Scalable Optical Packet Switch for Optical Packets with Multiple Modulation Formats and Data Rates

N. Calabretta, O. Raz, W. Wang, T. Ditewig, F. Gomez Agis, S. Zhang, H. de Waardt
E. Tangdiongga and H.J.S. Dorren

COBRA Research Institute, Eindhoven University of Technology, PO. Box 512, 5600MB – Eindhoven, The Netherlands n.calabretta@tue.nl

Abstract *We present a scalable, low latency optical packet switch for optical packets with multiple modulation formats. Results show error-free operation of 1x8 optical packet switch for 160Gb/s RZ-OOK, 320Gb/s NRZ-OOK and 100Gb/s DPSK multi-colored packets.*

Introduction

It is likely that future optical networks will carry a variety of data-formats. High capacity optical links might carry ultrafast OTDM data packets[1] or multi-colored optical packets with highly spectral efficient modulation formats, such as D(Q)PSK, OFDM, M-QAM[2-3] or a combination of those. Optical packet switch (OPS) nodes should transparently interconnect such links, avoiding power hungry optical-electrical-optical conversions. This implies that the OPSs should operate independently of the data-format. Up until now, there are no solutions for such an OPS.

Here, we demonstrate an optical packet switch employing in-band labeling to allow for transparent routing of multi-colored packets with multiple data formats and at different data bit-rates. The OPS employs a scalable, asynchronous and low latency label processor. We demonstrate that the switch operates error-free for 160 Gb/s OTDM RZ-OOK, 320 Gb/s (8x40Gb/s) NRZ-OOK and 100 Gb/s (10x10Gb/s) DPSK multi-colored packets. It is important to mention that the label processor and the switch do not need to be reconfigured when changing data format. We demonstrate for the first time a transparent 1x8 optical packet switch for 160 Gb/s data packets.

In-band labelling technique and processing

Generally, optical packets with payload at high data rate *B* can be generated in serial by using OTDM techniques[1,4], or in parallel by using *N* colored channels so that each channel has bit-rate *B/N*. In principle, both the OTDM packets and N-channels can be encoded by many modulation formats. We encode the address information of optical packets by in-band labels, i.e. the wavelengths of the labels are chosen within the bandwidth of the payload. We have already applied this technique for 160 Gb/s OTDM packets[4]; the labels were inserted within the spectrum of the OTDM signal (see fig. 1a). In case of multi-colored optical packets, each channel has a well defined spectrum and the labels can be inserted at wavelengths located at the notches (zero's) of the spectra of the multi-colored packets (see fig. 1(b-c)). We will show in this paper that this labeling technique can be applied to packets with different data formats. Each label is OOK encoded and has a binary value. Thus, 2^N addresses can be encoded by only using *N* in-band labels. This makes the in-band labeling scalable within the limited payload bandwidth.

Experimental set-up

The experimental set-up to demonstrate the OPS operation with in-band labeling for packets with multiple modulation format is shown in fig. 1. At the transmitter side, we generated payloads with three types of modulation formats. First, 160 Gb/s RZ-OOK payload centered at 1546 nm is generated by time-multiplexing 40 Gb/s modulated optical pulses. The 1.2 ps optical pulses make the 20dB bandwidth of the payload to be 5nm. Second, we generate 8x40 Gb/s NRZ-OOK multi-colored payload with channels from 1542.9 nm to 1549.1 nm spaced by 100 GHz. Third, 10x10 Gb/s DPSK multi-colored payload with channels from 1544.1 nm to 1548 nm spaced by 50 GHz. The optical address coupled to the payloads was generated by encoding 4 labels with the same duration as the packet payload and with wavelengths L_1=1544.36 nm, L_2=1545.16 nm, L_3=1546.92 nm, L_4=1547.72 nm. Note that the wavelengths of the labels are located in-band within the optical spectra of the three types of payload as shown in fig. 1 (a-c).

The optical packets including labels and payload are fed into the OPS. First, the label extractor separates the labels and payload by using a cascade of narrow-bandwidth fiber Bragg gratings (FBGs) centered at the labels wavelengths and optical circulators. The FBGs have Gaussian profile with 98% of reflectivity and 6 GHz at -3dB bandwidth to avoid significant slicing of the spectrum of the payload that leads to distortions. The separated payload is fed into the optical gates. Note that the labels output in parallel from the label extractor. This avoids complicated packet based clock-recovery and electrical serial-to-parallel conversion. The parallel labels are detected and processed by the combinatory network. The combinatory network operates asynchronously and can be scaled for larger number of labels without increasing the latency. For N optical labels, the

