A Novel Phase Encoding Scheme for Optical Packet Label Processing

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Abstract *An optical packet label encoding scheme based on synchronously modulated DPSK labels is proposed and demonstrated. This scheme allows high packet extinction ratio and supports low data rate DPSK label encoding and detection.*

Introduction

Optical label switching (OLS) is a promising technique to enable low-latency forwarding of high-speed optical packets in future packet-based networks. The optical packet labels are retrieved and updated in each network node while the packet payload data are forwarded in optical domain. Thus an efficient scheme to encode and extract these low bit-rate labels from the arriving packets is desirable. Several label encoding schemes using bit-serial [1], sub-carrier multiplexing (SCM) [2], and differential phase shift keying (DPSK) labels [3,4] have been recently proposed. In [4], the DPSK label was realized by directly phase-modulating the label information onto the carrier of the amplitude-shift-keying (ASK) modulated packets. At the intermediate routing nodes, labels were extracted using a DPSK demodulator and were erased using intensity-sensitive wavelength converters. Despite its simplicity, such scheme has some drawbacks. The extinction ratio of the intensity modulated packet has to be reduced to around 5~6dB, in order to accommodate the phase-modulated label. Moreover, since a label usually carries relatively smaller amount of data, it is advantageous to keep the label bit rate much lower than that of the packet payload. Typically, it should be a few hundreds of Mb/s so that low-speed components can be used for label detection and processing. With such DPSK label scheme, however, it is difficult to control the demodulator so as to meet the stringent detuning requirement at low bit rates. Laser linewidth also becomes a limiting factor.

In this paper, we propose an improved DPSK label encoding and detection scheme based on synchronously modulated DPSK labels. Our scheme embeds the low-speed label into the high-speed packet payload and completely eliminates the need to control packet extinction ratio. Stable demodulation of 311-Mb/s DPSK label embedded in 9.953-Gb/s packets was experimentally demonstrated.

Proposed label encoding scheme

Fig. 1 illustrates the operation principle of our proposed scheme. At the ingress router, data destined for a remote network node are assembled into optical packets as shown in Fig. 1(a). The payload data is segmented to match the bit period of the label. A pair of '1' (mark) bits are inserted between two consecutive payload segments. Then, the differentially pre-coded label is used to synchronously phase-modulate the whole optical packet with the boundary of the label bit transition aligned with the middle of the pair of mark bits in the optical packet. Thus the phase transition of the label may occur only at the interleaved mark bits, thus the label information is embedded and interleaved in the optical packet. To extract the label, a delayed-interferometer (DI) with a relative fiber delay of one packet payload bit period (T_p) is used. An optical pulse will be produced when there exists a phase transition between those two adjacent mark bits. As there is no phase transition over each payload segment, the destructive interference between adjacent payload bits at the DI output either cancels out each other or produces pulses which are 6-dB attenuated. As a result, the label is obtained in form of return-to-zero (RZ) pulse pattern at the label's repetition rate, as illustrated in Fig. 1(b). The label can then be further regenerated electronically by low-speed decision and reshaping circuits. With this scheme, the extinction ratio of the whole optical packet can be maintained high. Besides, the DI only requires a delay of one payload bit period rather than one label bit period thus is more practical.

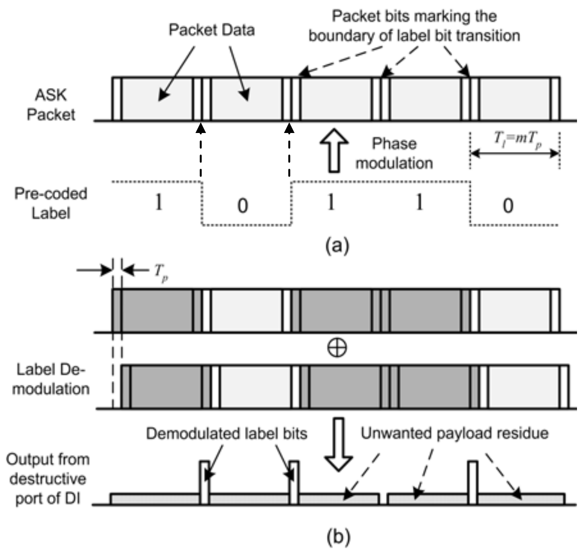

Fig. 1 Principle of (a) label modulation and (b) demodulation in our proposed scheme; T_p: packet payload bit period; T_l: label bit period; m: number of bits in each segment.

Experiment and Results

To verify the feasibility and performance of the proposed scheme, we have preformed a label encoding and detection experiment on 9.953-Gb/s packets. The experimental setup is shown in Fig. 2.

