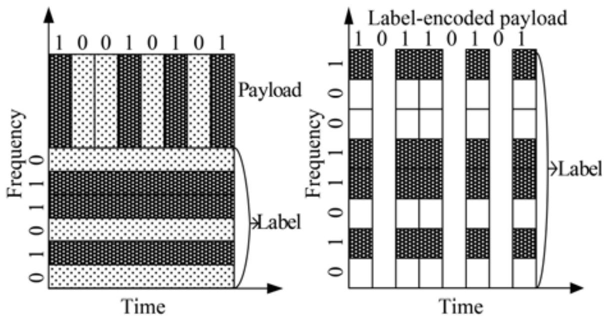
presented as a comparison.



(a) (b)

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

It can be seen from Fig.1 that the SAC label and payload have the same time interval in time domain in explicit and implicit optical packets. But the payload is encoded by the SAC label in implicit optical packet, and we also use having and not having power in the frequency slots to encode ‘0’ and ‘1’. Because label and payload occupy the same wavelength in frequency domain and the same time interval in time domain, the frequency efficiency and network throughput are very high in implicit SAC-label switching system. Fig.2 shows the simulation setup of frequency-swept coherent detection of implicit SAC-label switching system.

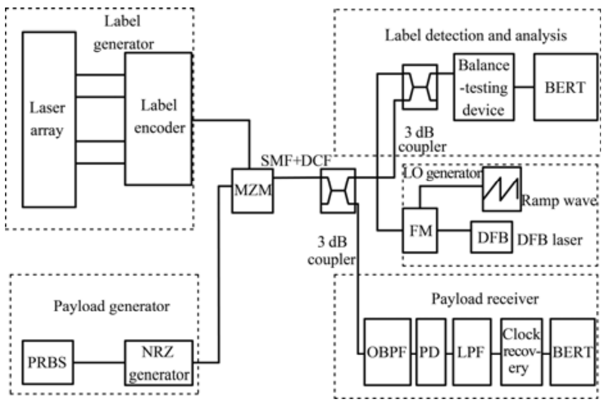
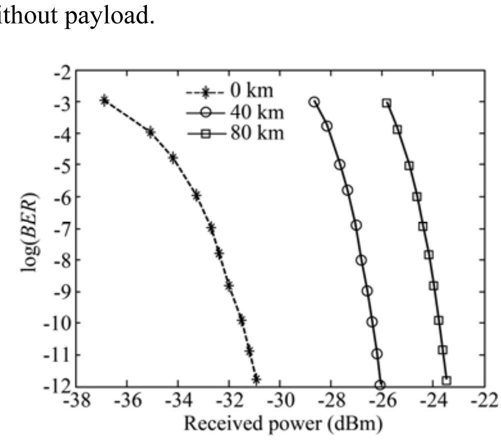


Fig.2 Simulation setup of frequency-swept coherent detection of implicit SAC-label switching system

