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40 Gb/s CSRZFSK signal generation and transmission labeled with ASK in optical packet networks

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ABSTRACT

We proposed and investigated superimposing intensity-modulated labels onto high-speed carrier-suppressed return-to-zero frequency shift keying-modulated payloads in optical label-switching packet networks. The transmission performances of 2.5 Gb/s ASK label on 40 Gb/s CSRZFSK payload is studied for the first time.

1. Introduction

Optical label switching (OLS) is an attractive approach to support low-latency and efficient packet routing for existing high-speed optical packet networks. One of the key issues of this approach is the method of coding the optical label onto the packet, as it not only directly determines the structure and the performance of the optical core router but also strongly related to the channel bandwidth efficiency and the transmission quality of the packet and label [1]. In-band signaling is one of promising techniques in terms of spectral efficiency where payload and label can share their bandwidth. To extract label from payload in identical bandwidth, setting orthogonal modulation formats between label and payload is one solution [2].

A combination of intensity modulation (IM) and frequency shift keying (FSK) is a promising technique for its desirable constant intensity characteristics and the comparable or even superior transmission performance as compared to the OOK format for optical label switching in optical packet systems. In previous technique, payload signals are in IM format, while label information is written by FSK signal. The merit of this FSK labeling is that an FSK transmitter generates the label information on the optical carrier frequency without affecting its intensity; however, the FSK label is generated by direct modulation of electric current in a laser light source, so the FSK bit rate is limited by the response of the laser. Moreover, a frequency discriminator and a tunable light source must be used to demodulate the old FSK label and generate a new one for the next hop at each core router, which may result in a great increase of the system complexity and cost [3–5]. Recently, a method was proposed by using an optical FSK modulator consisting of a pair of Mach–Zehnder structures, which is based on optical single sideband (SSB) modulation technique [6,7], another scheme, which utilizes the combination of two demodulated differential phase-shift keying DPSK signals to generate an optical FSK payload, has also been proposed [8,9], but both of them experimentally demonstrated just at 10 Gbit/s. To generate a high speed FSK signal at 40 Gbit/s and above, a scheme is reported to utilize a specially designed $LiNbO_3$ external FSK modulator [10], this scheme, however, requires relatively complicate manufacturing and integration.

In this paper, we propose to use CSRZFSK as the modulation format of the high speed packet payload on which the ASK modulated label was superimposed for the first time. When compared to the previously proposed OFSK labeling scheme [3–7], OOK labeling eliminates the need of CSRZFSK demodulation and modulation at the core routers, which can reduce the operation and manage-

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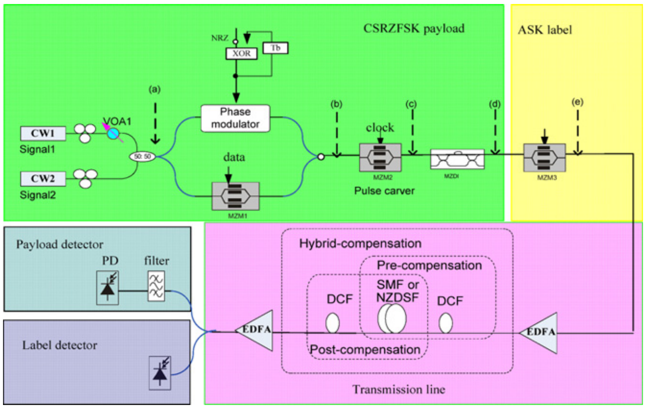

Fig. 1. Schematics of the CSRZFSK/ASK optical label switching system.

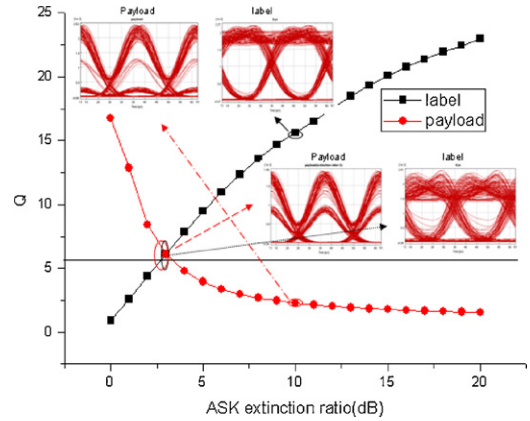

Fig. 3. Q performance under different extinction ratio of MZM2.

ment costs. Moreover, with the constant intensity property of the CSRZFSK payload, label swapping, which includes label erasure and label insertion, can be realized in a much simpler way. The induced degradation to the payload is quite small. Besides, the data rate of the OOK label can be adjusted more flexibly by means of intensity modulation and direct detection. We have demonstrated 80-km transmission of 2.5 Gb/s OOK label on 40 Gb/s CSRZFSK packet payload. Simulation results show that negligible (<1.8 dB) power penalty was induced to both the payload and the label after one stage of all-optical label swapping.

