All-optical self-routing of 40 Gb/s DPSK packets

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All-Optical Self-Routing of 40 Gb/s DPSK Packets

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Abstract: We demonstrate a self-routing all-optical circuit for switching 40 Gb/s DPSK packets. In our scheme, an all-optical header processor feeds a set-reset flip-flop that drives a coherent wavelength converter. We report an overall limited power penalty.
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In the future, optical networks should be able to handle hundreds of Tb/s data traffic and to efficiently route optical packets at high data rates in a variety of data-formats [1]. All-optical packet switching (AOPS) can have a role to play by exploiting its potential transparency to data formats, the high speed and the parallel operation in the optical domain. Moreover, photonic integration of the optical circuits might realize devices with reduced footprint, power consumption and costs.

Despite several AOPS demonstrations with OOK data packets, AOPS for phase-modulated data packets with large number of input and output ports has never been demonstrated. In the past, we reported an all-optical header processor for phase-modulated packets [2]. Notably this scheme requires only two switching elements regardless the number of labels to process. This allows asynchronous processing of a large label count at low power and with low latency. However, the overall AOPS operation, including the all-optical header processor, the set-reset flip-flop (FF) and the all-optical wavelength conversion of DPSK packets was not yet demonstrated.

Here we report a 1x4 AOPS system for 40 Gb/s DPSK data packets based on time-to-wavelength header processing including all required all-optical subsystems. We employed semiconductor based photonic integrated optical switches for implementing the asynchronous all-optical header processor, the optical FF for controlling the wavelength routing switch, and the wavelength routing switch itself. The wavelength routing switch is also implemented with a semiconductor based wavelength converter (WC), where, for the first time to the best of our knowledge, the output of the optical FF is used as WC pump for converting phase-modulated signals.

In Fig. 1 we report the experimental setup of the 1x4 AOPS. The optical DPSK packets are produced by two cascaded $LiNbO_3$ Mach-Zehnder modulators (MZMs): the first one is used to create the packets envelope (packet length: 1 μs, guard time: 20 ns). The second one produces the optical 40 Gb/s DPSK packet (λ=1552 nm). The PRBS length (2^{15}-1) has been chosen so that each packet contains at least one full PRBS sequence. The header is serial with the payload and phase-coded using PPM (pulse position modulation). The information in the header is for any packet, as follows: the first pulse is at the beginning of the packet whilst the position of second pulse gives the destination information [2]. The header pulses had 1.6 ns duration to meet the optimized operating switching speed of the FF.

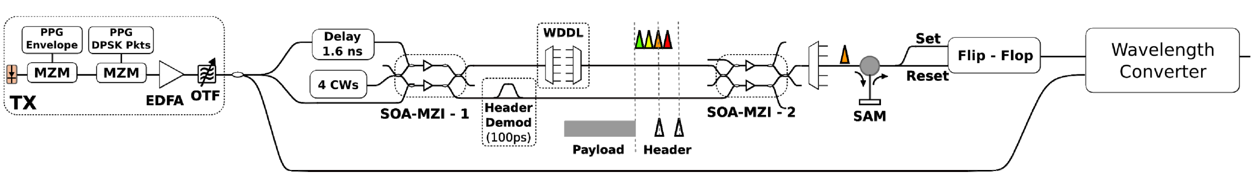

Figure 1 Experimental setup. WDDL: Wavelength Dependent Delay Line (realized by using two faced Arrayed Waveguide Gratings (AWGs) and fiber-based delay lines). SAM: Saturable Absorber Mirror. Wavelength Converter: Four-Wave-Mixing process in an SOA.

The packets are first amplified and then split in two signals: one signal is fed into the header processor for determining the packet's destination, while the second is delayed and input to a wavelength converter. The header processor converts univocally the time between the two header pulses, which identifies the destination information, to a distinct colored optical pulse. To this aim first the header processor produces 4 colored pulses with 1.6 ns duration and synchronous at the packet start by optically modulating 4 CW light-waves using a SOA Mach-Zehnder Interferometer (SOA-MZI-1) in push-pull configuration. The 4 coloured pulses with 200 GHz spaced, ranging from 1560.6 nm to 1548.5 nm, have a 1.6 ns duration according to the push-pull delay. The 4 colored pulses are then fed into a wavelength-dependent delay line (WDDL) so that at its output each colored pulse is shifted by one pulsewidth with respect to the previous one (colored sequence in Fig. 1). An example trace for those 4-pulse sequence is reported in Fig. 2-a. Simultaneously, at one of the pass-through port of the SOA-MZI-1 the header of the incoming

