WDM Optical IP Tag Switching with Packet-Rate Wavelength Conversion and Subcarrier Multiplexed Addressing

D. J. Blumenthal, A. Carena†, L. Rau, V. Curri†, and S. Humphries

Optical Communications and Photonic Networks Laboratory, Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106, Tel: (805) 893-4168, Fax: (805) 893-5705, Email: danb@ece.ucsb.edu. † Dipartimento di Elettronica Politecnico di Torino Torino, Italy

The exponential growth in Internet traffic has lead to a need to scale networks far beyond present speed, capacity and performance. Wavelength division multiplexed (WDM) fiber transmission and switching are seen as potential solutions to the performance and scaling bottlenecks and offer the potential for limited transparency to packet data-rate and format. However, Internet Protocol (IP) packet routing and forwarding presents a bottleneck as individual fiber link speeds approach Terabits/sec since packets must be processed at wire rates. The currently used packet forwarding process is IP header processing, where the destination address is processed on a hop-by-hop basis, and can pose a significant component of the packet forwarding bottleneck. An alternate approach is IP Tag Switching, a technique that has been proposed to simplify the packet forwarding process and enable scaling to Terabit rates [1].

In this paper we report the first experimental results of all-optical IP Tag Switching for WDM packet switched networks. This result demonstrates several features critical for future WDM optical IP tag routers including tag/header updating, packet-rate wavelength conversion and optical regeneration of the payload and tag/header. This experiment is based on the architecture proposed and simulated in [2] and combines optical subcarrier multiplexed (OSCM) addressing [3] with a cascaded cross-gain semiconductor optical amplifier wavelength converter (XGM SOA-WCs) and monolithically integrated interferometric wavelength converter (IWC) [4]. This cascaded WC architecture provides optical 2R regeneration, extinction ratio enhancement, wavelength conversion and reduced sensitivity to input power variations. Tag updating and regeneration is performed using a previously reported technique to remove and replace subcarrier headers during wavelength conversion without returning the baseband to the electronic domain [5]. This architecture also minimizes fiber dispersion induced power penalties for double-sideband modulated subcarrier signals since the tag is regenerated at each hop.

The WDM optical IP tag switching architecture is shown in Figure 1. An OSCM packet transmitter [6] modulates an RZ coded 150 Mbps header on a 16 GHz subcarrier. Headers consist of a 16 bit preamble, an 84 bit tag and a 4-bit framing sequence. We demonstrated tag switching with a NRZ coded 2.5 Gbps payload and packet duration of 1 μs as shown in Figure 2a. However, this subcarrier frequency will support baseband bit rates out to 10 Gbps. Tag/header clock and data are recovered on a packet-by-packet basis following a 10% fiber tap, an EDFA and an OSCM direct detection receiver. The OSCM receiver consists of a photodetector followed by distributed amplification, RF bandpass filtering and a Schottky barrier diode for square law detection. A SAW filter is used to recover the tag clock for each packet as shown in Figure 2b and a fixed digital delay is needed to realign data and clock. A tag switching processor performs serial-to-parallel conversion, computes a new tag, multiplexes it onto a RF subcarrier and sets a fast wavelength tunable laser to the new wavelength within 12ns.

A two stage modified XGM/XPM SOA-WC is used to perform wavelength conversion, optical header removal and header updating at the IP packet rate. The RF power spectrum of the incoming packet is shown in Figure 3a. Wavelength conversion using XGM in an SOA efficiently transfers the baseband payload but suppresses the RF subcarrier [5], effectively removing the old tag as shown in figure 3b. The XGM converts incoming WDM packets to a fixed internal wavelength (λ_{int}) allowing a fixed frequency optical filter to be used to recover the converted signal. The XGM also reduces the optical power dynamic range of incoming packets and is used to set a stable operating point for the IWC. One arm of an InGaAsP IWC [7] fabricated by Mats Gustavsson of Ericsson, Sweden, is injected with the filtered output of the XGM and the output of a rapidly tunable 4-section GCSR laser transmitter [8] is injected to both arms of the IWC. Two header reinsertion approaches were tried as shown in Figure 1. In the first approach, the injection current of the other SOA is directly modulated with the new SCM tag. In the second approach, the GCSR laser is externally modulated with the new SCM tag.

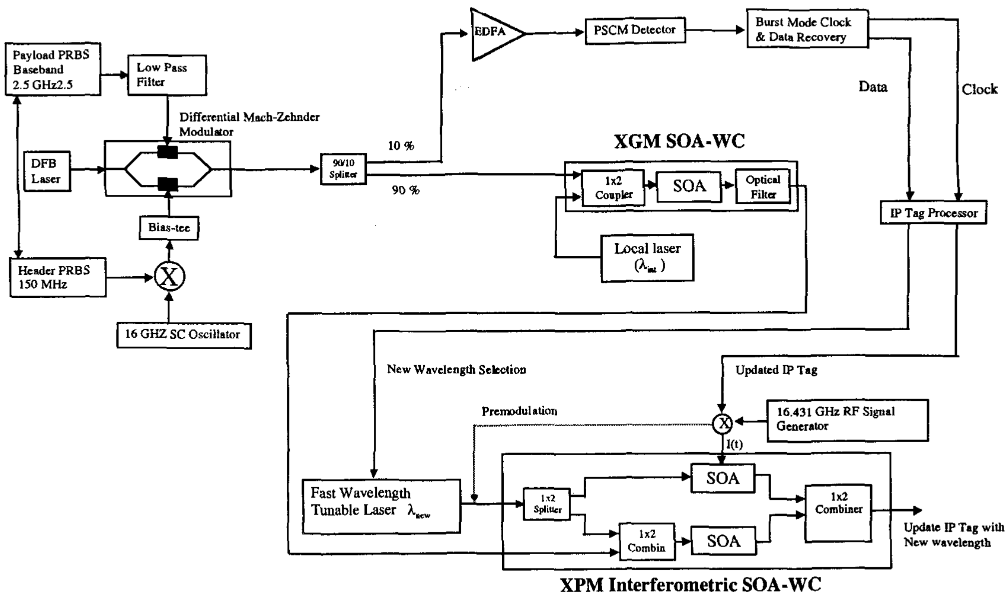

Figure 1. Architecture of WDM Optical IP Tag Switching Experiment using cascaded wavelength converters and optical subcarrier multiplexed tags.

