ELectronics EXpress

IEICE Electronics Express, Vol.3, No.23, 504–508

Optical burst switching with burst collision resolution using a fast 4x4 PLZT switch

Abdullah Al Amin[1a)], Katsuhiro Shimizu[1], Mitsuru Takenaka[1], Ryo Inohara[2], Kohsuke Nishimura[2], Yukio Horiuchi[2], Masashi Usami[2], Yutaka Takita[3], Yutaka Kai[3], Yasuhiko Aoki[3], Hiroshi Onaka[3], Toshiharu Miyahara[4], Tatsuo Hatta[4], Kuniaki Motoshima[4], and Yoshiaki Nakano[1]

[1] *Research Center for Advanced Science and Technology, University of Tokyo 4–6–1 Komaba, Meguro-ku, Tokyo 153–8904, Japan*

[2] *KDDI R&D Laboratories Inc., 2–1–15 Ohara, Fujimino, Saitama 356–8502, Japan*

[3] *Fujitsu Limited, 4–1–1 Kamikodanaka, Nakahara-ku, Kawasaki 211–8588, Japan*

[4] *Mitsubishi Electric Co. 4–1, Mizuhara, Itami, Hyogo 664–8641, Japan*

a) *amin@hotaka.t.u-tokyo.ac.jp*

Abstract: An optical burst switching (OBS) node with a fast 4x4 PLZT (Lead Lanthanum Zirconate Titanate) optical matrix switch and an electronic label processor is presented. Successful collision detection and collision resolution is demonstrated by two methods: deflection routing and shared wavelength conversion. Error-free performance at 10 Gbps payload was achieved for both. Switching speed of 3.5 μs was achieved, demonstrating small data granularity in the order of 10 μs.

Keywords: OBS, matrix switch, wavelength conversion, collision resolution

Classification: Photonics devices, circuits, and systems

References

[1] C. Qiao, Y. Chen, and J. Staley, "The potentials of optical burst switching (OBS)," *OFC2003*, Atlanta, USA, p.TuJ5, March 2003.

[2] D. J. Blumenthal, J. E. Bowers, L. Rau, H.-F. Chou, S. Rangarajan, W. Wang, and H. N. Poulsen, "Optical signal processing for optical packet switching networks," *IEEE Commun. Mag.*, vol. 41, pp. 23–29, 2003.

[3] A. Sahara, Y. Tsukishima, K. Shimano, M. Koga, K. Mori, Y. Sakai, Y. Ishii, and M. Kawai, "Demonstration of connection-oriented optical burst switching network utilising PLC and MEMS switches," *Electron. Lett.*, vol. 40, pp. 1597–1599, 2004.

[4] A. Sugama, M. Ishii, T. Akahoshi, K. Sato, M. Doi, T. Shiraisi, M. Kato, and H. Onaka, "Electro-optic beam-deflection switch for photonic burst switching," *ECOC 2004*, Stockholm, p.Mo4.6.3, 2004.

[5] T. Miyahara, A. Sugitatsu, T. Hatta, K. Takagi, K. Matsumoto, T. Aoyagi, S. Nishikawa, S. Nishimura, and K. Motoshima, "Monolithically integrated SOA-MZI wavelength converter with assist DFB-LD," *OFC 2004*, Los Angeles, p.ThS4, 2004.

[6] Y. Horiuchi and M. Suzuki, "Demonstration of dynamic self-routing in

DOI: 10.1587/elex.3.504
Received October 13, 2006
Accepted November 13, 2006
Published December 10, 2006

an all-optical burst switched mesh network with four optical label switch routers," *OFC2003*, Atlanta, p.TuJ4, 2003.

1 Introduction

Optical burst switching (OBS) and optical packet switching (OPS) have attracted much attention in recent years, due to the potential ability to switch multi-tera bits/sec (Tbps) data in wide area networks (WAN)s with a small foot-print, low power consumption and cost [1, 2]. In OBS/OPS concept, data is forwarded in the optical domain without optical-electronic-optical (OEO) conversion by an optical switch that is controlled by an attached header label before each data packet. Since an end-to-end wavelength path may be idle sometimes due to lack of enough traffic, using fast switching enables increased bandwidth efficiency by use of statistical multiplexing.

So far there have been several reports of optical burst switching using ms order switches and one/two way signaling [3]; however for real time applications latency of ms-order can be detrimental. Many trials of ns-sized optical packet switching are reported [2], but these schemes usually require optical variable buffer memory to avoid contention, which is still an immature technology. On the other hand, optical burst switching using μs-switch and wavelength conversion for contention resolution can be a realistic solution: μs-order latency will not affect most real-time application, and scalability will be easier to simplicity of the switch and contention resolution.

In this letter we report an OBS node using a novel 4x4 PLZT (Lead (Pb) Lanthanum Zirconate Titanate)-based optical matrix switch that switches within a few μs [4]. We implemented a label scheme for autonomous forwarding and contention resolution in the OBS node. Two methods were implemented, namely deflection routing and shared wavelength conversion. We show error-free switching with very small power penalty of less than 3 dB using 10 Gbps payload.