DPSK packets are demodulated by a 100-ps MZ-delayed interferometer, which produces the two OOK header pulses, as shown in Fig. 2-b which reports a typical demodulated header. The 4 colored pulse sequence and the demodulated header are injected into an AND gate (realized by a second non-linear switch, SOA-MZI-2). This gate selects only one pulse out of the 4 colored pulses, thus effectively mapping the packet destination (coded in the pulse position) into a wavelength [2]. A typical colored pulse obtained at the output of SOA-MZI-2 is shown in fig. 2-c. As can be seen, it shows a significant amount of intensity noise that is reduced by means of a commercially available Saturable Absorber Mirror (SAM). Fig. 2-d shows the colored pulse after the noise suppression stage. The selected colored pulse sets and resets (by split-and-delayed the pulse by one packet length) via an AWG one of the 4 optical flip-flop (FF). Each of the FF provides a distinct wavelength and acts as WC pump. The FF converts the optical pulse in a 1 μs optical gate (same as the packet duration) as shown in fig. 2-e (the header is repeated every 4 packets). The characteristics of the FF used in our experiment can be found in [3].

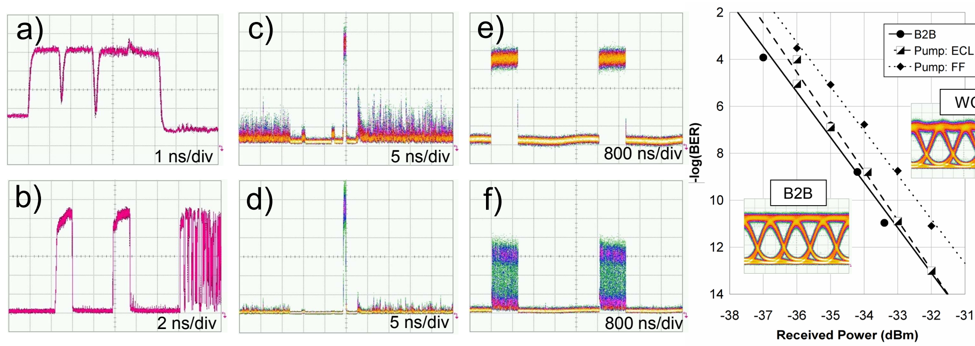

Figure 2 a) 4-λ colored pulses. b) detail of demodulated label, c) switched pulse at SOA-MZI-2 output. d) noise removal after R-SAM. e) FF-output. f) converted packets. Leftmost figure shows WC BER measurement with respective eye diagrams as insets.

The WC was based on FWM in a highly nonlinear SOA with 200 GHz detuning between the pump (the FF output, λ=1550.6 nm) and the input signal. Of course, a multi-pump FWM configuration should be considered for wider-band operation. The relative pump-signal power levels were optimized in order to obtain the highest conversion efficiency while minimizing the pump-signal cross gain modulation which can affect the phase-modulation in the converted signal [4]. The converted signal was extracted by using a tunable flat-top optical filter having 0.15 nm bandwidth and sent to an optically pre-amplified DPSK receiver for BER testing. We measured the power penalty induced by the WC by using two configurations: in the first case we effectively used the FF output as pump signal. In a second case, we used a gated external cavity laser (ECL) as optical pump. By comparing those results, we quantify the amount of the additional power penalty induced by the use of the FF gate. As can be seen, the use of the FF device adds about 1 dB power penalty, in respect to the use of the ECL

We demonstrated an all optical circuit for the AOPS of 40 Gbit/s DPSK packets. It effectively processes the header information, and uses it to automatically set the wavelength of the output packets: the circuit exploits a PPM coding of the header, a time-to-wavelength based header processor, a flip-flop and a wavelength converter based on FWM. For the first time, the output of an all-optical flip-flop has been used as the pump for the DPSK WC. Performance of the converted packets shows very good performance and low penalty, also in respect to a low-RIN CW pump.

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