

Improved optical coding method for orthogonal ASK/DPSK modulation format

Xue WANG, Zhixue HE, Hongxing LIU, Hong LIU, Wei LI, Dexiu HUANG, Nan CHI (✉)

Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, China

© Higher Education Press and Springer-Verlag 2008

Abstract Orthogonal ASK/DPSK labeling, which encodes label information on optical carriers in a modulation format, is regarded as a competing scheme to sub-carrier multiplexed optical labeling. However, the inherent cross-talk limits the extinction ratio (ER) of the payload and label sensitivity. In this paper, two optical coding methods—Manchester coding and 8B10B coding—which can remarkably improve the system quality to obtain acceptable ER are discussed. A novel optical packet encoding method—mark-insertion coding—is demonstrated to significantly reduce cross-talk between the amplitude shift keying (ASK) payload and the differential phase shift keying (DPSK) label through spectrum shaping. The performance of mark-insertion coding depends on the number of inserted ‘marks’. Finally, the transmission over a 40 km single mode fiber (SMF) is compared with optical label swapping for a 40 Gbit/s ASK payload and 2.5 Gbit/s DPSK label under these coding schemes. The experimental result is consistent with the theoretical analysis.

Keywords orthogonal modulation, amplitude shift keying (ASK), differential phase shift keying (DPSK), mark-insertion coding

1 Introduction

Orthogonal modulation techniques, which can improve processing ability in the switching node, have been proposed as efficient labeling schemes in all-optical label switching [1]. Several approaches have been studied for labeling optical packets, including serial-bit labeling [2] and sub-carrier multiplexing [3,4]. Simultaneously exploiting two dimensions of the light field, such as the intensity and the phase or frequency, has been suggested to modulate both payload and label on the same optical

carrier [5]. Such an “orthogonal modulation” labeling method is currently gaining more interest [6]. The modulation formats explored in optical packet switching could be amplitude shift keying (ASK), differential phase shift keying (DPSK), frequency shift keying (FSK) or polarization shift keying (PolSK). Recent experiments [5,6] show that at 40 Gbit/s, the DPSK and PolSK modulation formats are promising techniques to overcome nonlinear impairments and to extend the transmission distance [7].

The orthogonal modulation encodes label information on the optical carrier of the payload. One example is orthogonal ASK/DPSK labeling, which means that the payload is modulated on the amplitude and the label is achieved by modulating the phase of the optical carrier [8–11]. In previous demonstrations [9–11], orthogonal ASK/DPSK labeling revealed its superiorities in having a compact spectrum, simple label swapping and remarkable scalability. However, to satisfy DPSK detection, the inherent cross-talk between the two modulations leads to a limitation in system performance. This results in the deteriorating extinction ratio (ER) of the ASK [11], which significantly confines network scalability. Thus, it is necessary to seek effective methods to reduce modulation cross-talk and provide the proper DPSK detection with preferable ER of ASK.

Applying special coding on the ASK payload can alleviate the ER requirement. These methods are basically divided into two kinds: according to the principle focused on the basis of spectrum shaping and that of the time domain [12–15]. In this paper, these two schemes are compared in terms of system performance. A novel coding method based on the inserted ‘mark’, namely mark-insertion coding, is put forward. The principle of each modulation is proposed and the comparison of different coding methods is also given.

2 Principle

When changing the payload and label bit rate, the required ASK/DPSK labeled signal on the ER can be

obtained according to the analysis of transition theory. Figure 1 shows the configuration of the transmitter and receiver of the ASK/DPSK labeling scheme. The laser source is intensity-modulated to generate the ASK payload. The DPSK label is impressed by the subsequent phase modulator driven by the electrical pre-coded label signal. For the receiver, the labeled signal is split by using a 3 dB optical coupler. The output of one arm is directly detected by a photodiode, thus the optical payload is converted into the electrical domain. For the second output of the coupler, the DPSK label is either directly detected by a Mach-Zehnder delay interferometer (MZDI), which is followed by a photodiode connected to one of the output ports and forms a single-ended receiver, or by a dual detector connected to both output ports that implement a balanced receiver as shown in Fig. 1.

