

All-optical recognition method of double two-dimensional optical orthogonal codes-based labels using four-wave mixing

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Abstract: A novel all-optical label recognition method is proposed and demonstrated experimentally which is based on fiber Bragg gratings (FBGs)-based encoder/decoder and semiconductor optical amplifier (SOA). In this scheme, the optical label is firstly decoded properly, the decoded signal then generates the 1st and the 2nd order four-wave mixing (FWM) effect in different SOA, any of the frequencies achieved by the 2nd order FWM is extracted to recognize the optical label. The proposed solution can favor hardware simplicity over bandwidth efficiency in order to achieve the double two-dimensional optical orthogonal codes (2D-OOCs)-based optical label recognition in an optical packet switching (OPS) system where the bandwidth efficiency can be improved by FWM effect in SOA to achieve optical label processing and reasonable spacing of wavelengths for the payloads and optical label. The feasibility of the proposed method is validated by two experiments of the double 2D-OOCs-based optical label generation and recognition, the effect of the optical label on the payloads is also considered. These results show that the proposed method can (1) reduce effectively the code auto-correlation /cross-correlation requirements of the optical label identification and remove the cross-correlation pulses after optical decoding, (2) increase greatly the coding capacity and the number of the available optical labels, (3) improve the reliability and bandwidth efficiency of the optical label identification. The experimental results also show that the optical label has a high extinction ratio and can be operated easily.

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OCIS codes: (060.2330) Fiber optics communications; (200.4740) Optical processing; (999.9999) Optical code division multiple access.

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1. Introduction

The growth of network users and services leads to the soar of data in the backbone internet. Consequently, the demand for the backbone transmission capacity and switching scalability is ever-growing. Fortunately, the backbone capacity increment could be fulfilled by the huge bandwidth resource of optical fibers. But as the network speed rises up, the node of the backbone network becomes a bottleneck. As a result, more and more attentions are paid to the enhancement of the switching scalability and performance. Optical packet switching (OPS) is very promising one among all the proposed optical switching techniques [1–3]. High-speed packet forwarding over the optical fiber networks requires label processing techniques, such as label generation, label recognition, label swapping (erasing the old label and inserting a new label), synchronization and contention resolution [4]. So some challenges exist in the development of devices necessary for their implementation in optical switching networks, such as fast optical label recognition, fast and operational electro-optical (O/E) switches and all optical buffering. For example, the short label method is desired to reduce the complexity of the optical label processor [5], the multi-wavelength label method alleviates the hardware complexity and is compatible with label stacking [6] with the requirement of the high switching speed and reasonable cost.

To achieve high throughput in the optical router, ultra-fast optical label recognition on the order of picoseconds is required as well as minimal buffering. One of the most promising advances in packet switching systems in recent years has been the development of generalized multi-protocol label switching (GMPLS) networks for high-speed forwarding and routing [7]. However, the GMPLS implementation for optical networks is hampered by electronic processing times, still in the range of several nanoseconds or milliseconds per packet. The optical label is usually processed in the electrical field and therefore, all-optical label schemes have been proposed in order to recognize and process high speed optical label in all-optical or electrical-optical field [8-9]. Some methods for all optical processing of the label have been investigated, such as all-optical methods for processing optical packet headers have been employed by tunable fiber Bragg gratings (FBGs) [10], by four-wave mixing (FWM) in a semiconductor optical amplifier (SOA) [11], and by a semiconductor laser amplifier in loop optical mirror (SLALOM) configuration [12]. These methods have some advantages

especially not requiring optical clock recovery and reducing the complexity of the label header recognition, moreover, the bit-serial scheme has advantages because of enabling scalable labels with small number of bits, an optical digital-to-analog converter (ODAC)-type processor is used in this serial processing scheme [13]. The operation performances of a 40 Gbit/s, 2-bit ODAC and its application to optical label switching system have been investigated in Ref [14]. Due to the high performance and low cost of label hardware, the optical code (OC)-based label processor recognizes the multiple spectral amplitude coded (SAC)-based labels using FWM and selective filter [15], which can obtain a unique output wavelength that can identify each label. A label processor has been also used based on FWM with selective filter which can obtain a unique output wavelength to identify each label and therefore, to achieve routing [16]. In [17], a label stripping scheme that utilizes a semiconductor optical amplifier-based Mach-Zehnder interferometer (SOA-MZI) has been investigated. OC-based optical label is used since it can be easily recognized by the decoding technology, then, the label stripping and label recognition would be realized all optically and high label processing speed can be guaranteed. The conventional OC-based label can only provide 1-bit of information (matched or unmatched) during the decoding process. Recently, in order to support scalable OPS and packet-based multicasting, several multi-bit OC-based label schemes have been investigated in which a parallel-to-cascading technique which spreads the stacked / multisampling OC-based optical label multi-bit information in the time domain [18]. With this technique, the multi-bit OC-based label can be recognized through a cascaded decoder implemented by an FBG and one photodiode (PD). Therefore, the physical structure for multi-bit label's recognition is significantly simplified. In [19], an all-optical label erasing and recognition (AOLER) of a novel optical packet format has been demonstrated consists of a narrow-band fiber Bragg grating (FBG)-based filter and all-optical correlator. The capability of the FBG-based filter to convert a DPSK signal to OOK signal is exploited to separate the label from the payload and at the same time to convert the label to OOK in order to achieve all-optical recognizing by the optical correlator.

