Optical Packet Switching and Associated Optical Signal Processing

D. J. Blumenthal, John Bowers, Yi-Jen Chiu, Hsu-Feng Chou, Bengt-Erik Olsson*, Suresh Rangarajan, Lavanya Rau and Wei Wang
University of California, Santa Barbara, CA 93106
Tel: (805) 893-4168; Fax: (805) 893-5705; Email: danb@ece.ucsb.edu
* Optillion AB, Sweden

Abstract

In this talk we will review functions for optical packet switching and ultra-fast network functions that can be handled using all-optical signal processing technologies. We will review research results utilizing ultra-fast all-optical nonlinear fiber wavelength converters and InP integrated optical wavelength converters. Application to all-optical label swapping and WDM/OTDM networks will be discussed.

Introduction

Within today's Internet, data is transported using optical fiber transmission and wavelength division multiplexing (WDM) systems that today carry a typical 32-80 wavelengths modulated at 2.5 Gbps to 10 Gbps per wavelength. Today's routers and electronic switching systems need to handle almost 0.5 Terabit per second in order to redirect incoming data from fully loaded WDM links. Things become interesting when we consider that the capacity of optical fibers continues to double every 8-12 months. Today's state-of-the-art single fiber capacity exceeds 10 Tbps. Comparing this increase with that of electronic processor speeds which doubles every 18 months (Moore's Law) and comes at the expense of increased chip power dissipation we see that there is a potential bandwidth mismatch in handling capability between fiber transmission systems and electronic routers and switching systems.

The story is more complex when we consider that future routers and switches will potentially terminate hundreds or thousands of optical wavelengths and the increase in bit-rate per wavelength will head out to 40 Gbps and beyond to 160 Gbps. Additionally, electronic memory access speeds only increase at the rate of approximately 5% per year, an important data point since memory plays a key role in how packets are buffered and directed through the router. It is not difficult to see that the process of moving a massive number of packets per second (100 million packets/second and beyond the 1 Billion packets/second mark) through the multiple layers of electronics in a router, can lead to router congestion and exceed the performance of electronics and the ability to efficiently handle the dissipated power.

Optical Packet Switching and Label Swapping

All-Optical Label Swapping (AOLS) is one technique intended to solve this potential mismatch between fiber capacity and router packet forwarding capacity. AOLS imparts the functionality to direct packets through an optical network without the need to pass these packets through electronics whenever a routing decision is necessary [1-6]. Inherent to this approach is the ability to route packets independently of bit-rate, packet or coding format and packet length. Therefore AOLS is not limited to IP packets, but can handle ATM cells, bursts, data file transfer and other data structures.

An example AOLS network is illustrated in Figure 1. IP packets enter the network through an "ingress" node and are encapsulated with an optical label and then re-transmitted on a new wavelength. Once inside the network, only the optical label is used to make routing decisions and the wavelength is used to dynamically redirect (forward) packets. At the internal nodes, labels are read and optically erased, then a new label is attached to the packet and the optically labeled packet is converted to a new wavelength using all-optical wavelength conversion. Throughout this process, the contents (e.g., the IP packet header and payload) are not passed through electronics and are kept intact until the packet exits the optical network through the "egress" node where the optical label is removed and the original packet is handed back to the electronic routing hardware.

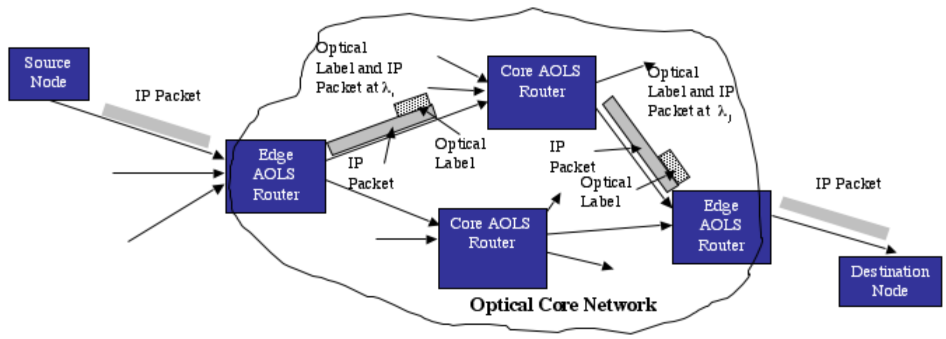

Figure 1. An optical label-swapping network.