2 Proposed node architecture

The proposed burst switching node architecture is shown in Fig. 1 (a). Multiple input and output links which are wavelength multiplexed to achieve a high capacity are interconnected by demultiplexers and an NxN space switch. This switch ideally should be non-blocking, bit-rate and format insensitive. We have used a switch that is based on 2D beam deflection by electro-optic effect for fast response and scalability to higher port count. PLZT-based electro-optic films were used for beam deflection upon application of electric field on triangular electrodes. A 4x4 matrix switch was built with 2 PLZT deflectors and glass-based slab waveguide and collimator lenses (Fig. 1 (b)). The electrodes were driven by DC voltages up to 200 V and were controlled by a FPGA (Field Programmable Gate Array) switch controller, which in turn received switching command from an external electronic label proces-

DOI: 10.1587/elex.3.504
Received October 13, 2006
Accepted November 13, 2006
Published December 10, 2006

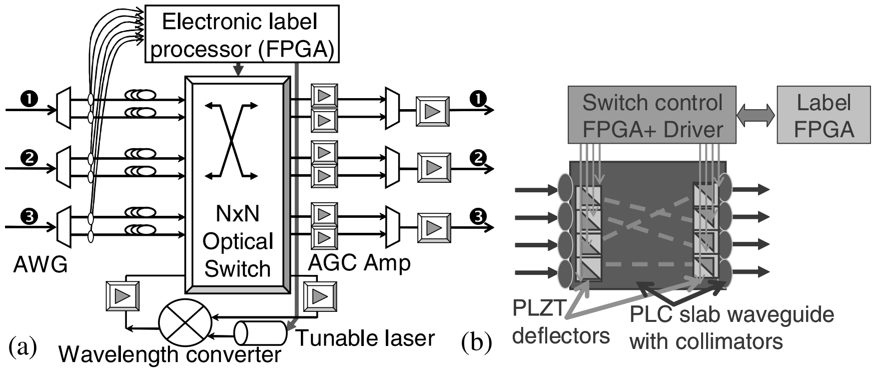

Fig. 1. (a) Proposed OBS node subsystem, (b) Sketch of the 4x4 PLZT switch

sor FPGA. The electronic label processor reads the source and destination information of each input burst, converting part of the input power by PDs to electronic signals. It then refers to an internal routing table and controls path setup and tear-down in the switch.

As some bursts may randomly try to access the same exit port simultaneously, the burst that comes late must be switched to another port or converted to another wavelength in order to achieve a low burst loss probability. We have implemented a shared wavelength converter scheme, where the routing table is programmed such that when a colliding burst is detected, the later one is switched to a fast tunable wavelength converter. The destination wavelength is controlled by label controller. For wavelength conversion, we used an active-passive integrated Mach-Zehnder interferometer semiconductor optical amplifier (MZI-SOA) module [5]. The converted burst then reenters the switch and is switched to a free port of the switch from where a 200 GHz channel spacing arrayed waveguide grating (AWG) multiplexes the burst into its intended link. If even the wavelength converter port is occupied, the burst can be deflected to another port, and subsequent nodes in the network can forward the burst to the correct destination.

We chose an in-band sub-carrier multiplexed binary phase shift keying (BPSK) label method (140 bits at 155 MHz), which do not need precise timing control with payload or RF signal processing [6]. The label format is bit polarity insensitive, which is useful when wavelength conversion in the inversion mode is implemented. The burst consist of a path setup label, payload and a release label. In order to generate the optical bursts, a tester with label generation and label analyzer function was implemented, which can generate up to 8ch of variable length bursts (9.95 Gbps PRBS $2^7 - 1$ payload). The label processor is implemented in FPGA, which reads the destination port from the label of incoming bursts asynchronously before the switch. It also maintains a user-programmable routing table with a maximum of 4 entries per destination address (DA).

DOI: 10.1587/elex.3.504
Received October 13, 2006
Accepted November 13, 2006
Published December 10, 2006

IEICE Electronics Express, Vol.3, No.23, 504–508

3 Burst switching and contention resolution experiment

In order to demonstrate dynamic label switching and contention resolution we have made a simplified burst routing and collision setup as shown in Fig. 2 (a). Bursts of 1 and 2 ms lengths were generated on wavelength 1554.1 nm by LN modulators, and transmitted from port 1 and port 2, respectively. In order to show contention resolution the bursts were made to collide sometimes on destination 1' and 2', which were instantly detected by the switch status table maintained in the label processor. Previously we needed to read the label again at port 3 input, however after reprogramming the controller FPGA, the path setup to and from port 3 can now be done simultaneously.

In case of burst collision, the burst that comes late cannot go to the 1st entry of its routing table, and subsequent options are tried. Here for simplicity, burst coming from port 1 (1 ms) is sent to port 4' in case of collision (deflection routing), and the burst coming from port 2 (2 ms) is wavelength converted to 1550.5 nm and then switched again to port 4'. Since the wavelengths are different, burst from different SA are easily separated with an AWG demultiplexer. The losses were compensated with burst compatible auto gain controlled Er-doped fiber amplifier (AGC-EDFA) which suppresses surge. During the label reading and switch setup time, the payload was delayed 25 μs by 5 km of single mode fiber (SMF).