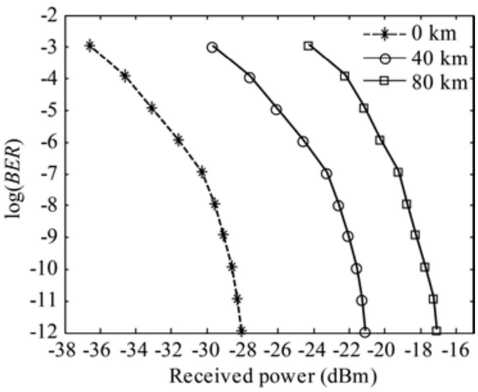
As shown in Fig.2, for label generator, a continuous wave (CW) laser array and a label encoder are used to generate 2^7-1 pseudorandom binary sequence (PRBS) label signals with 30 dB extinction ratio (ER) at 156 Mbit/s, the wavelengths are 1551.51 nm, 1551.54 nm, 1551.57 nm and 1551.60 nm, the average emission power is 0 dBm, and the line width is 10 MHz. For the generation of payload, a 2^{15}-1 PRBS is utilized to produce a non-return-zero (NRZ) electrical signal, and then the NRZ signal is applied to modulate the optical label signal through a Mach-Zehnder modulator (MZM) to generate 2.5 Gbit/s implicit IM payload signal. This implicit SAC-label optical single packet is transmitted over B2B, 40 km, 80 km through single mode fiber (SMF), dispersion compensation fiber (DCF) and erbium doped fiber amplifier (EDFA). At the receiving end, a frequency-swept laser or optical local oscillator (LO) is simulated by using an optical frequency modulator driven by a ramp wave generator, and its input is a distributed feedback (DFB) laser with 1551.60 nm wavelength, 100 kHz line width, and power of 0 dBm. In order to cover all the available label frequencies, the frequency-swept range is from 1551.51 nm to 1551.60 nm. The SAC label is combined with the frequency-swept LO by a 3 dB coupler. Then the combined signals are transformed into electrical domain by a balanced photo detection receiver. The electrical label signal is filtered by a 120 MHz low-pass filter (LPF). A bit error rate tester (BERT) is utilized to measure label signal quality. For the payload signal analysis, an optical band-pass filter (OBPF) at 1551.57 nm with 4 GHz bandwidth, a PD, an LPF with cut-off frequency of 2.5 GHz, a clock recovery module and a BERT are all used. The simulation software VPI transmission maker 8.3 is used for this purpose. And a four-code 156 Mbit/s label and 2.5 Gbit/s IM payload are considered to demonstrate and access its performance.

Fig.3 shows the transmission performance of explicit SAC-label switching system with 156 Mbit/s label and 40 Gbit/s payload.

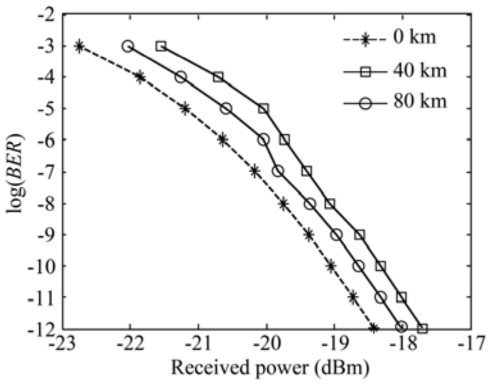
From Fig.3(a), when the BER of 156 Mbit/s label is 10^{-9}, the received optical power (ROP) values are -32.1 dBm, -26.6 dBm and -24.0 dBm after B2B, 40 km and 80 km transmission, respectively. Compared with B2B transmission, the power penalties are 5.6 dB and 8.1 dB after 40 km and 80 km transmission, respectively. From Fig.3(b), when the BER of label is 10^{-9}, the ROP values are -29.0 dBm, -22.0 dBm and -18.2 dBm after B2B, 40 km and 80 km transmission, respectively, and the power penalties are 7.0 dB and 9.8 dB, respectively. From Fig.3(c), when the payload BER is 10^{-9}, the ROP values are -19.4 dBm, -18.9 dBm and -18.6 dBm after B2B, 40 km and 80 km transmission, respectively, and the power penalties are 1.5 dB and 1.2 dB, respectively. This reveals that when adding payload and transmitted over 80 km, the SAC-label power penalty is 9.8 dB, and it is 1.7 dB more than that without payload.



(a) Label BER versus ROP without payload



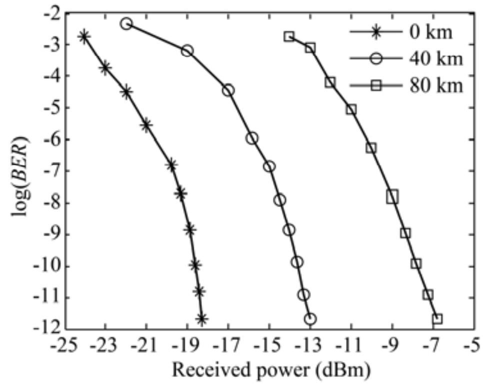
(b) Label BER versus ROP with 40 Gbit/s payload