2. Proposed labeling scheme

Fig. 1 shows the simulation setup of 40 Gb/s CSRZFSK signal. Two lasers CW1, CW2 with carefully selected center frequency are utilized as the CSRZFSK source. The signal (shown in Fig. 2(a)) is modulated by MZM1 or PM thus to generate a DPSK signal (shown in Fig. 2(b)), it is found that about 0.29 dB improvement for the receiver sensitivity can be achieved by using MZM as the phase modulator, therefore, the frequency modulation signal using MZM is adopted, the optical field exiting MZM1 is given by

$$E_{in} = A \cdot \cos(\pi B t + \varphi) \quad \varphi \in (0, \pi) \tag{1}$$

The CSRZ-DPSK signal (shown in Fig. 2(c)) forming is realized in the second MZM (MZM2), sinusoidally driving an MZM2 at half the data rate between its transmission maxima results in pulses with 67% duty cycle and with alternating phase. CSRZ-DPSK signal generation can be mathematically described as:

$$E_{out} = jE_{in} \sin\left(\frac{\varphi_1 - \varphi_2}{2}\right) \exp\left(j\frac{\varphi_1 + \varphi_2}{2}\right) \tag{2}$$

where E_{in} and E_{out} describe the optical input and output fields of the MZM2. E_{in} represents the optical field of a 40 Gb/s DPSK signal, which is generated in MZM 1. φ_1 and φ_2 are the optical phases of the two modulator arms and φ_1 is biased with a voltage V_{bias}, φ_1 and φ_2 are defined as:

$$\varphi_1 = \frac{\pi}{2}\frac{V_1}{V_\pi}\sin(\omega t + \psi) + \frac{\pi}{2}\frac{V_{bias}}{V_\pi} \tag{3}$$

$$\varphi_2 = \frac{\pi}{2}\frac{V_2}{V_\pi}\sin(\omega t) \tag{4}$$

where V_1 and V_2 are the amplitudes of a sine-clock signal, and ψ stands for a phase difference between the two sine-clock signals. V_π is the voltage required for a π-phase shift. The MZM2 used for CSRZ-DPSK generation is biased at $V_{bias} = 0$ and $V_1 = V_2 = V_\pi$. ψ equals π. The frequency of the sine-clock amounts to $f_0 = 20$ GHz (equivalent to the half bit rate). The mathematical representation of the generated CSRZ-DPSK signal can be given as:

$$\begin{aligned} E_{\text{CSRZDPSK}} &= jE_{in}\ \exp(-j\beta L)\sin\left(\frac{\varphi_1 - \varphi_2}{2}\right)\exp\left(j\frac{\varphi_1 + \varphi_2}{2}\right) \\ &= jE_{in}\ \exp(-j\beta L)\sin\left[\frac{\pi}{2}(\sin\omega_0 t + \pi) - \sin\omega_0 t\right] \\ &\quad \cdot \exp\left[\left(j\frac{1}{2}\left(\frac{\pi}{2}(\sin\omega_0 t + \pi) + \sin\omega_0 t\right)\right)\right] \\ &= -jE_{in}\ \exp(-j\beta L)\sin\left[\frac{\pi}{2}(\sin\omega_0 t)\right] \end{aligned} \tag{5}$$

With

$$\varphi_1 = \frac{\pi}{2}\sin(\omega_0 t + \pi) = -\frac{\pi}{2}\sin(\omega_0 t) \tag{6}$$

$$\varphi_2 = \frac{\pi}{2}\sin(\omega_0 t) \tag{7}$$

Then CSRZDPSK signal is demodulated to intensity modulation by the following MZDI, while the coupling ratios of the MZDI's two

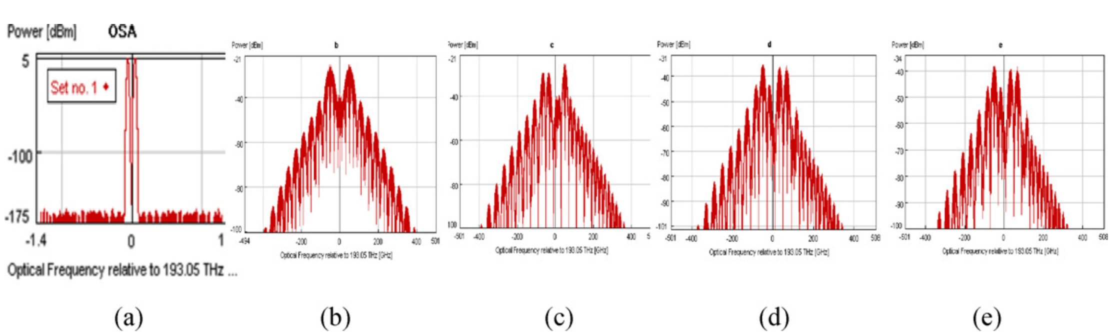

Fig. 2. Optical spectra of different point in Fig. 1.