The input and switched burst waveforms are shown in Fig. 2 (b). As can be seen, we have achieved 100% burst label recovery and contention resolution by wavelength conversion. The node latency was only 25 μs, corresponding to the 5 km delay line, which can be further reduced by optimizing switching time. As shown in Fig. 3 (a), the label reading and switch control need only a 3.5 μs to setup the new connection at optimized condition, which allow a guard time of $\sim$10 μs and data granularity of 10 μs order. 100 and 200 μs burst switching is shown in the bottom of Fig. 3 (a), as a proof of variable length burst switching ability.

BER measurements were done at the node exit for both after deflection

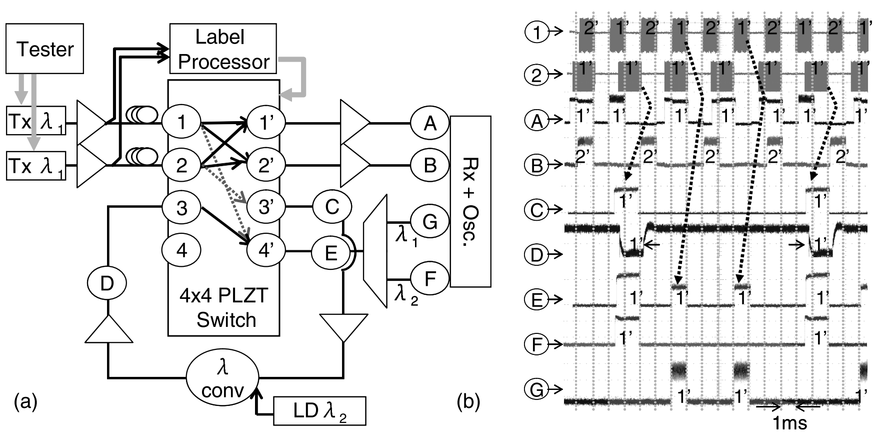

Fig. 2. (a) Experimental setup for burst switching. (b) Input and switched burst waveforms with contention resolution by wavelength conversion (trace F) and deflection (trace G)

DOI: 10.1587/elex.3.504
Received October 13, 2006
Accepted November 13, 2006
Published December 10, 2006

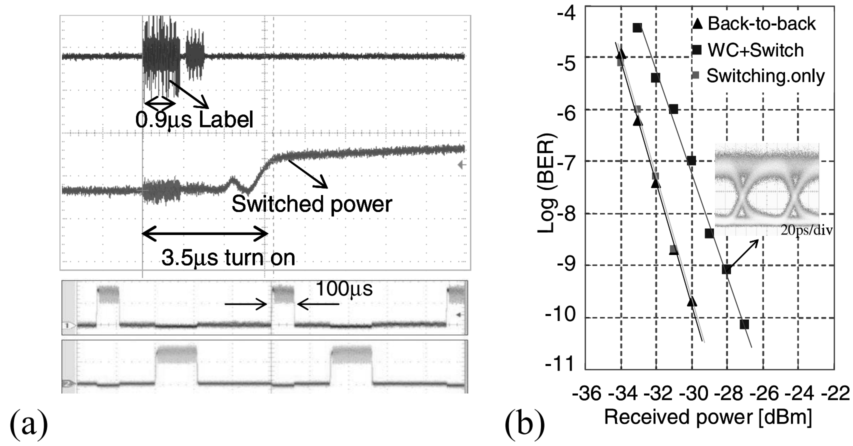

Fig. 3. (a) Switch setup time with optimized condition (top) and faster burst switching using 100 μs order burst lengths (bottom). (b) BER measurement results for switching and contention resolution

and wavelength conversion after switching (points G and D in Fig. 2 (a), respectively). Error-free contention resolution at 10 Gbps (PRBS $2^{31} - 1$) was achieved in both cases, with only 2.6 dB of power penalty for wavelength conversion and negligible penalty for the deflection case. Inset of Fig. 3 (b) also shows a clearly open eye after wavelength conversion. A further reduction of the penalty will be possible in the future with improvement of the devices used here.

4 Conclusion

In this letter we have described an optical burst switching node using a 4x4 PLZT matrix switch and wavelength conversion for the first time. Using an FPGA based label processor, asynchronous variable length bursts could be forwarded correctly and contention was solved with the help of burst-by-burst wavelength conversion or deflection routing. Error-free switching was achieved with low power penalty of 2.6 dB for switching and wavelength conversion. Even though the wavelength converter was only used with a fixed wavelength, efforts are underway to develop the full functionality of a stand alone optical burst switching node with capability of higher port counts and higher bit rates.

Acknowledgments

This work was done as part of "Photonic Network Project" of NEDO, under supervision of Optoelectronic Industry and Technology Development Association (OITDA).

DOI: 10.1587/elex.3.504
Received October 13, 2006
Accepted November 13, 2006
Published December 10, 2006