The performance limitation of ASK/DPSK labeling stems from the cross-talk between the two modulation formats that is induced by the simultaneous amplitude and phase modulation on the same optical carrier [1]. Since the sensitivity of the DPSK signal would be deteriorated with an increasing value of ER due to the reduced signal power when an ASK ‘0’ is transmitted, a limited value of ER has to be applied for the payload [10]. In the frequency domain, the cross-talk between the payload and label is generated by the overlap of the payload spectrum with the label spectrum. Because the label bit rate is much lower than the payload bit rate due to the limited control information and the required compatibility with low cost electronics for label processing, the label signal is a narrow-band signal. If the payload spectrum is shaped to have a null at direct current (DC), the cross-talk will be suppressed significantly as shown in Fig. 2. Several line coding techniques can generate a DC-null spectrum, including Manchester-coding [12] and 8B10B coding [13].

Besides spectrum reshaping, a new coding scheme realized in the time domain is proposed to eliminate limitation to the ER, hereafter referred to as mark-insertion coding. This coding method, interleaved DPSK label, is better understood on the basis of time domain. The principle of this method is depicted in Fig. 3. Assuming that the DPSK bit rate is N times lower than the payload bit rate, m bit of ‘marks’ are inserted for every $N+m$ bit-stream of the payload with equal time spacing. The demodulated DPSK data can then be achieved over these inserted ‘marks’. In the conventional interleaved DPSK label scheme, 2 bit of ‘marks’ are added within one label period. These two mark bits have to be precisely located at the rising and trailing edge of the label period. Therefore, the payload and label alignment is constrained to bit-level synchronization. In our new scheme, the DPSK label can be detected under a time slot and synchronized coarsely with the payload, totally eliminating the need for bit-level synchronization. Mark-insertion coding ensures the DPSK demodulation even when continuous zeros of the payloads are transmitted, and the requirement on the ER is thereby alleviated.

3 Experiment set-up

In this section, 8B10B coding and mark-insertion coding are both proposed, as they can alleviate the inherent cross-talk between the payload and label.

3.1 8B10B coding

8B10B coding, which owes its popularity to the Ethernet environment, has a relatively high bandwidth efficiency of 80%. It compounds 8 bit code into 10 bit code, including

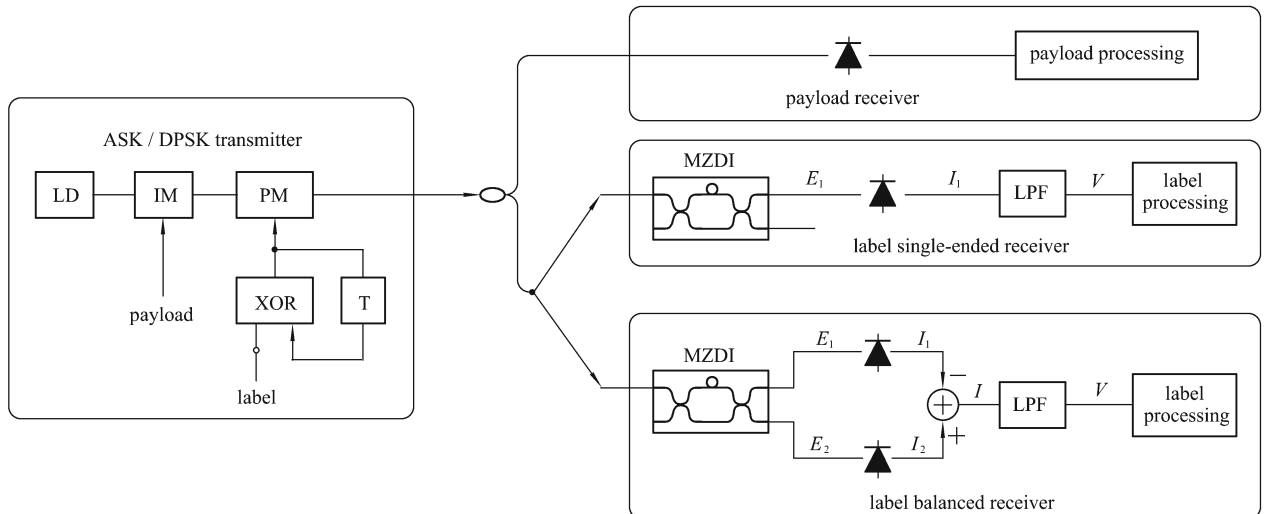


Fig. 1 Configuration of optical ASK/DPSK transmitter and receiver (LD: laser diode; IM: intensity modulator; PM: phase modulator; MZDI: Mach-Zehnder delay interferometer; LPF: low-pass filter; XOR: exclusive OR; T: time required for 1 bit transmission)