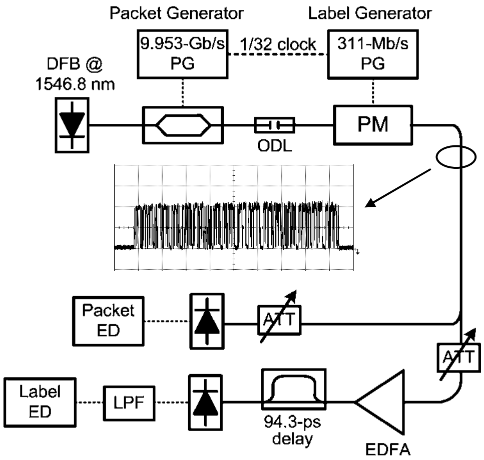

Fig. 2 Experimental Setup; ODL: optical delay line, ED: error detector, ATT: tunable attenuator, LPF: low-pass filter. Inset: packet waveform.

Optical packets were generated by intensity modulating the output from the DFB laser. The 9.953-Gb/s pattern generator (PG) was programmed to produce 64-byte packets with random payload using the packet structure as illustrated in Fig.1(a). The extinction ratio of the packet was measured to be about 12 dB. The length of each payload segment is set to 4 byte, corresponding to a label bit rate of 311 Mb/s. The clock output from this PG is then divided by 32 and used to synchronize with the label pattern generator producing pseudo-random label pattern (2^{31}-1) at 311 Mb/s. The optical packet was appropriately delayed and fed into the phase modulator (PM) where the label pattern was written onto the packet. The waveform of the packet is shown in the inset of Fig. 2. The output from the phase modulator was then split into two paths. One of them was fed into a 10-Gb/s receiver for BER measurement of the packet payload. As shown in Fig. 4, the BER curves for packets with and without labels coincide with each other, indicating no power penalty for label encoding. On the other hand, the second output path was used for label detection and BER measurement. To detect the label, the signal was amplified and fed into a fiber-based DI with a relative fiber delay of 94.3 ps. The phase difference between the two arms was adjusted to obtain the destructively interfered pattern form the output port and the resultant waveform is shown in Fig. 3(a). The periodic spikes are eye-patterns of the demodulated label bits formed by interference between the two adjacent mark bits embedded in the packet. Some close-up waveforms from various parts of the demodulated output are shown in Fig. 3(b). The pulse width of the demodulated label bits was about 100 ps. As expected, the payload segment was suppressed

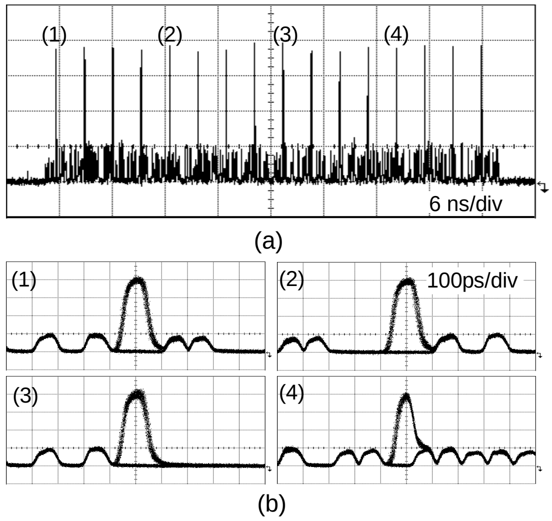

Fig. 3 (a) Demodulated output from DI, and (b) close-up waveforms of some label eye-diagrams.

approximately by 6 dB at the DI output. This output waveform was then detected by a 2.5-Gb/s receiver followed by a 1.78-GHz low-pass filter. The resultant signal was used for BER measurement and the result is shown in Fig. 4. It is shown that error-free label detection was achieved and the label receiver sensitivity at a BER of 10^{-9} was -31 dBm. Thus, the results proved the feasibility of our proposed scheme.

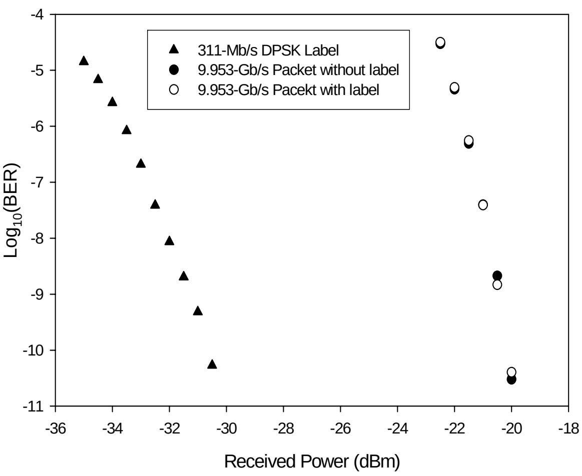

Fig. 4 BER curves for labels and packet payloads.

Summary

We have proposed and experimentally demonstrated an improved DPSK label encoding scheme for OLS networks. This scheme supports robust low-bit-rate DPSK label encoding and detection. In addition, by interleaving and embedding the label bits inside the optical packet, high extinction ratio of the packets can be maintained. This project was partially supported by a CUHK Direct Grant (Project No. 2050296).

References

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