Scalable optical packet switching at 160 Gb/s data rate

Scalable Optical Packet Switching at 160 Gb/s Data Rate

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Abstract *We investigate the feasibility of a 1x4096 optical-packet-switch (OPS) operating at 160Gb/s, by cascading two 1x64 OPSs in a fat-tree configuration. We find error-free operation with 5.7dB penalty over the complete system.*

Introduction

Boosted by the traffic increase in the access networks future optical networks should handle hundreds of Tb/s data traffic. To satisfy this demand, high capacity optical links will carry high data-rate packets[1]. On the other hand, optical packet switch (OPS) nodes should support a large number of ports that transparently connect such high capacity network links. Transparency of the OPS is the first key issue since it avoids high power optical-electrical-optical conversion and high speed burst mode receiver. Scalability of the OPS to a large number of input/output ports operating at high data rates is the second issue. The third issue is the latency of the OPS that determines the throughput of the switch. To the best of our knowledge, OPS with a large output ports (> 64) at data rate of 160 Gb/s has never been demonstrated.

Here, we demonstrate the feasibility of a 1x4096 OPS at a data rate of 160 Gb/s by cascading two 1x64 OPSs in a two stages fat tree configuration. The OPS employs a novel scalable, low latency (<3 ns) and asynchronous label processor.

System operation

The schematic of the OPS and the packet format are shown in Fig. 1. Packet payload is generated by time-quadrupling a 40 Gb/s data-stream consisting of 256 pre-defined return-to-zero bits (λ_p=1546 nm) into a 160 Gb/s data-stream using a pulse interleaver. Each pulse has duration of 1.2 ps making the 20 dB bandwidth of the payload to be 5 nm. The resulting packet payload consists of a 3.6 ns data burst. The guard-time between the packets is 2.8 ns. The payload length was limited by the pattern generator and does not form a fundamental restriction. We encode the address information of the optical packets by in-band labels, i.e. the wavelengths of the labels are chosen within the bandwidth of the payload[2]. Each label has the same duration as the packet payload and represents a binary value. Thus, by using N in-band labels, 2^N possible addresses can be encoded. This makes the in-band labeling scalable within the limited payload bandwidth. We encode 64 addresses by using 6 in-band labels (λ_{L1}=1543.88nm, λ_{L2}=1544.36nm, λ_{L3}=1545.16 nm, λ_{L4}=1546.92 nm, λ_{L5}=1547.72nm, and λ_{L6}=1548.20nm). The advantage of in-band labeling is that labels extraction can be done asynchronously by passive wavelength filtering.

The OPS consists of a label extractor/eraser, a combinatory network, and optical gates for payload switching. After the optical packets are fed into the OPS, the label extractor separates the labels and the payload. The label extractor consists of a cascade of narrow-bandwidth fiber Bragg Gratings (FBGs) and optical circulators. The FBGs are centered around the central wavelengths of the labels. The FBGs have a Gaussian profile with 98% of reflectivity and a -3 dB bandwidth of 6 GHz. This is essential to avoid distortions in the packet payload. Afterwards the payload is fed into the optical gates. The labels output the label extractor in parallel and are opto-electronic converted before being fed into a combinatory network. The combinatory network operates asynchronously. The combination of a combinatory network and this form of optical label processing makes complicated packet based clock-recovery and electrical serial-to-parallel conversion redundant. The combinatory network can be scaled to

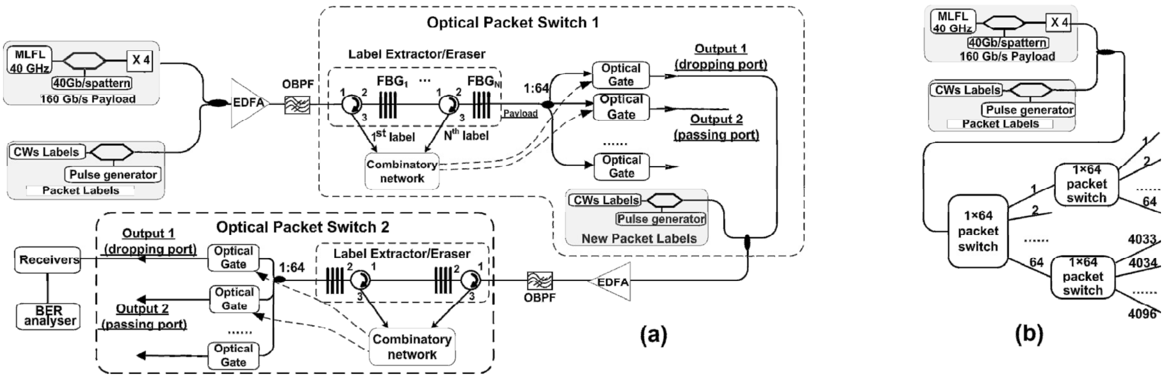

Fig. 1(a): Experimental set-up, (b) the fat-tree configuration.

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a larger number of labels without increasing the latency. For 6 optical labels, the combinatory network provides 64 distinct outputs, which act as control signals for driving 64 optical gates (output ports). The optical gates are electro-optic switches that support any data format and data-rate. Figure 1 describes two of such OPS cascaded in a fat-tree configuration. Both OPSs can address 64 outputs which makes that the overall system can address 4096 outputs.