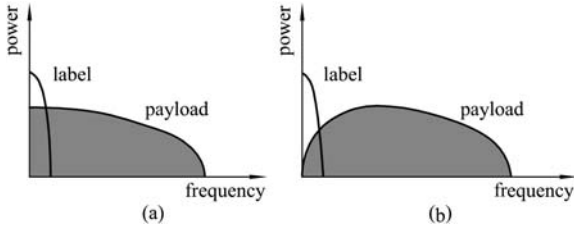


Fig. 2 Principle of spectrum reshaping scheme. (a) Randomly coded payload; (b) DC-null coded payload

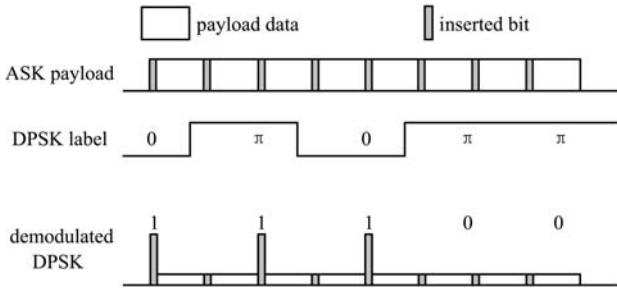


Fig. 3 Principle of mark-insertion coding for ASK/DPSK labeling

256 data character codes and 12 control character codes. The coding on different plans can achieve various optimum system performances. Its application in an optical link to ASK/DPSK labeling is shown in Fig. 4. The signal source is a wavelength-tunable external cavity laser (ECL) working at 1550 nm. The 2.5 Gbit/s DPSK signal, pseudo-random binary sequence (PRBS) $2^{23}-1$, is impressed through a phase modulator. Since the test signal is a PRBS pattern, the pre-coder circuit for the DPSK format is not applied. Two push-pull type Mach-Zehnder modulators (MZM) are used to generate the return-zero (RZ) payloads at 40 Gbit/s. 8B10B coding is directly generated by encoding a 2^7-1 PRBS by programming the data pattern generator, which corresponds to a periodical data pattern of 160 bit. In this way, an optical ASK/DPSK signal comes out.

3.2 Mark-insertion coding

The set-up of the ASK/DPSK labeling and transmission is shown in Fig. 5. Similar to Fig. 4, the ECL works at 1550 nm to produce a proper tunable laser. The 2.5 Gbit/s or 622 Mbit/s DPSK signal (PRBS $2^{15}-1$) is impressed through a phase modulator. A subsequent MZM is driven by a 40 or 10 Gbit/s coded data-stream. One mark is inserted for every 15 bits of payload; every label bit time has one inserted ‘mark’ for a label at 2.5 Gbit/s and 4 ‘marks’ for a label at 622 Mbit/s. After transmission through a 40 km spool of standard single mode fiber (SMF) and a matching 6 km spool of dispersion compensating fiber (DCF), the labeled signal arrives at the receiver, split by a 3 dB optical coupler. The output of one arm is directly detected by a photodiode so as to convert the optical payload into the electrical domain. For the other output of the coupler, the DPSK label is directly detected by an MZDI, followed by a photodiode connected to one of the output ports and forming a single-ended receiver. The MZDI has a delay of approximately 8 cm corresponding to 1-bit duration (400 ps) of the DPSK signal at 2.5 Gbit/s. A 1.8 GHz electrical low-pass filter (LPF) is used to suppress high frequency noise.

4 Experimental results

In the 8B10B coding scheme, Fig. 6 clearly shows a trade-off between the ER requirements on payload and label with nearly 7 dB ER when the payload is a 2^7-1 PRBS. Due to the increased length of the continuous ‘marks’ and ‘spaces’, the optimum value can be greatly decreased when a longer PRBS sequence is used for the payload. When the payload is coded by a PRBS 2^7-1 sequence, the ER of the payload can exceed 8.6 dB, and the desirable DPSK label detection cannot be obtained. However, for the 8B10B coded signal, acceptable ER as high as 12 dB can be

