Self-controlled all-optical label and payload separator for variable length bursts in a time-serial IM/DPSK scheme

Self-Controlled All-Optical Label and Payload Separator for Variable Length Bursts in a Time-Serial IM/DPSK Scheme

J. J. Vegas Olmos, I. Tafur Monroy, J. P. Turkiewicz, Y. Liu, and A. M. J. Koonen

***Abstract*—We demonstrate an all-optical label and payload separator based on nonlinear polarization rotation in a semiconductor optical amplifier. The proposed scheme uses a variable packet length composed of a label and payload information signal modulated intensity modulation and differential phase-shift keying (DPSK) format, respectively. The separation is obtained by using the payload signal itself, exploiting the DPSK feature of being power constant, as a pumping light source. Therefore, the proposed scheme is asynchronous and does not need an external control signal.**

***Index Terms*—Nonlinear optics, optical signal processing.**

I. Introduction

OPTICAL label swapping (OLS) is a promising technique for implementing optical packet switching (OPS) functions over wavelength-division-multiplexed (WDM) optical networks [1]. Due to the ever increasing line bit rate of data transmission over WDM links, today the bottleneck is moving toward the electronics that processes the signal at the core nodes of the network. All-optical label swapping techniques due to their potential for ultrafast operation are a promising solution for packet routing speeds matching line rates and therefore avoiding any processing bottleneck [2]. At the ingress node of an OLS network, packets with a common destination or class of service will be aggregated and equipped with a short fixed optical label. Core nodes process this label and based on its information perform a routing decision. Therefore, the optical label is usually separated from the payload for the corresponding signal processing at the core nodes. Several schemes have been proposed to separate the label (header) and payload information by using all-optical signal processing techniques based on nonlinear polarization switches [2], [3]. Most of the proposed approaches use an external control pulse synchronized with the label bits, which increases the complexity of the node architecture. Recently, a scheme [4] without the need of a synchronized external control pulse was proposed. However, it requires Manchester encoding of the payload data for its proper operation and, thus, it compromises the payload format.

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The authors are with COBRA Research Institute, Eindhoven University of Technology, Eindhoven 5600 MB, The Netherlands (e-mail: j.j.vegas@tue.nl; i.tafur@tue.nl; j.turkiewicz@tue.nl; Y.Liu@tue.nl; a.m.j.koonen@tue.nl).

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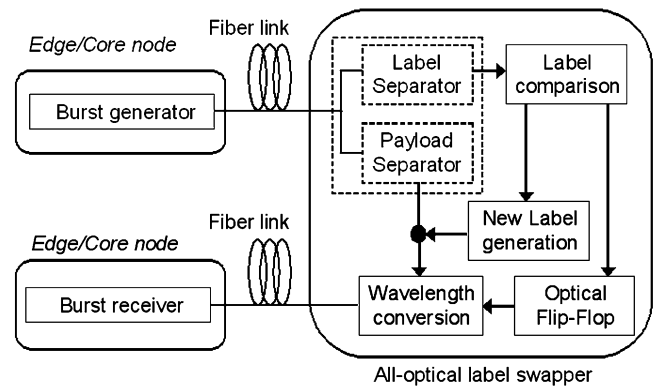

Fig. 1. Generic OLS node architecture.

In this letter, we propose a novel all-optical label and payload separator scheme with no need of external synchronized control signal. The proposed scheme uses a combined scheme with an intensity modulation (IM) for the label and differential phase-shift keying (DPSK) for the payload. The separation is performed by using the nonlinear polarization rotation effect in a semiconductor optical amplifier (SOA) [5]. The polarization rotation is induced by using the payload signal itself. Thus, the role of the control pulse is performed by the payload signal, exploiting the constant amplitude feature of the DPSK modulation format. In this way, the proposed scheme operates asynchronously and self-controlled because the timing for the label separation is contained in the burst format itself. Moreover, optical transmission by using DPSK modulation format [6], [7] has been demonstrated to be robust against chromatic dispersion, polarization-mode dispersion, and cross-phase modulation effects, enabling record high capacity in transmission links. We report on the experimental demonstration of the proposed scheme for 10-Gb/s DPSK payload and variable label bit rate up to 10 Gb/s. Furthermore, we demonstrate variable-length burst operation without observed distortion in the eye diagrams of both label and payload signals.

II. Node Architecture and System Concept

Fig. 1 shows the generic all-optical label swapper unit block diagram [8]. When a core label swapper receives a burst, first the optical label and the payload are extracted. The optical label is processed by a label comparison subsystem [9], which is formed by optical correlators that generate an optical pulse if an address match is found. The label comparison block generates a pulse signal which sets both the new label generation block and the

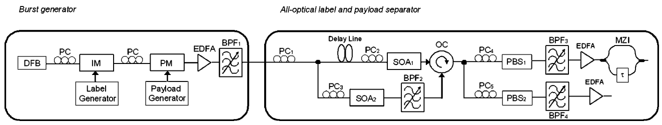

Fig. 2. Experimental setup.