Above mentioned optical label processing methods have been considered in terms of the one-dimensional-based label format, but as one-dimensional SAC-based label scheme is unable to get sufficient use in the limited wavelength resource. To achieve more optical labels in a comparative little wavelength resource, the multiple optical orthogonal codes (MOOCs)-based optical label and the recognition method of such optical labels have been investigated [20-21], although the processing of the MOOCs-based optical label is considered worthwhile for optimum studies. In this paper, we use the FBG and optical matrix to encode/decode optical labels in time and frequencies field and FWM effect in a SOA to recognize the double 2D-OOCs-based optical labels for the first time. In this scheme, the difficulty associated with the electrical field is not only overcome, but more optical labels are also generated in the OPS networks.

2. Principle of optical label generation and recognition

2.1 Optical label generation

The proposed double 2D-OOCs-based optical label generation scheme is shown in Fig. 1. The scheme is employed by an optical switching matrix and two FBGs-based encoders. The pulse is generated by the modulation of continuous light from a wide-spectrum laser source and the pulse for optical label after a polarization controller (PC) is equally split into two branches by a 1×2 splitter. Two pulses after different delay lines of delay 1 # and delay 2 # are transmitted to an optical switching matrix which is controlled by the control signal. Two branches of the signal through the circulator are then encoded by the FBGs-based encoders for the 2D-OOCs in time and waves field. The encoded pulses from both branches are coupled to achieve the double 2D-OOCs-based optical labels. Different double 2D-OOCs-based optical labels can be produced by controlling the optical switching matrix to switch the signal to different exchange model. For example, we assume that the one (1 #) and another one (2 #) of two branches are expressed by A and B respectively, the double 2D-OOCs-based optical label

of BA (series of 2# and 1#) can be then obtained by the controlled optical switching matrix, as shown in Fig. 1. Moreover, AB, AA and BB for the optical labels can be also obtained by the proper delay lines, the controlled optical switch, and different optical encoders. In this scheme, two groups of the FBGs-based encoders are used, and each group is composed of three FBGs according to the requirements of the OOC for an optical label. The Bragg wavelengths of the FBGs in each optical encoder are allowed to be identically. Finally, the double 2D-OOC-based optical label is coupled with the payloads to obtain optical packet. As a result, the proposed scheme can greatly increase the number of the optical labels and saves a lot of the wavelengths resources.

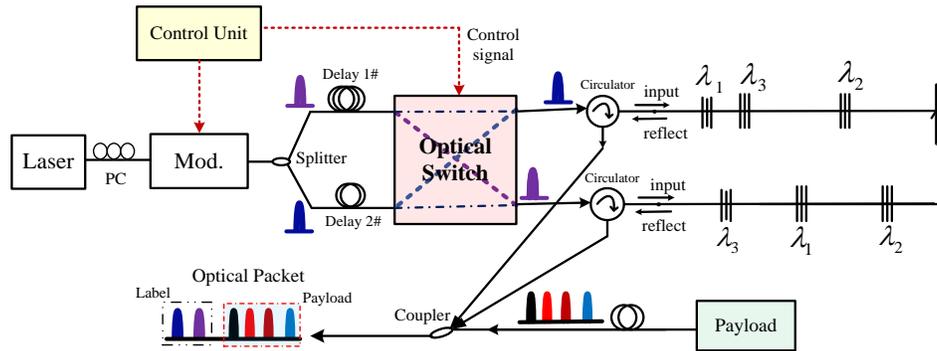
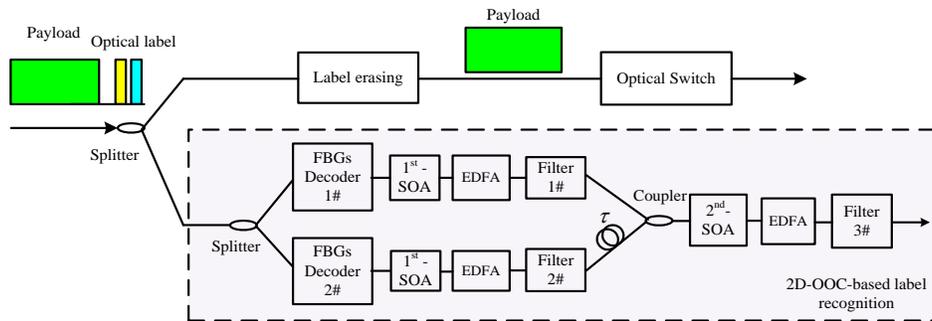