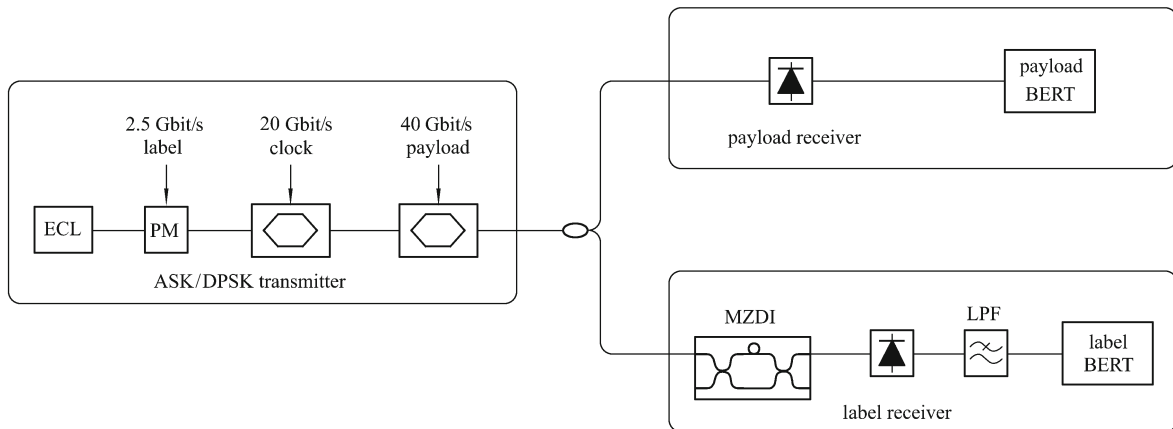


Fig. 4 Configuration of 8B10B coding labeling on optical ASK/DPSK transmitter and receiver (ECL: external cavity laser; PM: phase modulator; MZDI: Mach-Zehnder delay interferometer; LPF: low-pass filter; BERT: bit-error ratio test set)

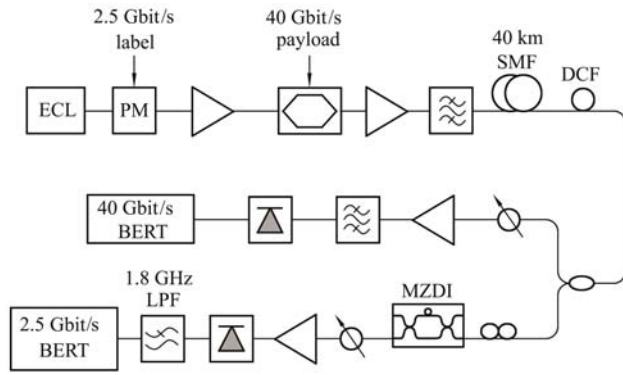


Fig. 5 Configuration of optical ASK/DPSK transmitter and receiver in mark-insertion labeling (ECL: external cavity laser; PM: phase modulator; DCF: dispersion compensating fiber; MZDI: Mach-Zehnder delay interferometer; LPF: low-pass filter; SMF: single mode fiber)

achieved. This results in a 15 dB enhancement of the label sensitivity compared to the PRBS case, as well as an improvement of 3.5 dB for the payload. Hence, the limitation on the ER is overcome by employing 8B10B coding to the payload, and the system performance is significantly improved.

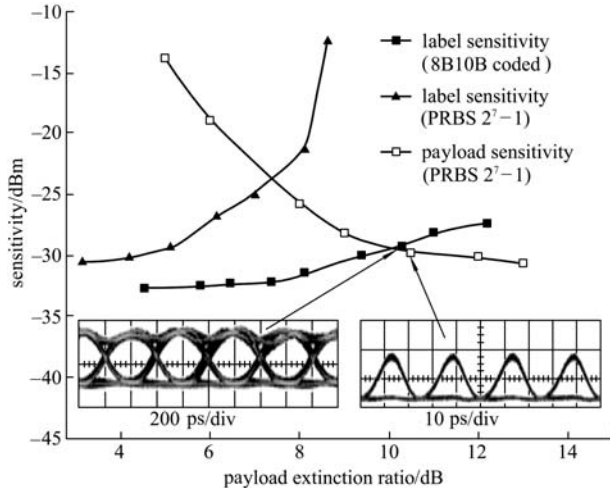


Fig. 6 8B10B coding: measured receiver sensitivity for payload and label vs input ER of payload (the insets show eye diagrams of the 40 Gbit/s RZ payload and the demodulated 2.5 Gbit/s DPSK label for an 8B10B encoded payload with 10.3 dB ER)