The output of the WDM Optical Tag Switching experiment is shown in Figure 2C. The packets are cycled among four wavelengths and individually detected using a tunable optical filter. The pedestal is due to incomplete extinction ratio sacrificed in order to cover the complete wavelength range of the tunable laser using the IWC. The final signal is noninverting due to the inverting XGM and operation of the IWC in the inverting mode. We measured the transmission BER for the tag switched baseband payload and observed a 4 dB power penalty for all four wavelengths. This performance is expected to improve to include extinction ratio enhancement using optimally designed wavelength converters. The BER of the recovered SCM tag/header is shown in the right hand side of Figure 4. The shift between the transmitted signal and tag switched signal is due to introduction of an EDFA at the photoreceiver.

In summary we have demonstrated for the first time WDM all-optical IP Tag Switching with wavelength conversion and subcarrier multiplexed addressing. Switching over four wavelengths covering 16 nm was demonstrated with noninverting wavelength conversion of 2.5 Gbps payloads and burst mode recovery of tag/headers.

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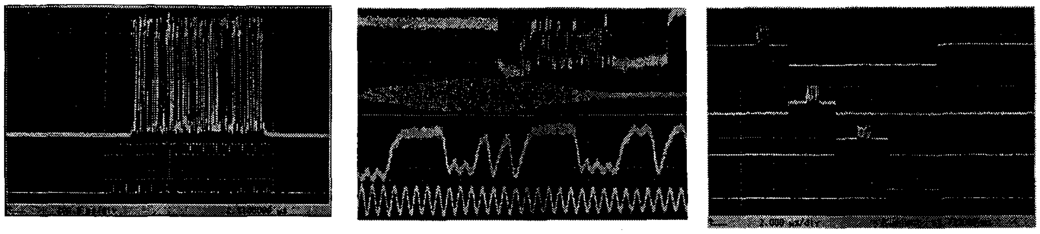

(a) (b) (c)

Figure 2. (a) Parallel received 2.5 Gbps payload (upper trace) and 150 Mbps Tag/Header (lower trace). (b) Recovered Tag/Header clock and data. (c) Output of Tag Switching experiment illustrating noninverting wavelength conversion at the packet rate between four output wavelengths.

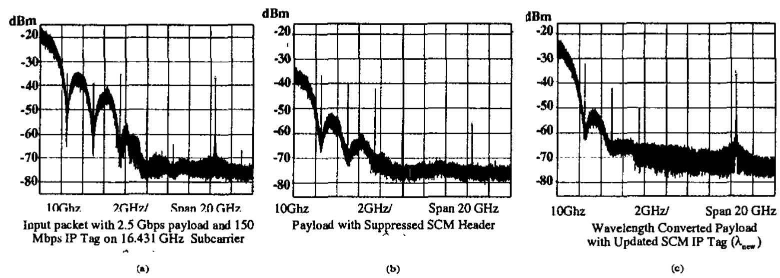

Figure 3. RF power spectrum for (a) packet input to tag switching setup, (b) output of XGM-WC showing SCM header suppression and (c) remodulated output of tag switching with wavelength conversion.

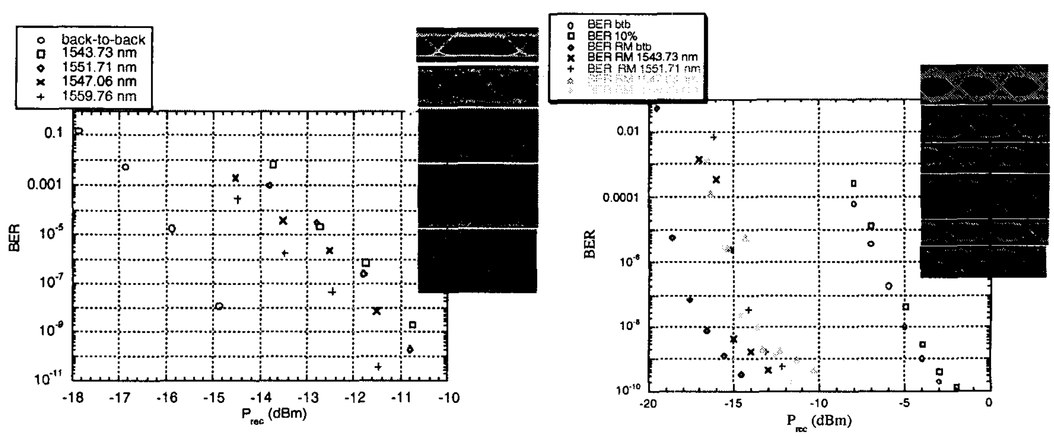

Figure 4. On Left: Measured transmission BER for output baseband payload for four different wavelengths and back-to-back. On right: Measured BER for recovered SCM Tag at transmitter and after Tag switching for four different wavelengths.