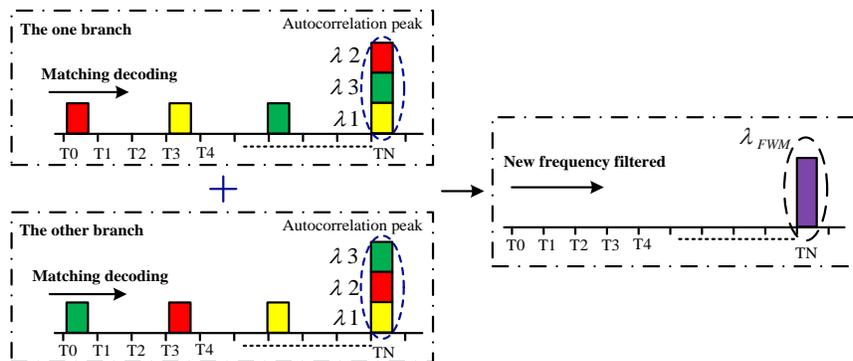
Fig. 1. Schematic of the double 2D-OOCs-based optical label generation. PC: polarization controller, Mod: modulator.

2.2 Optical label recognition

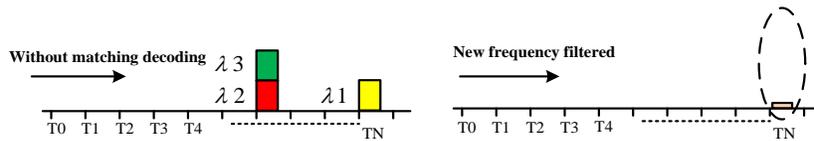
The optical packet is firstly split into two branches, the one branch is only used to optical switch after optical label erasing; the other branch is sent into the double 2D-OOCs-based label recognition unit. The FBGs-based decoders, the SOA and the filter are used in the optical label recognition scheme, as shown in Fig. 2(a). The double 2D-OOCs-based optical label can achieve two autocorrelation peaks with three wavelengths through the matched FBGs-based decoders, as shown in Fig. 2(b), titled as case 1. Two of the branches after different splitters are sent into the FBGs-based decoders 1 # and 2 #, which correspond to two 2D-OOCs of the optical label, in order to achieve optical decoding properly. In case 1, through the optical encoders 1 # and 2 # corresponding to two branches, three wavelengths are all overlap of the optical power peaks, which can achieve two of the autocorrelation peaks corresponding to two 2D-OOCs respectively, as shown in the left of Fig. 2(b). Two of the decoded optical label signals then generate the 1st order FWM effect in two SOA respectively, and two groups of 9 frequencies have been then obtained due to three wavelengths of the decoded optical label in the SOA. After two erbium doped fiber amplifiers (EDFAs), two of the signal pulses with different frequencies are extracted as the identification signals of different 2D-OOCs using filters 1 # and 2 # respectively. Note that different frequencies filtered express different optical codes. After a proper adjustment using the fiber delay lines, two of the filtered wavelengths are coupled into another SOA to generate the 2nd order FWM effect, and which can obtain two of new wavelengths. The one wavelength is filtered using the filter 3 # after an EDFA, which is extracted to identify the signal as the optical label. The double 2D-OOCs-based optical label cannot achieve the autocorrelation peaks without matching decoding, as shown in Fig. 2(c), titled as case 2. When any of the double 2D-OOCs for the optical label does not match the FBGs-based decoder, its output is then cross-correlation or noise. As a result, there is not extracted to identify the signal as the optical label.



(a)



(b)



(c)

Fig. 2. Principle of the proposed double 2D-OOCs-based optical label recognition in (a), the output of the optical label with matching decoding in (b), and without matching decoding in (c). SOA: semiconductor optical amplifier, FBGs: fiber Bragg gratings, EDFA: erbium doped fiber amplifier.

3. Experimental setup, results and discussion

3.1 Optical label generation experiment

The experimental setup of the double 2D-OOCs-based optical label generation is shown in the shadow of Fig. 3. The configuration word and the control signal of a CONFIG_ACK are produced to the input of the optical switch by field programmable gate array (FPGA) control circuit according to the routing information and a single needed pulse is generated by an embedded parallel / serial conversion module. An FPGA signal is modulated on the continuous wave from a laser source after a PC using a modulator. The modulated pulse is split into two branches. Two of the branches through two proper delay lines are sent into an optical switch, are then switched to the corresponding optical paths of the FBGs-based encoders to achieve the signal encoded respectively. Two of the encoded signals are coupled to obtain the double 2D-OOCs-based optical label. Finally, the double 2D-OOCs-based optical label through an EDFA is coupled with the payloads to generate an optical packet.