For mark-insertion coding, Fig. 7 shows the relationship between the measured receiver sensitivities of the 40 Gbit/s payload and the label. The received eye-diagrams of the DPSK label are shown in Fig. 8 for a label at 2.5 Gbit/s. As expected, a good trade-off is observed between the sensitivity of the payload which degrades while that of the label enhances. For a payload coded with a 2^7-1 PRBS sequence, an optimum value of 7 dB ER is obtained, with which the payload and label have the same sensitivity. It should be noted that this optimum value can

be greatly decreased when a longer PRBS sequence is used for the payload due to the increased length of the continuous ‘marks’ and ‘spaces’. Additionally, this optimum value can be enhanced to more than 9 dB when mark-insertion coding is applied to the payload. For the DPSK label at 2.5 Gbit/s, the optimum ER value is around 9 dB, and enhancement on the payload and label sensitivity is about 6 dB.

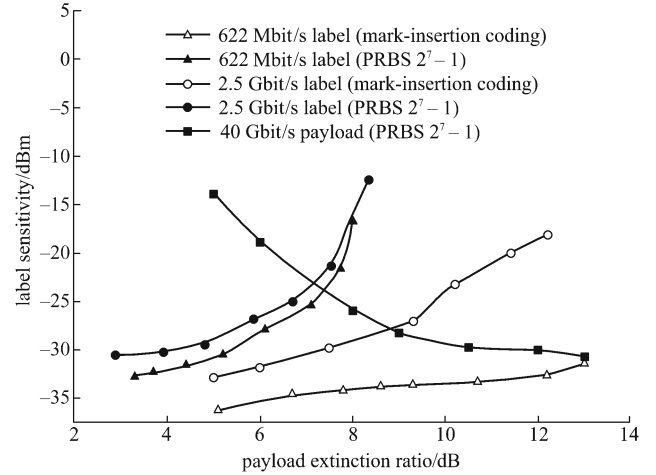


Fig. 7 Mark-insertion coding: measured receiver sensitivity for the payload at 40 Gbit/s and label vs input ER of the payload

The system performances of 8B10B coding and the proposed mark-insertion coding are evaluated back-to-back for the ASK/DPSK signal consisting of a payload at 40 Gbit/s and a label at 2.5 Gbit/s. 8B10B coding is directly generated by encoding a 2^7-1 PRBS. This is done by programming the data pattern generator corresponding to a periodical data pattern of 160 bit. For mark-insertion coding, one mark is inserted for every 15 bits of payload. Every label bit time has one inserted ‘mark’ for a label at 2.5 Gbit/s, and 4 ‘marks’ for a label at 622 Mbit/s. The DPSK demodulator has a delay of 8 cm corresponding to 400 ps. The label bit sequence is a $2^{23}-1$ PRBS.

Comparing Fig. 7 with Fig. 8, it is clear that for the 8B10B coded signal, the ER can rise from 7 to 10.3 dB, and the improvement of 3.3 dB for the payload results in an enhancement of the label sensitivity around 8 dB. In the mark-insertion coding scheme, the ER of the payload is improved from 7 dB to more than 9 dB and the label sensitivity enhancement exceeds 6 dB. Figure 9 clearly demonstrates that the 8B10B scheme achieves a better system performance compared to the mark-insertion coding method. According to the results above, it can be concluded that under the condition of 40 Gbit/s payload and different coded label, poor label information can be well added and transmitted through distant routes in mark-insertion coding packets. Among these two coding methods, 8B10B scheme offers the largest ER of payload and the best enhancement of the label sensitivity of transmission link.

