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DC-balanced line encoding for optical labeling scheme using orthogonal modulation

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Abstract: It is shown both theoretically and experimentally that 8B/10B encoding is an efficient technique to mitigate the inherent modulation crosstalk in optical labeling scheme using orthogonal modulation.

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1. Introduction

An orthogonal modulation method, differential-phase-shift-keying/intensity modulation (DPSK/IM) or frequency-shift-keying/intensity modulation (FSK/IM), has been proposed and demonstrated as an efficient labeling scheme to implement optical label switching [1]-[2]. However, proper detection of the DPSK or FSK label usually requires the IM extinction ratio to be reduced [3], which results in a poor payload sensitivity and degraded transmission performance.

It has been shown that a DC-balanced encoding of the payload, Manchester encoding, can effectively improve the modulation performance of the optical labeling scheme using orthogonal modulation [4]. However, Manchester code has a poor coding efficiency since it doubles the bandwidth requirements on the payload transmitter/receiver.

8B/10B is another kind of DC-balanced code, which specifies no more than 4 sequential identical bits and a running disparity less than +/-1 across data words of 10 bits [5]. Compared with the 100% extra bandwidth for the Manchester code, it only requires an extra 25%, thus having higher bandwidth efficiency. 8B/10B encoding is widely employed in Gigabit Ethernet (1.25 Gb/s), Fiber channel (1.06 Gb/s) and other high-speed networks. In addition, the generation of 10 Gb/s 8B/10B code has been demonstrated through the proper configuration of an electrical multiplexer [6]. In this paper, we investigate the possibility of applying 8B/10B encoding to the orthogonal optical labeling scheme. The performance of a 8B/10B-encoded payload in optical labeling is theoretically analyzed and compared with Manchester- and NRZ-encoded payloads. It is shown that 8B/10B encoding can also effectively improve the label receiving performance if the label bit-rate is limited below certain values. In the experiment, 8B/10B encoding is applied to an optical FSK labeled signal transmission link consisting of a 10 Gb/s IM payload and a 156 Mb/s FSK label. A good modulation performance is achieved.

2. Theoretical Analysis

In an orthogonal modulation scheme, the power spectral density (PSD) of the optical intensity of the demodulated label is given by [7]

$$S(\omega) \propto \left[\delta(\omega) + n^2 L_p(\omega) + m^2 P_p(\omega) + m^2 n^2 L_p(\omega) \otimes P_p(\omega) \right] \quad (1)$$

where m and n represent the intensity modulation depth of the optical payload and demodulated optical label respectively while $L_p(\omega)$ and $P_p(\omega)$ represent the PSD of the label and the payload information respectively. As indicated by equation (1), the IM payload induces two crosstalk components that stem from spectral overlap with the label, hence degrading the label receiving performance.

A signal to noise ratio (SNR) is defined to evaluate the modulation crosstalk according to,

$$SNR = \frac{\int_0^{\omega_c} L_p(\omega) d\omega}{m^2 \int_0^{\omega_c} \left[\left(\frac{1}{n}\right)^2 P_p(\omega) + L_p(\omega) \otimes P_p(\omega) \right] d\omega} \quad (2)$$

where ω_c is the effective bandwidth of the label electrical receiver.

By inserting $P(\omega)$ for the power spectra of the NRZ (unencoded), Manchester and 8B/10B code, we can calculate the label SNR value in the above cases. In the calculations, the label is assumed to have a typical NRZ spectrum, and the optical label demodulator is assumed to operate in an ideal condition, thus n has a value of 1.0.

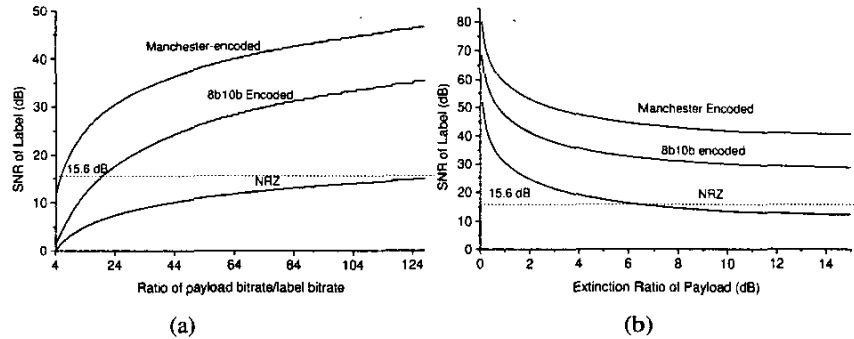


Fig. 1 SNR performance of label in the presence of NRZ/Manchester/8B/10B payloads

As Fig. 1(a) shows, a SNR improvement of the received label can be achieved if Manchester or 8B/10B encoding is applied. Such a SNR improvement will be greatly enhanced at lower label rates. In 8B/10B case, the label bit-rate should be lower than 1/20 of the payload bit-rate to achieve an acceptable SNR value of 15.6 dB (corresponding to Q factor of 6.0). Then, by setting the ratio of payload bit-rate to label bit-rate to be 64, we calculate the relation between label SNR and payload extinction ratio (ER). As Fig. 1(b) shows, the label SNR is strongly degraded by a high-ER of the NRZ-payload. Thus the ER has to be kept below 7 dB to ensure acceptable label detection. On the other hand, through 8B/10B encoding, the label SNR is improved more than 15 dB, hence overcoming the limitations on ER. As Manchester encoding can suppress more low frequency contents, it has an even better performance than 8B/10B, as indicated in both figures. However, considering the coding efficiency, 8B/10B is a more suitable scheme when a stringent bandwidth efficiency requirement is imposed on the labeled signal transmission link.