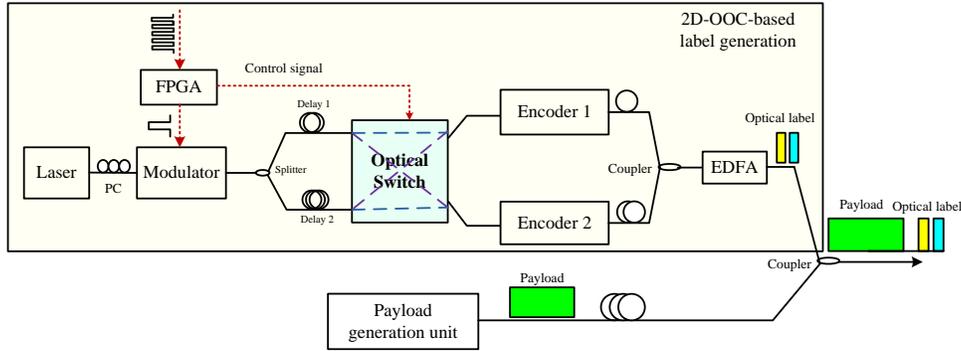


Fig. 3. Experimental setup of the double 2D-OOCs-based optical label generation. FPGA: field programmable gate array.

The width of a single pulse is 2 ns because the maximum frequency of the FPGA is 500 MHz, as shown in Fig. 4 (a). An output single pulse is sent into the intensity modulator which is used to modulate the continuous wave from a laser source. The modulated signal is a single optical pulse, as shown in Fig. 4 (b). The impedance of the output circuit of the FPGA board does not match the modulator input ports precisely, and the received optical pulse is little distorted. However, the modulated signal still has a good performance with a signal to noise ratio (SNR) of about 23 dB.

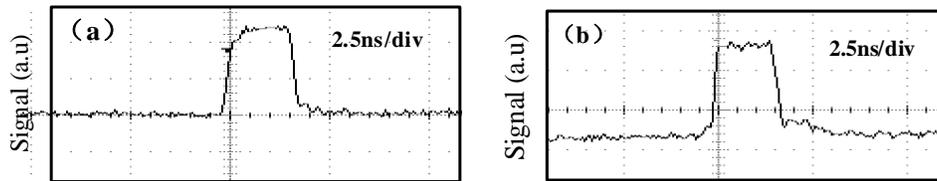


Fig. 4. Optical pulse waveforms, (a) the output of the pulse from an FPGA, (b) the output of the modulated pulse signal.

There are encoded to obtain two 2D-OOCs by different FBGs-based encoders in time and frequency field, whose code words are C_{11} [7,10,17] and C_{12} [5,11,13] in time field, where C_{11} [7, 10, 17] indicates that the 7th, 10th, 17th positions in the OOC sequence are “1” and the other positions are “0”. The code length of L is 19 and the code weight of k is 3. Both the FBGs-based encoders consist of three FBGs with different center wavelengths arranged as a serial. Three FBGs are identical in two FBGs-based encoders, but the arrangement positions of the FBGs are different. Two 2D-OOCs contain three identical wavelengths, which are 1552.5 nm, 1554.1 nm and 1557.3 nm respectively. Assume that the employed frequency of the j th can be expressed by $F^j_{\text{frequency}}$, the employed arrangement time slot of the j th can be expressed by T^j_{time} and the corresponding 2D-OOCs in time and frequency field can be then expressed by $C [(T^1_{\text{time}}, F^1_{\text{frequency}}), (T^2_{\text{time}}, F^2_{\text{frequency}}), \dots, (T^k_{\text{time}}, F^k_{\text{frequency}})]$. Two 2D-OOCs are coupled through a coupler to achieve the double 2D-OOCs-based optical label whose orders are determined by the optical encoders and optical delay lines. The length of the fiber delay line for the time guard slot between two OOCs of the 2D-OOCs-based optical label is set to 5 m. The optical label signal is then amplified by an EDFA. The polarization of the optical signal can be adjusted by a PC before the optical switch to get a better extinction ratio of about 26 dB through the optical switch, the optical waveforms of an optical packet consisted of the double 2D-OOCs-based optical label and the payloads are shown in Fig. 5. From Fig. 5, it is found clearly that the encoded waveforms of two 2D-OOCs express successfully one double 2D-OOCs-based optical label. The waveforms of the double 2D-OOCs-based optical label are shown in the left top of this figure, and the partial waveforms of

the payloads are shown in the right top of this figure. We can also see that this optical packet has a good performance after the optical packet is processed, including the optical label generation, the EDFA-based amplification and the transmission with a 25 km fiber. Especially a SNR of the payloads closes to 17 dB.

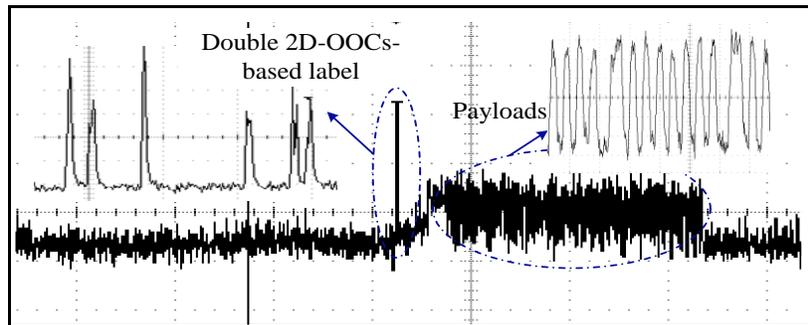


Fig. 5. Optical waveforms of an optical packet consisted of the double 2D-OOCs-based optical label and the payloads.