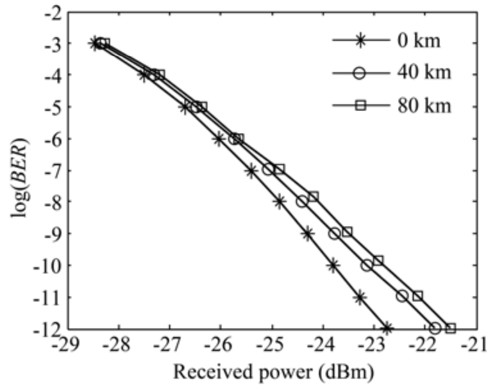
(c) Payload BER versus ROP

Fig.3 The transmission performance of 156 Mbit/s label and 40 Gbit/s payload in explicit SAC-label switching system

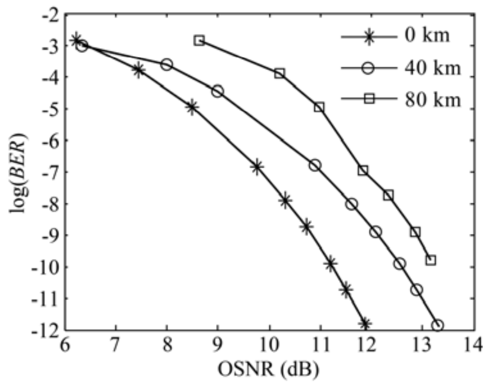
Fig.4 shows the transmission performance of 156 Mbit/s label and 2.5 Gbit/s payload in implicit SAC-label switching system. From Fig.4(a), when the BER of label is 10^{-9}, the SAC-label ROP values are -19.0 dBm, -14.0 dBm and -8.3 dBm after B2B, 40 km and 80 km transmission, and the power penalties compared with B2B are 5.0 dB and 10.7 dB, respectively. From Fig.4(b), when the BER of payload is 10^{-9}, the ROP values are -24.3 dBm, -23.8 dBm and -23.5 dBm after B2B, 40 km and 80 km transmission, and the power penalties are 0.5 dB and 0.8 dB, respectively. At the same time in Fig.4(c), when the payload BER is 10^{-9}, the OSNRs are 10.7 dB, 12.1 dB and 12.9 dB, respectively, and the OSNR penalties are 1.4 dB and 2.2 dB. So, for the SAC-label, the power penalty is 10.7 dB, and it is 2.6 dB more than that without payload. Besides, from Fig.3(b) and Fig.4(a), it can be seen that after 80 km transmission, the label power penalty is 9.8 dB in explicit SAC-label switching system, while 10.7 dB in implicit SAC-label switching system. Secondly, after 80 km transmission, the payload power penalties are 0.8 dB and 1.2 dB in implicit and explicit SAC-label switching systems, respectively. These data suggest that in explicit and implicit SAC-label switching systems, the power penalties of payload and label are almost equal while the payload bit rates are 40 Gbit/s and 2.5 Gbit/s, respectively. That is to say, the frequency efficiency is high in implicit SAC-label switching system, while the payload bit rate is high in explicit SAC-label switching system.



(a) Label BER versus ROP



(b) Payload BER versus ROP



(c) Payload BER versus OSNR

Fig.4 The transmission performance of 156 Mbit/s label and 2.5 Gbit/s payload in implicit SAC-label switching system

In conclusion, a new optical label switching system with implicit SAC-labels is proposed in this paper, and a frequency-swept coherent detection technology using an optical oscillator is used to detect these labels. Through simulation, we analyze the transmission performance of label and payload in implicit SAC-label switching system, and compare the results with that in explicit SAC-label switching system. The results suggest that in explicit transmission, the performance of SAC-label and IM payload almost does not affect each other after 80 km transimission. However, in implicit SAC-label switching system, the performance is limited by payload and labels bit rate, while the frequency efficiency is high enough.

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