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Optical packet switch sub-system with label processing and monolithically integrated InP optical switch


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Abstract: We demonstrate a 1x16 optical packet switch sub-system for 160 Gbps RZ-OOK and 12 x 10 Gbps multi-wavelength DPSK packets. We show error-free operation with maximum penalties of 0.7 dB for 160 Gbps RZ-OOK and 0.6 dB for multi-wavelength DPSK packets.

OCIS codes: (060.6719) Switching, packet; (200.4740) Optical processing; (130.7408) Wavelength filtering devices.

Optical packet switch (OPS) sub-systems have potential to play an important role in future packet routers or computer interconnects. It is important that OPS sub-systems support router architectures that have large number of ports. Therefore it is important to investigate data-rate and data-format transparent OPS sub-systems that can address a large number of ports, to reduce costs, power and the number of components. Moreover, photonic integration of the optical switches is essential to reduce footprint and power consumption. To realize such scalable OPS sub-systems, data format and data rate transparent label processing technique, which is capable to process a large number of labels, and photon integrated switches with large number of ports should be realized. Here we demonstrate a data-format and bit-rate transparent 1x16 OPS sub-system that includes optical label processing and a 1x16 photonic integrated optical switch with low insertion losses. We demonstrate error-free operation for 160 Gb/s OTDM RZ-OOK packets as well as for 120 Gb/s (12x10Gb/s) DPSK multi-wavelength packets at the expense of power penalties of 0.7 dB and 0.6 dB, respectively.

The OPS sub-system is shown in Fig. 1. We generate two types of payloads. Firstly, we generate 160 Gb/s RZ-OOK payload by time-interleaving 16 data-streams at 10 Gb/s consisting of modulated $2^{31}$-1 PRBS RZ bits ($\lambda_p$=1546 nm). The optical pulses have duration 1.5 ps which corresponds to a -20 dB bandwidth of 5 nm. Alternatively, 12 channels with wavelengths between 1543.7 nm and 1548.5 nm (50 GHz spacing) were DPSK modulated by a pre-coded 10 Gb/s NRZ data sequence. A packet gate was used to make packets with 147.2 ns payload length and guard-band of 32 ns. The packets are equipped with address using in-band labels that have the same duration as the payload [1]. For the RZ-OOK packets the wavelengths of the labels are chosen to be within the -20 dB bandwidth of the payload (see Fig. 1a). For the DPSK multi-wavelength packets, we use the same label wavelengths, but they are spectrally located in the notches of the spectra of the DPSK multi-wavelength payload (see fig. 1b). This kind of in-band labelling has two advantages: firstly N labels allow for encoding $2^N$ addresses which makes that a relatively large number of ports can be addressed within the limited payload bandwidth. Secondly, in-band labelling allows for parallel and asynchronous optical pre-processing of the labels, which makes it easy to implement parallel electronic switch control without high speed clock recovery. This is essential for reducing latency and power consumption. If an optical packet is input in the OPS sub-system, the labels are extracted by using four cascaded reflective fibre Bragg gratings (FBGs) with wavelengths centred at the centre wavelength of the labels. The 3dB bandwidth of the FBGs is 6 GHz, and the centre wavelengths are L1=1543.9 nm, L2= 1544.3 nm, L3= 1547.7 nm and L4=1548.2 nm.

Figure 1. Experimental set-up and optical spectra of the OOK and DPSK packets: a-b) input packets, c-d) after label extractor, e-f) after the switch.
Thus four labels allow for addressing 16 outputs. The extracted labels are photo-detected, and the corresponding label voltages are fed into the switch controller. The switch controller maps a combination of 4 label voltages into unique set of 24 analog output voltages that are required to control the electro-optical switch. The switch controller is based on an FPGA that contains a lookup table. Finally, the payload is fed into an integrated 1x16 electro-optical space switch, which is based on electro-optical beam steering in an arrayed waveguide grating (AWG). By applying electrical signals (<1.6 V) to the phase shifters, the beam is steered to one of the AWG outputs. More details on the switch fabrication and operation are reported in [2]. The device size is 4.5 mm × 2.6 mm, the wavelength-dependent loss is 0.8 dB within the C-band (1530-1565 nm), switching speed ~ 6 ns, and cross talk suppression ~ 17 dB.

Firstly, we investigated operation of the 1x16 OPS using RZ-OOK packets. We input a series of packets into the 1x16 OPS, with labels such that each consecutive packet is routed to the next port (see Fig. 2). The optical power of each extracted labels was -20 dBm. Fig. 2 shows the traces at each output as well as eye-diagrams that show clear open eyes. The optical power of the payload at the input of the 1x16 switch was 7 dBm (measured in the fiber). The optical power at the output of the switch was -12 dBm. Assuming 6 dB of coupling losses per facet, the on chip loss is ~7 dB. The extinction ratio for each output was between 11 dB and 17 dB. A similar experiment was carried out for multi-wavelength DPSK packets. Fig. 2 (middle panel) shows the corresponding data traces and eye diagrams at each output, for the channel with a wavelength of 1544.1 nm. This channel (spectrally located in between two labels) is most sensitive to distortion by the label extraction. We used similar average optical powers as for the OOK experiment, and we observed similar extinction ratios. At the receiver side, one packet out of 16 switched by the OPS is evaluated by BER analysis. Fig. 2 (right panel) reports BER results only for output 11, which has the lowest extinction ratio. Thus, this channel shows the worst BER results. Panel a) reports results for 160 Gb/s RZ-OOK and panel b) shows results for the 12x10 Gb/s NRZ-DPSK. The 160 Gb/s OOK data were time demultiplexed to 10 Gb/s by using two cascaded electro-absorber modulators. The DPSK multi-wavelength channels were selected by a tuneable filter and demodulated by a 1 bit delay Mach -Zehnder interferometer. Fig. 2 shows error-free operation with 0.7 dB penalty for 160 Gb/s RZ-OOK packets and 0.6 dB penalty for the 120 Gb/s NRZ-DPSK packets.

We have demonstrated a data-format and bit-rate transparent 1x16 OPS sub-system by using a scalable and asynchronous label processing technique and a photonic integrated optical switch. Scalability of the switch terms of ports and data rate is not limited by the OSNR degradation due to the insertion losses as in broadcast and select switches where the losses increase proportional to the port number. We demonstrate error-free operation for 160 Gb/s OOK and 12x10 Gb/s DPSK with low penalty (< 0.7 dB), which indicates that use in large systems is possible.

References