3.2 Optical label recognition experiment

3.2.1 Experimental setup of optical label recognition

The optical packet is divided into two parts by a 50×50 splitter when it reaches the core node of an OPS system. One part is sent into the erasing unit to erase optical label for the payloads switching. And the other part is sent into the label recognition unit to identify optical label. The autocorrelation peak is very difficult to handle using optic-electric (O/E) conversion, because it is very narrow of 2 ns through the FBGs-based decoder. Therefore, the new optical label recognition of the autocorrelation peak through the FBGs-based decoder is considered and an experimental system is set up, as shown in Fig. 6. A simple experimental demonstration is constructed to verify the feasibility of the proposed all-optical recognition scheme based on our existing experimental conditions. The experimental setup is mainly used to process the autocorrelation peak of the output waveforms from the FBGs-based decoder containing three identical wavelengths with the autocorrelation peak. Two cases for the input decoded signals are considered, the one case is assumed as a single pulse generator unit for the ideal label decoded; the other case is just the optical decoded label that is decoded by the optical FBGs-based optical decoders, as shown in the 2 # and 1 # units of Fig. 6 respectively. For the one case (2 #), different wavelengths from the lasers array through a PC are sent into an EDFA 1, the signal from a pulse pattern generator (PPG) is modulated on different wavelengths using a modulator. For the other case (1 #), the double 2D-OOCs-based optical label consisted of three wavelengths is decoded properly using the FBGs-based optical decoders. The autocorrelation of the 2D-OOCs from 1 # part or the single pulse from 2 # part for the optical label passes through an EDFA 2, and three wavelengths after a de-multiplexer (DeMUX) are coupled to a SOA 1, which then generate FWM effect. Two 2D-OOCs of the optical label contain exactly three identical wavelengths, and thus they are the same that the two 2D-OOCs after a properly decoded pulse can be obtained using the 1st order FWM effect in the relevant SOA 1. Two frequencies-based pulses after an EDFA 3 are extracted through a DeMUX, are then coupled into a PC by a 2×1 coupler. Two wavelengths after an EDFA 4 are sent into another SOA 2 to achieve the 2nd order FWM effect, one wavelength of which is extracted through a filter (such as a DeMUX) as the identifying signal. In order to simplify the experimental system, the signal with three wavelengths generates the 2nd order FWM in another SOA. And two of the new pulses as long as their frequencies are different, which are then extracted as two of different 2D-OOCs identification signal. Additionally a pulse is also generated by the single pulse generator unit, as shown in 2 # part of Fig. 6, and its pulse width is set to 0.5 ns.

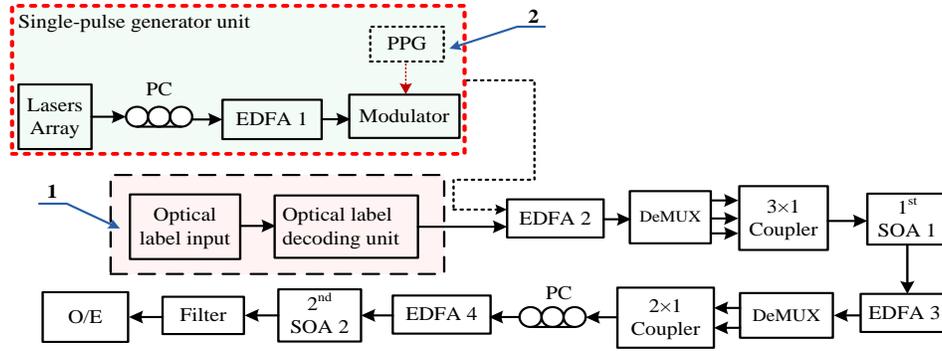


Fig. 6. Experimental setup of the proposed optical label recognition. PPG: pulse pattern generator, DeMUX: de-multiplexer.

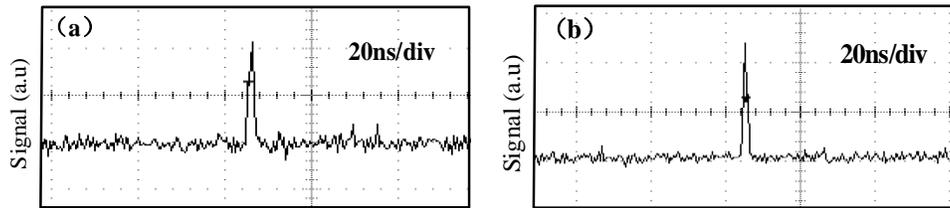


Fig. 7. Optical pulse waveforms, (a) the autocorrelation peak waveform of C_{11} [7,10,17], (b) the autocorrelation peak waveform of C_{12} [5,11,13].