At the output of both OPSs, the data payload is demultiplexed and analyzed by a bit-error rate tester.

Results

First, we evaluate the performance of a single 1x64 OPS for 160 Gb/s data packets. We transmit 64 packets with 6 in-band labels as shown in fig. 2a. The average power at the input of the label extractor was 9 dBm. The optical spectra at the input and output of the label extractor are shown in fig. 3(a-b). In the experiment we investigated the behavior of a 1x64 switch by using only two optical gates and a 18 dB attenuator to account for the 1:64 splitting losses. Using two optical gates is sufficient to evaluate the cross-talk between the output ports as well as the switching dynamics. Fig. 2b shows the control signal generated by the combinatory network driving the optical gate of output 1. Note that the electrical voltage of the control signals were 4.5 V that is sufficient to drive the optical gate without additional amplifiers. Figs. 2(c-d) shows the switched packets at switch 1 (drop port) and switch 2 (passing port), respectively. The cross-talk between the ports was 21.4 dB. The dropped packets were detected and the BER was measured. Fig. 4 shows that error-free operation was obtained with 2dB of power penalty.

Next, we evaluate the behavior of two cascaded 1x64 OPSs in a fat-tree configuration as shown in fig. 1b. To do this the dropped output of OPS 1 acts as the input of OPS 2. New labels are added at the input of OPS 2. The second OPS has a similar configuration as for OPS 1 and is again evaluated using two optical gates in combination with a 18 dB attenuator. Fig. 2e shows the control signal generated by the combinatory network driving the optical gate of the

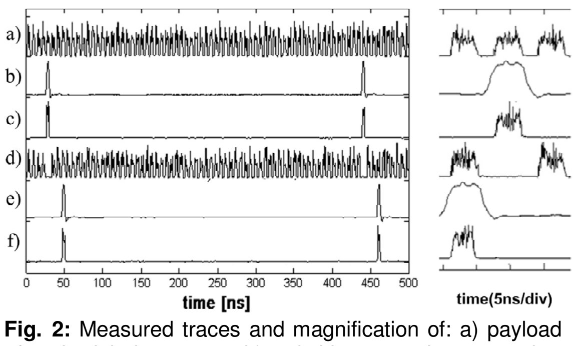

Fig. 2: Measured traces and magnification of: a) payload after the label extractor; b) switching control generated at OPS1; c) dropped payload at OPS1; d) passing payloads at OPS1; e) control generated at OPS2; f) dropped payload at OPS2.

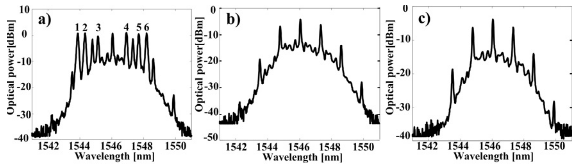

Fig. 3: Spectra of (a) input packet (b) switched packet after OPS 1 (c) switched packet after OPS 2.

dropping port. Fig. 2f shows the dropping port. Fig. 3c shows the spectrum of the dropped packets after two cascaded 1x64 OPSs. At the output of OPS 2, the packets are demultiplexed, and the BER is evaluated. Fig. 4 reports the BER measurements and eye diagrams. The eye diagram after the second OPS is broadened since the 160 Gb/s payload propagates more than 30 m of fiber without dispersion compensation. Error-free operation was obtained with a power penalty of 5.7 dB. Note that the label extraction (after two OPSs) causes only 1 dB of power penalty (see fig. 4). The additional power penalty is caused by the large splitting ratio and the insertion losses of the optical gates in combination with pulse broadening due to dispersion.

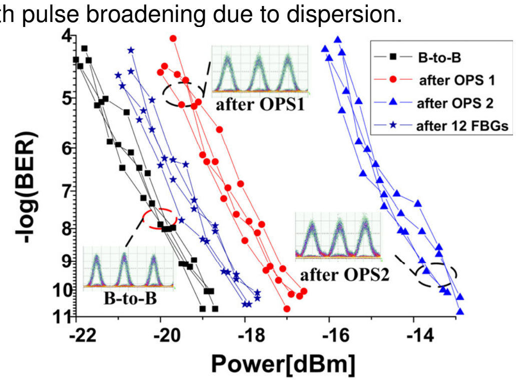

Fig. 4: BER curves and eye diagrams.

Conclusions

We have demonstrated the feasibility of a 1x4096 OPS operating at channel rate of 160Gb/s by cascading two 1x64 OPSs in a fat-tree configuration. The 1x64 OPS utilizes an asynchronous and scalable optical label processor for in-band labeling. The label processor employs parallel all-optical label processing in combination with an asynchronous combinatory network. This results in a latency < 3 ns. The data-format transparency of the optical gates suggests possible switching of payloads with different modulation formats. Results show error-free operation with 2 dB of power penalty for the 1x64 OPS, and error-free operation with 5.7dB penalty after two cascaded OPSs.

Acknowledgements

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