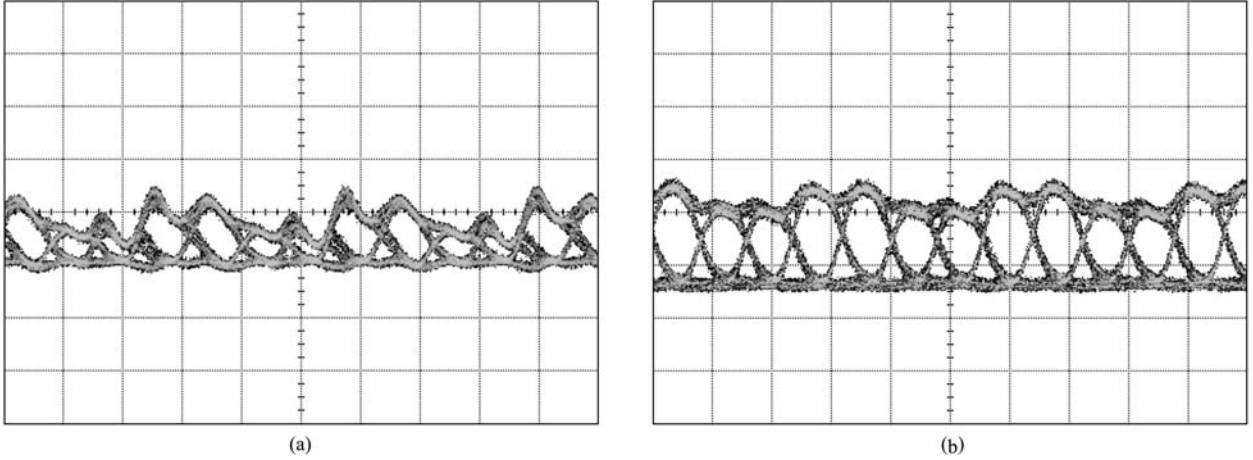


Fig. 8 Mark-insertion coding with received DPSK label at 2.5 Gbit/s and 500 ps/div. (a) ER = 12 dB; (b) ER = 5 dB

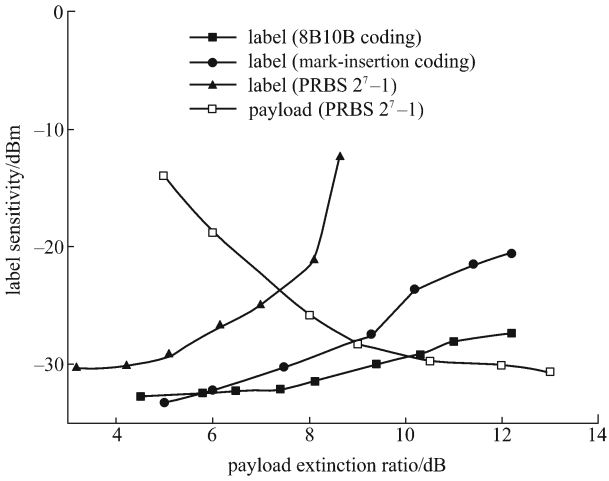


Fig. 9 8B10B and mark-insertion coding: measured receiver sensitivity for the payload and label vs input ER of the payload

In consideration of bandwidth efficiency, it can be seen that 8B10B coding has a relatively high bandwidth efficiency of 80% and therefore has its popularity in the Ethernet environment. In mark-insertion coding, m bit of ‘marks’ are inserted for every $N+m$ bit-stream of the payload. The DPSK label can be coarsely synchronized with the payload; the delay of the label demodulator is equal to $1/m$ times of the label bit-duration. Since $1/m < 1$, the delay of the demodulator is reduced, and a more stable and practical DPSK demodulator can be realized. The payload bandwidth efficiency of this scheme is given by $N/(N+m)$. The bandwidth efficiency as a function of the label bit rate and m is illustrated by Fig. 10. For instance, if one 1-bit ‘mark’ is inserted for every 15 bit of the payload, the coded payload is 40 Gbit/s ASK and the label is 2.5 Gbit/s DPSK. The bandwidth efficiency of the payload would then be 93.75%. For an ASK payload at 40 Gbit/s and DPSK label at 2.5 Gbit/s, mark-insertion coding can outperform 8B10B coding by means of the bandwidth efficiency when m is less than 4.

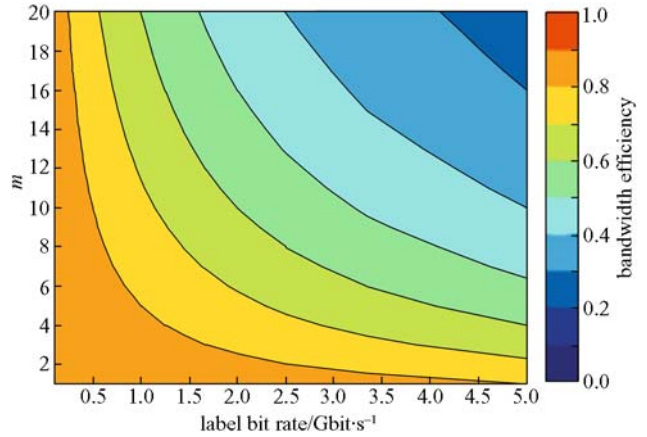


Fig. 10 Bandwidth efficiency as a function of label bit rates and number of inserted marks

5 Conclusions

In conclusion, the performance of ASK/DPSK labeling requires the ER of the payload to be limited to allow detection of the ASK/DPSK signal. To increase the ER of the payload while simultaneously ensuring DPSK reception, two kinds of coding methods have been presented: 8B10B coding and mark-insertion coding. By employing these two coding schemes on a 40 Gbit/s ASK payload and a 2.5 Gbit/s DPSK label, the acceptable ER can be increased up to more than 9 dB, which results in a significant enhancement exceeding 6 dB in label sensitivity. It is also found that the performance improvement of the mark-insertion coding depends on the number of the inserted ‘marks’.