Figures 7 (a) and (b) show the autocorrelation peak waveforms of two 2D-OOCs in the optical label through the corresponding decoders with three wavelengths respectively. Figure 7 (a) shows the waveform of the 2D-OOC whose code word is C_{11} [7, 10, 17], and Fig. 7 (b) shows the waveform of the 2D-OOC whose code word is C_{12} [5, 11, 13]. We can find that the autocorrelations of these 2D-OOCs have good performance, which also show the optical label has been decoded successfully.

3.2.2 Experimental results of optical label recognition

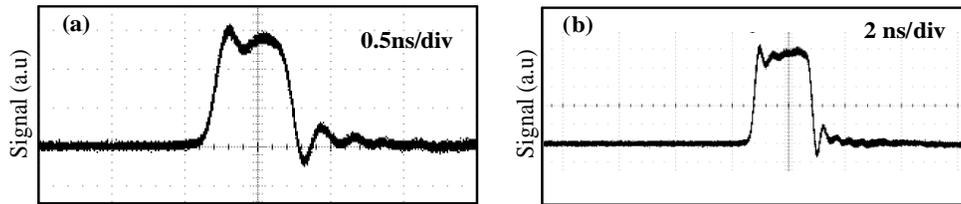


Fig. 8. The waveforms, (a) the single pulse with 0.5 ns, and (b) the autocorrelation peak with 2 ns.

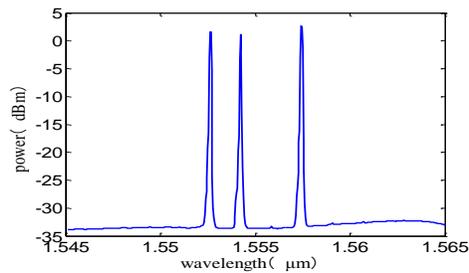


Fig. 9. The spectra of the autocorrelation peak.

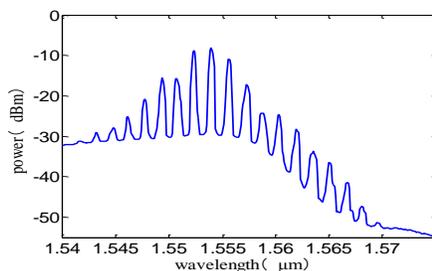


Fig. 10. The spectra of the 1st-order FWM in a SOA.

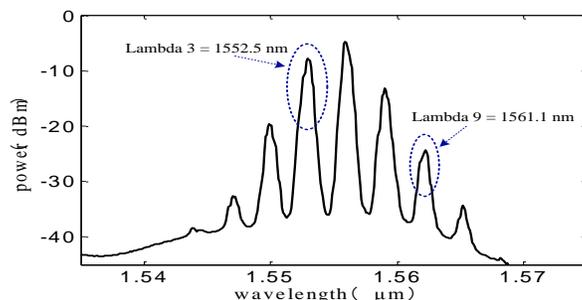


Fig. 11. The spectra of the 2nd-order FWM in another SOA.

In this work, three wavelengths of λ_3 , λ_4 and λ_6 from the lasers array are 1552.5 nm, 1554.1 nm and 1557.3 nm respectively. A bias voltage of the modulator is set to 2.6 V. The width of single pulse signal is 0.5 ns and the output power is -19.8 dBm for case 2 # of Fig. 6. The width of the decoded pulse signal is 2 ns and the output power is -18.1 dBm for case 1 # of Fig. 6. The waveforms are shown in Figs. 8 (a) and (b) respectively, we can find that the input pulse signals for case 1 # and case 2 # have good SNR performance of about 18.3 dB and 20 dB respectively. The spectra of the autocorrelation peak with 2 ns are shown in Fig. 9, and three wavelengths are clearly found. The pulse signal is as the autocorrelation peak through the FBGs-based decoder. The single pulse is obtained by the optical label decoded unit and its power is -3.75 dBm using amplification of an EDFA. The pulse transmits into the SOA and the 1st order FWM effect is generated resulting in 9 frequencies. Among these frequencies, two are the same compared with two out of three original frequencies, so that there are only 7 of new frequencies which are $\lambda_0 = 1547.7$ nm, $\lambda_1 = 1549.3$ nm, $\lambda_2 = 1550.9$ nm, $\lambda_5 = 1555.7$ nm, $\lambda_7 = 1558.9$ nm, $\lambda_8 = 1560.5$ nm and $\lambda_9 = 1561.1$ nm respectively, as shown in Fig. 10. Two pulses with the new frequencies from the WDM de-multiplexer are coupled into a SOA to induce the 2nd order FWM effect after a certain amplification processing. Two of the new frequencies are generated, whose wavelengths are $\lambda_3 = 1552.5$ nm and $\lambda_9 = 1561.1$ nm respectively, as shown in Fig. 11. Two of the new frequencies (λ_5 and λ_7) are also extracted by the WDM de-multiplexer, whose powers are -9.76 dBm, -9.96 dBm, and -9.98 dBm, -10.94 dBm respectively, as shown in Fig. 12(a) and (b) for the case 1 of Fig. 6 with 2 ns, in Fig. 12(c) and (d) for the case 2 of Fig. 6 with 0.5 ns. Two of the new pulses are considered as two 2D-OOCs identification signals of the optical label, and different frequencies can represent different 2D-OOCs. Finally, any one of two frequencies is extracted as the recognition signal of the optical label by a WDM de-multiplexer, the corresponding wavelength λ_9 is 1561.1 nm and its associated waveform is shown in Fig. 13(a) for the case 1 of Fig. 6 with 2 ns, and in Fig. 13(b) for the case 2 of Fig. 6 with 0.5 ns respectively.

