A Novel Phase-modulated Label Pattern Recognition Scheme Based on Parallel Bit Comparison Using Cross-phase Modulation

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Abstract *An optical phase-modulated label pattern recognition scheme is proposed and demonstrated, by optically comparing the incoming label pattern with a local pattern. This scheme conducts label bit comparison in parallel and is capable of recognizing any label patterns.*

Introduction

Optical label recognition is one of the essential functions in label switching networks. A common approach for bit-serial label recognition employed nonlinear optical processing with successive electrical post-processing [1-2]. It could recognize different label patterns by programming the electronics but both of its optical and electrical modules were quite complicated. Another method utilized all-optical correlation [3-4], which largely relaxed the requirement on electronics. However, each correlator could recognize only one label pattern and it required special label data format.

Recently, a new method based on all-optical logic XOR gates has been proposed [5]. It compared the incoming label pattern and the local reference pattern bit by bit through XOR operation, and a third signal was used to carry and summarize the bitwise comparison results together. This scheme could recognize any label pattern. However, it would involve *N* XOR gates for *N*-bit label, which was costly and complicated, and might have cascadability problem due to noise accumulation.

In this paper, we propose a novel optical correlator for phase modulated (PM) bit-serial label recognition. It handles label bit comparison in parallel, thus offering much more simple and robust operation. The decision of successful recognition is simply achieved by measuring the output optical power. Besides, it can also recognize any incoming label pattern according to the local pattern, and is potentially capable of handling variable-length label patterns.

Principle of Operation

Fig. 1 shows the principle of operation of our proposed all-optical PM label recognition scheme. An optical pulse train which is intensity modulated with a designated label pattern is aligned and combined with the incoming optical PM label before they are fed into a segment of dispersion-shifted fiber (DSF). Since the locally generated optical pattern is intensity modulated and has strong optical power, it can alter the phase of the incoming PM label signal via cross-phase modulation (XPM) in the DSF. If the binary pattern encoded in the incoming PM label signal is the same as that in the local pattern, the incoming PM label signal will be converted to have the same phase in all of its pulses. By using an optical delay-line interferometer (DI), which has a relative delay between two arms equivalent to the label period, the destructive port of the DI would have no pulse output. On the contrary, if the incoming PM label pattern does not match with the local optical pattern, there would be at least one pulse with its phase different from others in the XPM-modified label signal after the DSF. As a result, there would be at least one optical pulse output from the DI's destructive port. For common bit-serial PM labeling, a PM label and its phase-complementary label are regarded to be the same (e.g. pattern "1010" can be encoded as either "$\pi 0 \pi 0$" or "$0 \pi 0 \pi$"), thus a label pattern is also judged to be matched with its complementary pattern in our scheme. According to the output power measurements, we can judge if the incoming label pattern matches with the local pattern. In this way the all-optical label pattern recognition is realized.

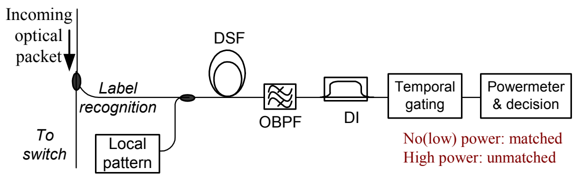

Fig. 1. Schematic of the proposed all-optical label recognition scheme.

Experiment

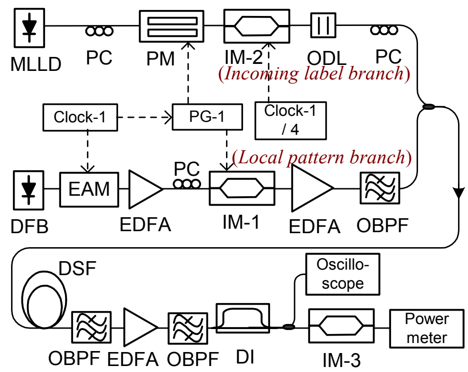

Fig. 2. Experimental setup.