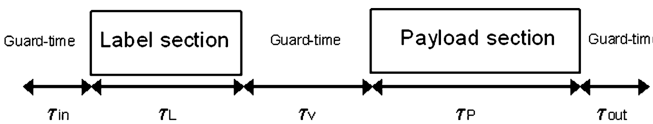

Fig. 3. Burst format.

optical flip-flops. The new label generation block creates the new label that contains the information required to forward the burst to the next hop. At the same time, the optical flip-flop [10] emits a continuous-wave signal at a certain wavelength, which will be used as a probe signal for the wavelength conversion block.

The experimental setup is depicted in the Fig. 2. The burst is composed of a payload signal and its corresponding label. The label information is conveyed in IM modulation using the lightwave carrier generated by a distributed feedback laser signal at 1553.44 nm. The payload information is conveyed in DPSK modulation on the same lightwave carrier using a time-serial scheme. The modulation signal is in the nonreturn-to-zero format based on a $2^{31} - 1$ pseudorandom bit sequence. The average output power after the burst generation was measured to be -18 dBm. An erbium-doped fiber amplifier was used to amplify the signal up to 5.1 dBm. After the burst is generated, it enters the all-optical label and payload separator block shown in Fig. 1. This separator block is composed of two SOAs, two polarization beam splitters (PBS), and one optical circulator. Polarization controllers (PCs) and optical bandpass filters (BPF) are also necessary for adjusting the operating point of the separator. The burst signal is split and injected into the SOA1 after a fixed delay line, which ensures that the label part of the burst arrives simultaneously with the payload part of the signal version passing through SOA2. The polarization of this label signal is adjusted by using the PC2 to match the orientation of the PBS2. The other part of the splitted burst signal is amplified in SOA2 and used as a high-intensity pump control signal for the SOA1. The role of SOA2 is, hence, to set the proper pump signal power level. The injected pump signal, aligned to coincide with the label at the SOA1, introduces additional birefringence in the SOA1 as compare to the case when no pump signal is present [5]. Therefore, the label part experiences a rotation on its polarization state in SOA1 and leaves the system through the output of the PBS2. Because the payload part does not experience excess of birefringence, it leaves the system by the output of the PBS1.

Fig. 3 shows the burst structure, which is composed of a label section and a payload data section, spaced out by a guard time. The payload can be used as a control signal, supporting variable burst length as long as the control signal does not overlap in SOA1 with the payload section. Therefore, the guard time value can be chosen to guarantee this condition. Supporting variable burst length is an attractive feature for networking in terms of granularity in optical-switched networks [11], [12]. As explained above, the payload signal is used as a control signal to induce nonlinear polarization rotation in SOA1. If we assume a security guard-band equal to $\tau_{\text{in}/2}$, and taking into account the length of the payload (τ_P), the only remaining constraint is avoiding that the control signal overlaps with the payload section. Therefore, assuming another guard-time equal to $\tau_{\text{in}/2}$, we can easily determine that the packet may have a variable length, between

$$\begin{cases} \tau_{p\_}\text{min} = \frac{\tau_{\text{in}}}{2} + \tau_L + \frac{\tau_{\text{in}}}{2} \\ \tau_{p\_}\text{max} = \frac{\tau_{\text{in}}}{2} + \tau_L + \left(\tau_v - \frac{\tau_{\text{in}}}{2}\right) \end{cases}$$

where τ_{p_min} and τ_{p_max} are the minimum and the maximum length of the packet. Therefore, a factor of variability equal to $\tau_v + \tau_{\text{in}}$ is obtained for this scheme.

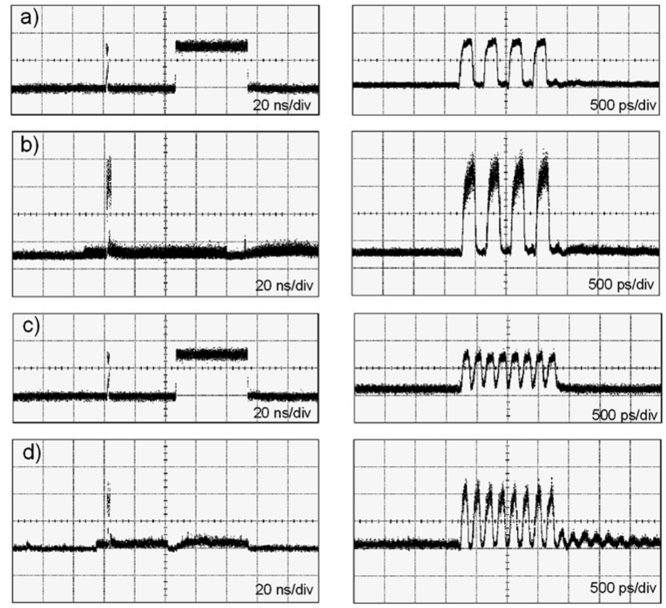

Fig. 4. Traces of the label separation for a bit rate of 5 and 10 Gb/s. (a) and (c) correspond to the burst and its label at 5 and 10 Gb/s, respectively. (b) and (d) correspond to the separated label and a detail of the separated label at 5 and 10 Gb/s, respectively. The vertical axis scale is 5 mV/div in all the pictures.