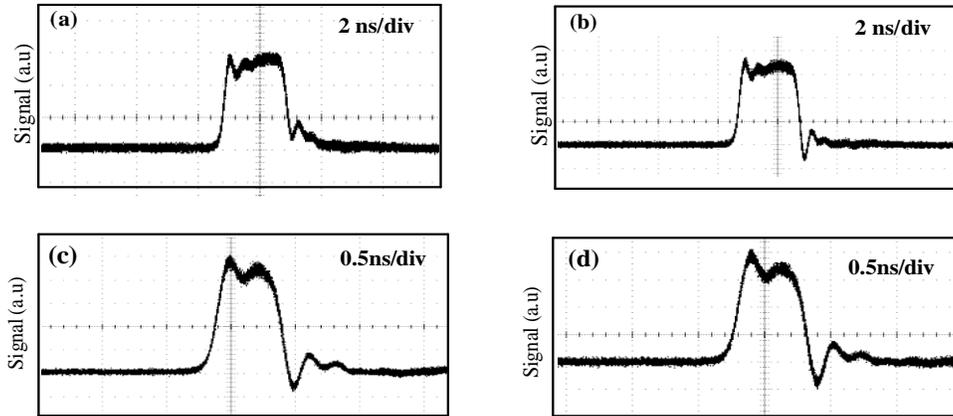


Fig. 12. The waveforms, (a) the waveform of the new wavelength λ_5 with 2 ns for 1 # part of Fig. 6, (b) the waveform of the new wavelength λ_7 with 2 ns for 1 # part of Fig. 6, (c) the waveform of the new wavelength λ_5 with 0.5 ns for 2 # part of Fig. 6, (d) the waveform of the new wavelength λ_7 with 0.5 ns for 2 # part of Fig. 6.

The WDM de-multiplexer replaces the filter and its bandwidth is of 1.6 nm. The result of the experiment is not very ideal because of such wide bandwidth. Figure 13(a) shows the waveform of the new wavelength λ_9 with 2 ns for case 1 # of Fig. 6, but the amplitude of noise and the fluctuating are relatively large because of the bandwidth and optical en/decoders influence. Moreover, the amplitude of noise is very large because of the wide bandwidth, as shown in Fig. 13(b) for the case with 0.5 ns. The pulse from the WDM de-multiplexer contains a large number of other frequencies resulting in relatively large magnitude in noise because of beat frequency. In the experiment, there are two issues that undermine occurrence of FWM by the influence of the pulse (including multiple wavelengths): the polarization of the pulse which can be controlled by adjusting the polarization controller and the extinction ratio of the pulse before inputting into the SOA. The pulse transmits through the WDM de-multiplexer to reduce noise, thereby the extinction ratio is increased, and a high extinction ratio of the pulse is obtained with about 22 dB. In Fig. 10, the effect of the FWM is very well mainly because the pulse has a relatively high extinction and the noise power is also very small. As a result, the integral of the power spectrum is power of the pulse. In Fig. 11, the pulse width is relatively large due to the bandwidth of WDM de-multiplexer, so that the spectral of the pulse is widened. The experimental results are partly affected to some extent because of the experimental conditions, but the results are quite obvious and the feasibility of the method is validated successfully by experimental demonstration.

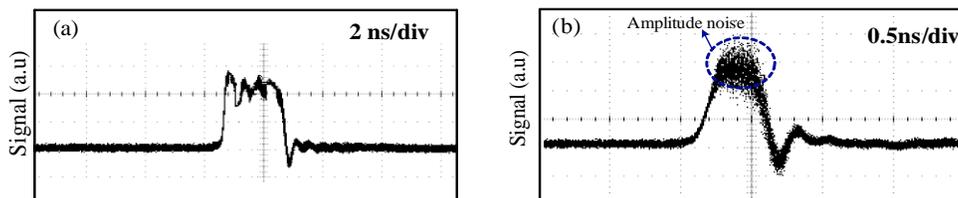


Fig. 13. The waveforms, (a) the new wavelength λ_9 with 2 ns for 1 # of Fig. 6, (b) with 0.5 ns for 2 # of Fig. 6.