The function of optical label swapping can be handled using the module architecture illustrated in Figure 2. These functions have been demonstrated using several wavelength converter technologies to perform optical signal processing functions. These functions and the InP based and nonlinear fiber technologies are summarized in the technology matrix shown in Figure 3. The optical signal processing functions performed by these technologies include optical data regeneration, optical label removal, optical label rewriting, and packet rate wavelength conversion.

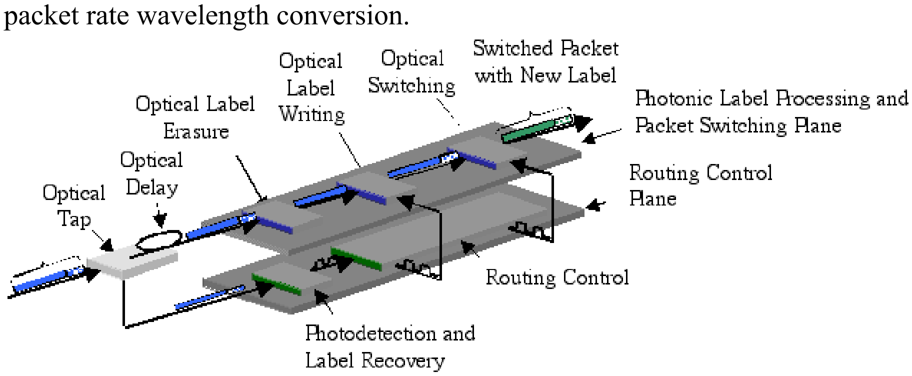

Figure 2. Optical label swapping module function.

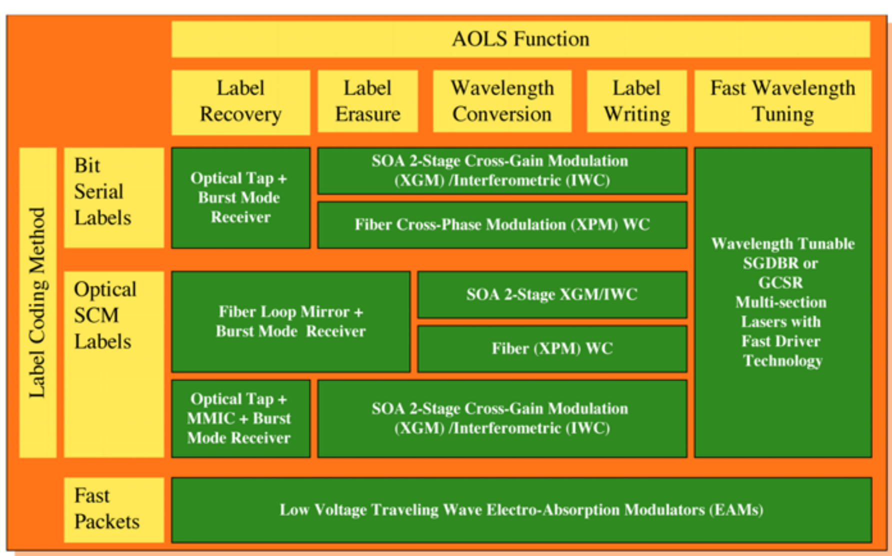

Figure 3. Optical label switching technology-function matrix.

Ultra-Fast WDM/OTDM Networks

The OTDM/WDM network shown in Figure 4 employs optical signal processing elements based on nonlinear fiber wavelength converters [7]. The basic elements are the WDM/OTDM and OTDM/WDM transmultiplexers and OTDM add/drop multiplexers [8-11]. These technologies have been demonstrated at 40 Gbps and 80 Gbps with multicasting capabilities and have the potential to scale to higher bit -rates.