Acknowledgements This work was supported by the Hi-Tech Research and Development Program of China (No. 2007AA01Z260), National Natural Science Foundation of China (Grant No. 60777010) and Program for New Century Excellent Talents.

References

1. Koonen T, Sulur, Monroy I T, et al. Optical labeling of packets in IP-over-WDM networks. In: Proceedings of the 28th European Conference on Optical Communication (ECOC'02), Copenhagen. 2002, 2: 10.1109/ECOC.2002.204491
2. Takada A, Park J H. Architecture of ultrafast optical packet switching ring network. *Journal of Lightwave Technology*, 2002, 20(12): 2306–2315
3. Blumenthal D J, Olsson B, Rossi G, et al. All-optical label swapping networks and technologies. *Journal of Lightwave Technology*, 2000, 18(12): 2058–075
4. Blumenthal D J, Carena A, Rau L, et al. All-optical label swapping with wavelength conversion for WDM-IP networks with subcarrier multiplexed addressing. *IEEE Photonics Technology Letters*, 1999, 11(11): 1497–1499
5. Hickey M, Barry C, Noronha C, et al. Experimental PSK/ASK transceiver for the STARNET WDM computer communication network. *IEEE Photonics Technology Letters*, 1993, 5(5): 568–571
6. Koonen T, Morthier G, Jennen J, et al. Optical packet routing in IP-over-WDM networks deploying two-level optical labeling. In: Proceedings of the 27th European Conference on Optical Communication (ECOC'01), Amsterdam. 2001, 4: 608–609
7. Xu L, Chi N, Oxenløwe L K, et al. A new orthogonal labeling scheme based on a 40-Gb/s DPSK payload and a 2.5-Gb/s PolSK label. *IEEE Photonics Technology Letters*, 2005, 17(12), 2772–2774
8. Xu L, Chi N, Oxenløwe L K, et al. Optical label encoding using electroabsorption modulators and investigation of chirp properties. *Journal of Lightwave Technology*, 2003, 21(8): 1763–1769
9. Chi N, Carlsson B, Holm-Nielsen P V, et al. Dispersion management for two-level optically labeled signals in IP-over-WDM networks. In: Proceedings of the 28th European Conference on Optical Communication (ECOC'02), Copenhagen. 2002, 2: 10.1109/ECOC.2002.204490
10. Chi N, Carlsson B, Zhang J F, et al. Transmission performance of all-optically labelled packets using ASK/DPSK orthogonal modulation. In: Proceedings of the 15th Annual Meeting of the IEEE Lasers and Electro-Optics Society (LEOS'02), Glasgow. 2002, 1: 51–52
11. Chi N, Zhang J F, Holm-Nielsen P V, et al. Transmission and transparent wavelength conversion of an optically labelled signal using ASK/DPSK orthogonal modulation. *IEEE Photonics Technology Letters*, 2003, 15(5): 760–762
12. Ho M C, Lu C L, Hofmeister R T, et al. Nonlinear cross-talk reduction by spectrum shaping in subcarrier signaling WDM networks. In: Proceedings of Conference on Lasers and Electro-Optics (CLEO'98), San Francisco. 1998, 29–30
13. Zhang J F, Holm-Nielsen P V, Chi N, et al. DC-balanced line encoding for optical labeling scheme using orthogonal modulation. In: Proceedings of Optical Fiber Conference (OFC'04), Los Angeles. 2004, 1: 23–27
14. Lin Y, Yuang M C, Lee S, et al. Using superimposed ASK label in a 10-Gb/s multihop all-optical label swapping system. *Journal of Lightwave Technology*, 2004, 22(2): 351–361
15. Hung W, Chan C, Chen L. A novel optical packet labeling scheme using interleaved low-speed DPSK labels. *IEEE Photonics Technology Letters*, 2004, 16(2): 698–700