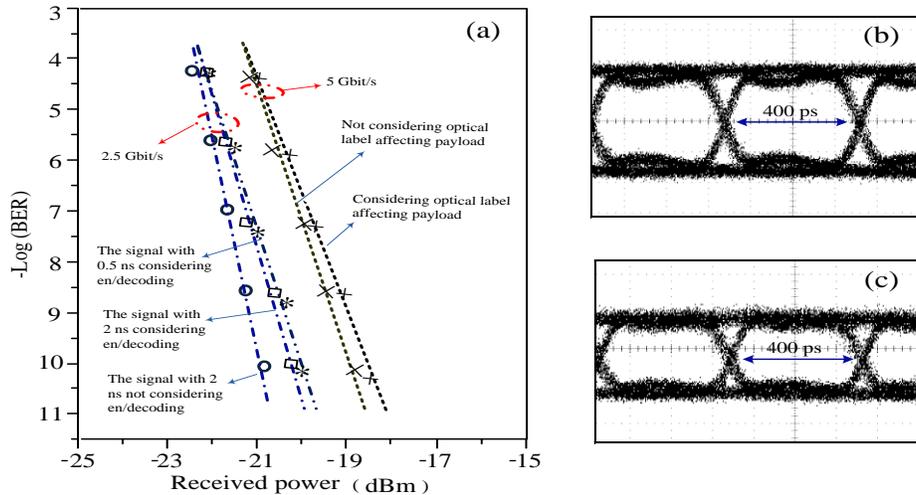


Fig. 14. BER versus the received power of the payloads with the double 2D-OOCs-based optical label for an OPS system with 2.5 Gbit/s and 5.0 Gbit/s for different cases in (a), eye diagrams for any two cases in (b) and (c).

Bit error rate (BER) and eye diagrams performances of the payloads in double 2D-OOCs-based optical label optical packet for OPS were measured with 2.5 and 5.0 Gbit/s payloads for different cases in this system, as shown in Figs. 14(a), (b) and (c) respectively. We assume that the autocorrelation of the double 2D-OOCs-based optical label is the ideal single pulse from a single pulse generator unit with 0.5 ns, as shown in the 2 # of Fig. 6, which is just expressed as considering the effect of optical decoding on 2.5 Gbit/s payloads, as case 1. The results of case 1 are expressed with “*” of the left of Fig. 14(a). The performance ($\text{BER} = 10\text{E}-9$) was obtained when the receiving power is -19.9 dBm. The autocorrelations of the 2D-OOCs-based optical label are obtained by the optical FBGs-based decoders with 2 ns, as shown in the 1 # of Fig. 6, which are expressed as with/without considering the effect of optical encoding on 2.5 Gbit/s payloads, as case 2 and 3. The results of case 2 and 3 are shown with “□” and “○” of the left of Fig. 14(a), the eye diagrams were obtained at a received power of -20.6 dBm and -21.2 dBm for case 2 and 3, as shown in Figs. 14(b) and (c) respectively. We can find that, at a BER of $10\text{E}-9$, the performance has a low penalty of about 0.4 dB and 0.9 dB between that of case 1 and 2, 3 respectively. These results indicate that the narrow pulse over the fiber transmission would generate partly dispersion effect, and the optical en/decoders would induce the amplitude noise and the cross-correlation, which affect the performance of the double 2D-OOCs-based optical label OPS system. The autocorrelations of the double 2D-OOCs-based optical label are obtained by the optical FBGs-based decoders with 2 ns, as shown in the 1 # of Fig. 6, which are expressed as without / with considering the effect of optical label on 5 Gbit/s payloads, as case 4 and 5. The results of case 4 and 5 are shown with “×” and “+” of the left of Fig. 14. Similarly, at a BER of $10\text{E}-9$, the performance has a low penalty of about 0.6 dB between that of case 4 and 5.

4. Conclusion

In this paper, a new method of the optical label generation has been proposed by the double 2D-OOCs in time and frequency field, which can be applied for an OPS system. And a novel method of the all-optical label recognition has been proposed and demonstrated experimentally by the FBGs-based optical decoder and SOA. The feasibility of the methods of the double 2D-OOCs-based optical label has been validated by the experimental demonstration in terms of three wavelengths, two optical codes with code length of 19 and code weight of 3 and the autocorrelation peak width of 2 ns. Additionally the input single pulse with 0.5 ns has been also studied, which has indicated the proposed method of optical

label recognition is also feasible for shorter period of the 2D-OOCs-based optical label. On the condition of same code length and code weight, this scheme greatly increases the capacity of codes and the number of available labels, compared with the conventional methods and effectively reduces the code auto-/cross-correlation requirements of optical label identification which makes the design of the 2D-OOC code easier.

Acknowledgments

This work is supported partly by the Science Foundation of China under Contract No. 60807028, the Fundamental Research Funds for the Central Universities under Contract No. E022050205 and the Fundamental Research Funds for Youth Project under Contract No. JX0801. The authors would like to thank Dr. B. Xu, Dr. Y. Ling, Dr. X. W. Yi, and Mr. X. Lu from UESTC for their inspiring discussion and help, and anonymous reviewers for valuable comments that improve the clarity and quality of this paper.