3. Experimental Setup and Results

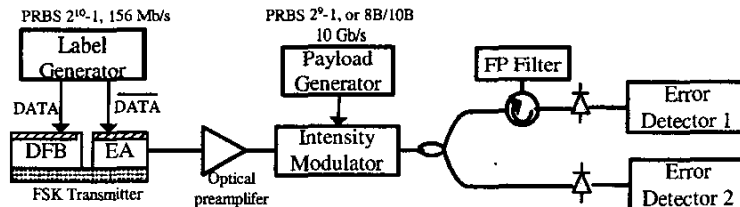


Fig. 2 Experimental setup of an optical FSK labeled signal transmission link

In order to verify the performance of 8B/10B encoding when it is applied to the optical labeling scheme using orthogonal modulation, we have experimentally set up an optical link shown in Fig. 2.

Two pseudo-random-bit-sequence (PRBS) data pattern generators were used to generate the payload and label information. A directly modulated DFB laser integrated with an electro-absorption (EA) modulator performed the optical FSK modulation. The FSK tone spacing was set to be 20 GHz, and the label bit-rate was set to be 156 Mb/s. The payload information is then added through an intensity modulator operating at 10 Gb/s. At the receiver node, the labeled signal was split using a 3 dB coupler. The signal in one arm was directly detected and input into the payload receiver. In the other arm, a Fabry-Perot (FP) filter with 20 GHz full-width half-maximum (FWHM) bandwidth was used to achieve the FSK demodulation. The demodulated label was then received by an electrical receiver with 600 MHz bandwidth.

The 8B/10B code is directly generated through encoding a PRBS 2^9-1 by programming the data pattern generator, corresponding to a periodical data pattern of 1280 bits. As shown in Fig. 3(a), the low frequency components of the payload spectrum below 100 MHz are greatly suppressed through 8B/10B encoding. Thus with

8B/10B encoding, much less interference noise from the IM payload is observed in the electrical spectrum of the demodulated label, shown in Fig. 3(b).

Fig. 4 shows the relation between the label receiver sensitivity and the ER of payload. Through 8B/10B encoding, the degradation of the label receiver sensitivity with the increased ER is limited to a certain range. The insets show the eye-diagrams of the received label when the IM payload ER is equal to 10 dB, which further verify the performance improvement in the presence of 8B/10B encoding.

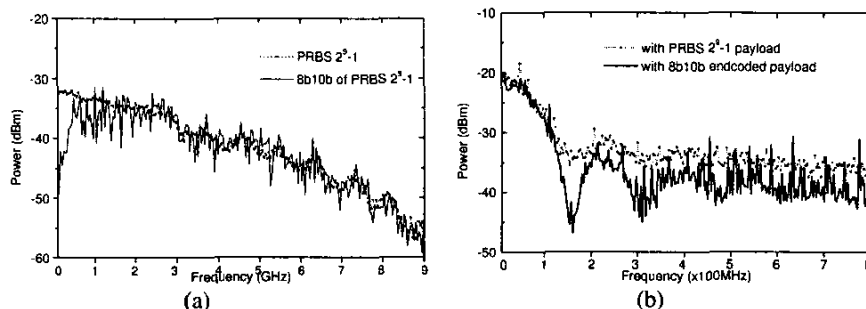


Fig. 3 (a) Power spectra of PRBS- and 8B/10B-encoded payloads (b) Power spectra of demodulated labels in the presence of PRBS and 8B/10B payloads

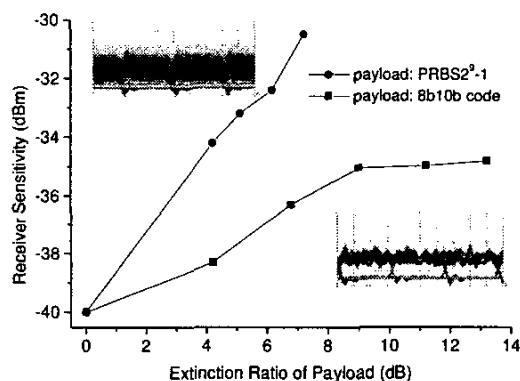


Fig 4. Label receiver sensitivity versus IM ER in the presence of PRBS and 8B/10B payloads

4. Conclusions

It is shown that 8B/10B encoding of the payload can effectively improve the optical labeling performance if the label bit-rate is limited below certain values. In the experiment, 8B/10B encoding is applied to an optical FSK labeled 10 Gb/s signal transmission link. A good modulation performance is achieved.

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