Fig. 2 shows the experimental setup. A mode-locked laser diode (MLLD) generated an optical pulse train with ~1.5-ps pulsewidth at 1554.1 nm. A pattern generator (PG-1) operating at 10.61-Gb/s modulated the pulse train via an optical phase modulator. A 3-GHz intensity modulator (IM-2), driven by (10.61/4)-GHz square clock, was inserted to gate the continuous optical PM signal and produce 4-bit optical packet label. After passing through a tunable optical delay line (ODL) and a polarization controller (PC), the optical label signal was combined with a 10.61-Gb/s intensity-modulated control signal at 1545.3 nm. The pulsewidth of the control signal was around 20 ps, carved by an electro-absorption modulator (EAM). The PM label signal (~−15 dBm) and the intensity-modulated control signal (~21 dBm) were coupled into a piece of 4-km dispersion-shifted fiber (DSF). Then an optical bandpass filter (OBPF) with a 2-nm bandwidth was used to extract the data signal. A DI with a relative delay of 94.3 ps was employed before the output signal was separated and fed into a 50-GHz oscilloscope and another 3-GHz intensity modulator (IM-3, served as the optical temporal gating and driven by another programmed PG) followed by an optical power meter.

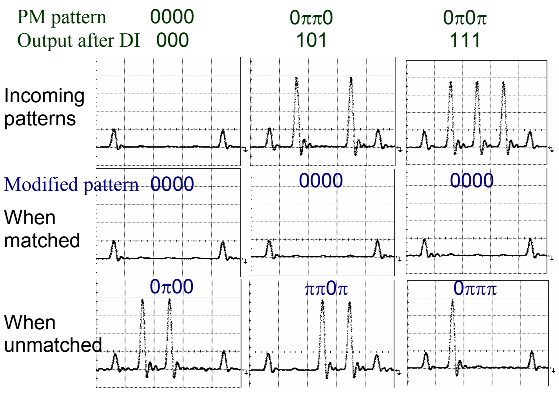

Fig. 3. Waveforms of the incoming label patterns before and after recognition. All waveforms were captured after the DI. Time scale: 100 ps/div.

At first, we properly adjusted the ODL to align the incoming label with the same or different local pattern, as the matched or unmatched cases, respectively. Fig. 3 shows the waveforms of three different 4-bit label patterns after the DI. The three incoming label patterns were “0000”, “0ππ0” and “0π0π”. The top row of Fig. 3 shows the intensity waveforms of the original three incoming label patterns after the DI. The generation of the two small side pulses was due to the empty guard bands present before and after the label, and they could be removed after passing through the time gating device (IM-3). If the local patterns were matched patterns “0000”, “0110” and “0101”, then the three label patterns were all modified into the phase of “0000” and the DI outputted only two small side pulses (shown in the middle row of Fig. 3). On the contrary, if the local patterns were unmatched ones, for example “0100”, “1011” and “0010”, the DI output at least one large pulse (shown in the bottom row of Fig. 3). The DI output in the pattern-unmatched cases certainly had much larger optical power than that in the matched cases, though there was very small amount of residual power in the matched case due to incomplete phase change and phase noises.

Fig. 4 shows the measured optical power at the output of the recognition module with the three 4-bit label patterns. The matched case was observed when the incoming pattern and the identical local pattern were temporally pattern-aligned. We recorded and plotted the output power of recognition for the matched case and several unmatched cases. We found that the unmatched cases resulted in relatively large output power while the matched case gave very small power (normalized to 0 dB), as determined by the noise level and the power meter sensitivity. The worst case of differentiating the matched case and the unmatched cases had a substantial power difference of > 9 dB, and thus could be easily processed by a simple electronic thresholding circuit.

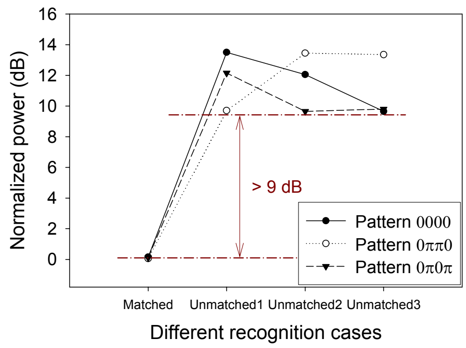

Fig. 4. Measured power in the pattern-recognized case and the pattern unmatched cases, for three incoming patterns “0000”, “0π0” and “0π0π”.

Summary

We have proposed a novel all-optical scheme for optical bit-serial PM label pattern recognition. The incoming PM label pattern was compared with an intensity-modulated local pattern in parallel via XPM. The recognition result can be obtained by simply measuring the DI output power. We tested three different 4-bit patterns and found the power difference between the matched case and the unmatched cases was at least 9 dB. This scheme can recognize any label patterns without additional complexity as compared with previous schemes, and can potentially support ultrafast label recognition at higher speed.
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References

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