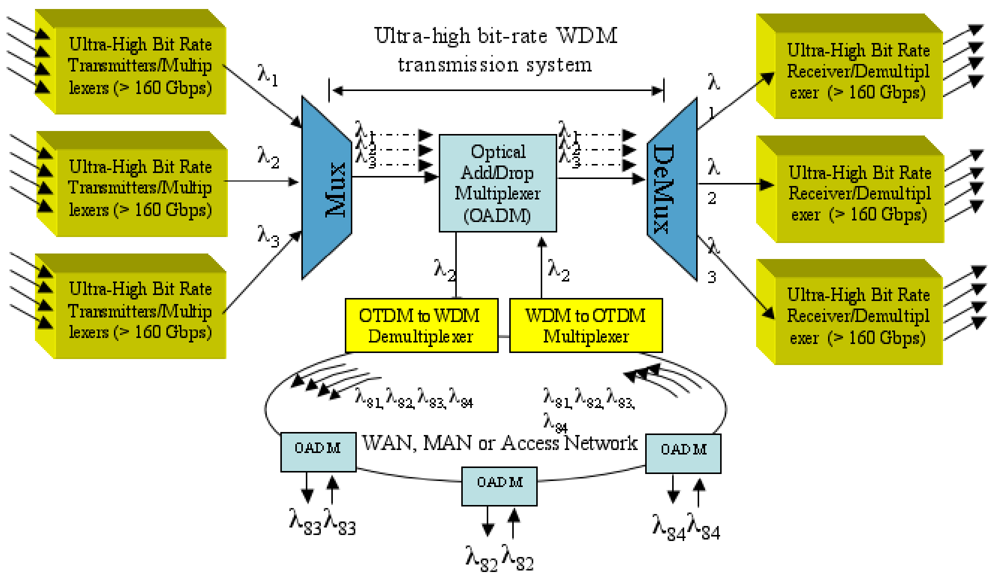

Figure 4. WDM/OTDM network based on ultra-fast all-optical wavelength converters.

[1] "Routing Packets with Light," D. J. Blumenthal, *Scientific American*, January (2001).

[2] "Photonic Packet Switches: Architectures and Experimental Implementations," D. J. Blumenthal, P. R. Prucnal, and J. R. Sauer, *Proceedings of the IEEE*, 82 (11), 1650-1667, November (1994).

[3] B. Bostica, A. Cappellari, M. Burzio, B. Vercellone, C. Guillemot, A. Gravey, P. Gravey, F. Masetti, M. Sotom, M. Renaud, "A Novel Packet Switching network Adopting Transparent Optical Packets," *CSELT Technical Reports*, Vol. 24, No. 6, CSELT, pp. 1049-56, Dec. 1996.

[4] D. J. Blumenthal, B-. E. Olsson, G. Rossi, T. Dimmick, L. Rau, M. Masanovic, O. Lavrova, R. Doshi, O. Jerphagnon, J. E. Bowers, V. Kaman, L. A. Coldren and J. Barton, "All-Optical Label Swapping Networks and Technologies," *IEEE Journal of Lightwave Technology, Special Issue on Optical Networks*, Dec. 2000.

[5] Y. M. Lin, W. I. Way, and G. K. Chang, "A Novel Optical Label Swapping Techniques using Erasable Optical Single0Sideband Subcarrier Label," *IEEE Photonic Technology Letters*, Vol. 12, pp. 1088-90, Aug. 2000.

[6] A. Carena, M. D. Vaughn, R. Gaudino, M. Shell and D. J. Blumenthal , "OPERA: An Optical Packet Experimental Routing Architecture with Label Swapping Capability," *IEEE Journal of Lightwave Technology, Special Issue on Photonic Packet Switching*, Vol. 16, No. 12, pp. 2135-45, Dec. (1998).

[7] "All-Optical Demultiplexing using Fiber Cross-Phase Modulation and Optical Filtering," B. E. Olsson and D. J. Blumenthal, *IEEE Photonics Technology Letters*, **13** (8), pp. 875-877, August (2001).

[8] "WDM to OTDM Multiplexing using an Ultra-fast All-Optical Wavelength Converter," B. E. Olsson, L. Rau and D. J. Blumenthal, *IEEE Photonics Technology Letters*, **13** (9), September, (2001).

[9] B. E. Olsson and D. J. Blumenthal, "80 to 10 Gbit/s Demultiplexing using Fiber Cross-Phase Modulation and Optical Filtering," *Proceedings of the IEEE/LEOS 13^TH^ Annual Meeting*, (LEOS '00) Puerto Rico, Paper TuB 4, pp. 159-160, November 13 – 16, (2000).

[10] L. Rau and D. J. Blumenthal, "Wavelength Multicasting Using an Ultra High-Speed All-Optical Wavelength Converter," *Technical Digest of the Optical Fiber Communication Conference (OFC '01)*, Anaheim, CA., March 17-23, (2001).

[11] "All-optical add-drop of an OTDM channel using an ultra-fast fiber based wavelength converter," L. Rau, S. Rangarajan, W. Wang and D. J. Blumenthal, *Conference on Optical Fiber Communications (OFC '02)*, Anaheim, CA, Mar 19-22 (2002).