III. Experiment and Results

Two different bit rates for the label have been investigated. Namely, 5- and 10-Gb/s intensity modulated labels containing the hexadecimal words "AA" and "AAAA," respectively, were used to explore the versatility of the scheme. The used payload length was set to have duration of 47 ns, i.e., 470 bits at 10-Gb/s DPSK. The τ_v was set to be 45 ns. The pump signal average power level was 1.78 dBm for the long payload and -0.05 dBm for the short payload. Fig. 4 shows the results at the output of the all-optical separator. The extinction ratio (ER) of the original signal was 13.5 dB, obtaining similar values at the output for each case. The suppression ratio is 9.4 and 7.9 dB for the 5- and 10-Gb/s cases, respectively. Therefore, the label bit rate can vary within the range of the gigabit per second transmission, obtaining recoverable labels at the output. The payload was then operated at two different lengths, with a fix label at 10 Gb/s. The

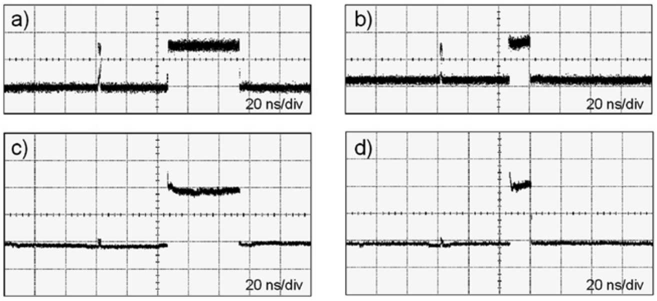

Fig. 5. Traces of the original burst with (a) a long and (b) a short payload for a 10-Gb/s label, and (c), (d) the output of the payload port, where we obtain only the payload. The vertical axis scale is 5 mV/div in all the pictures.

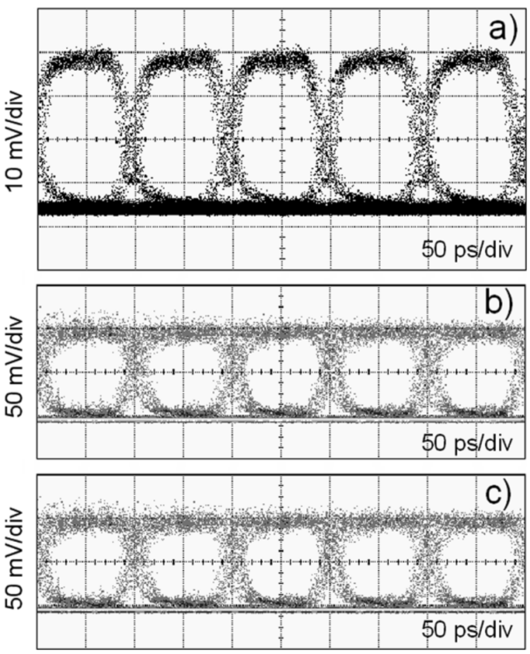

Fig. 6. Eye diagrams of (a) the original payload signal, (b) the separated short payload, and (c) the separated long payload.

long payload was chosen to have, as a proof-of-concept demonstration, 470 bits and the short one 140 bits, achieving a variability factor between the long and the short payload equals to 3.4. The separation results are shown in Fig. 5. The suppression ratio is 8.5 and 10.0 dB for the long and the short payload, respectively. Fig. 6 shows the back-to-back eye diagram of the DPSK signal, which had an ER of 14.5 dB, and the eye diagrams of the recovered DPSK signals for both the long (14.8 dB of ER) and short (15.3 dB of ER) payload cases. Therefore, the DPSK signal quality is not affected by our label separation scheme and is preserved without appreciable degradation in the optical domain.

IV. Conclusion

We have demonstrated experimentally the feasibility of a self-controlled variable burst length, variable bit rate all-optical label and payload separator by using nonlinear polarization rotation in a SOA. The used payload modulation format is DPSK which reduces the pattern dependence effects in the SOA and, moreover, is a promising candidate for achieve robust dispersion transmission along optical fiber links. The results show a proper label and payload separation with suppression ratios higher than 9.0 dB for different label bit rates and payload length. The proposed scheme has the prospects for integration in a photonic circuit due to the use of SOA-based devices.

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