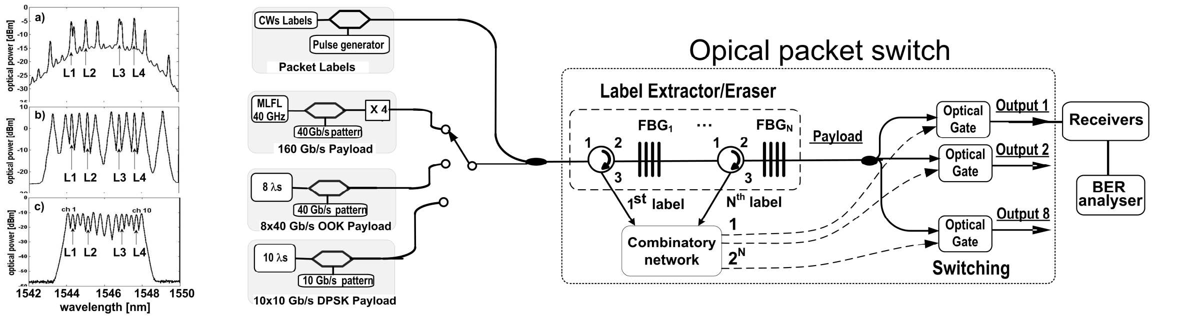

Fig. 1: Experimental set-up. Three types of modulation formats are generated and processed by the packet switch.

combinatory network provides 2^N distinct outputs, which act as control signals for driving the 2^N optical gates (output ports). The optical gates are electro-optic switches to guarantee packet data formats transparency. The switched optical packets are then received and analyzed by BER tester.

Results

First, we investigate the compatibility of in-band labels and payloads with multiple modulation formats. We fed into the OPS packets with 4 in-band labels and data payload with different formats. We evaluate the quality of the payloads after filtering the in-band labels The BER measurements are shown in fig. 2. For 160 Gb/s RZ-OOK, error-free operation with 0.4 dB power penalty was measured (see fig. 2a). Similarly, less than 0.5 dB penalty was measured for the 8x40 Gb/s NRZ-OOK format and 10x10 Gb/s DPSK. Those results indicate that in-band labeling can be used as universal optical address technique with any payload formats without compromising the signal quality.

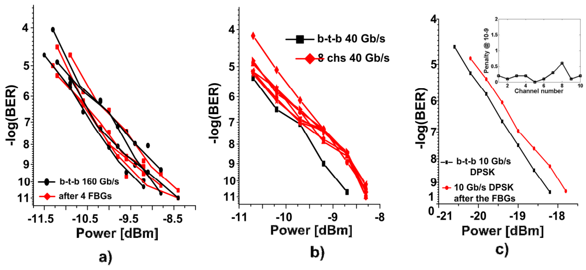

Fig. 2: BER results after the label extractor for: a) 160 Gb/s RZ-OOK; b) 40 Gb/s NRZ-OOK; c) 10 Gb/s DPSK.

Next, we demonstrate the switching performance of a 1x8 optical packet switch for 160 Gb/s RZ-OOK packets. The packets have duration of 8.8 ns and are separated by 4 ns guard band. The packets had 3 dBm of optical power. Three in-band labels are used to address the 8 output ports. Figs. 3(a-f) show the time evolution of the optical packets along the OPS. Figs. 3(a-d) show the separated payload and the labels by the label extractor. The payload is fed into the optical gates. The labels are processed by the combinatory network, which produces a control signal (see fig. 3e) for each labels combination. The control opens one optical gate, switching the packet to one of the 8 outputs (see in fig. 3f). The measured cross-talk between the output ports was higher than 18 dB. The measured BER of the switched packet is reported in fig. 4. Error-free operation was obtained with 0.8 dB of power penalty compared to the back-to-back payload BER.

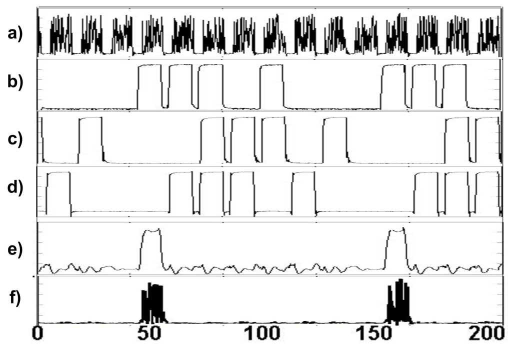

Fig. 3: Measured traces at different points of the OPS.

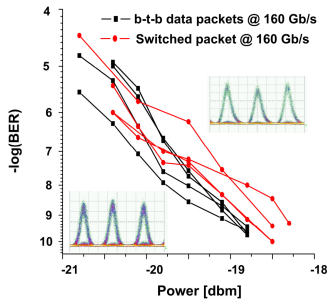

Fig. 4: BER measured at the optical packet switch output.

Conclusions

We have demonstrated that OPS employing in-band labeling allow for transparently routing optical packets with multiple modulation formats. Low power penalty (<0.5 dB) operation after labels extraction confirms that in-band labeling technique is compatible with multi-colored payload with any data format. We have successfully demonstrated 1x8 OPS for 160 Gb/s RZ-OOK packets that utilizes a novel asynchronous and scalable optical label processor with low latency regardless the number of labels, and data-format transparent optical gates for switching payloads with any modulation format. Error-free operation with 0.8 dB of penalty suggests that at least 8 labels can be attributed, scaling the OPS to 256 output ports.

References

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