FS 10:30 AM - 12:30 PM
Murphy 2-3

Optical Packet Switching

Ioannis Tomkos, *Athens Info. Tech., Greece, Presider*

FS1 10:30 AM

Error-Free Multi-Hop Cascaded Operation of Optical Label Switching Routers with All-Optical Label Swapping

J. Cao, M. Jeon, Z. Pan, Y. Bansal, Z. Wang, Z. Zhu, V. Hernandez, J. Taylor, V. Akella, S. Yoo, *University of California, Davis, CA;* K. Okamoto, *NEL, Ibaraki, Japan;* S. Kamei, *NTT, Atsugi, Japan, Email: jcao@ucdavis.edu.*

This paper discusses multi-hop routing, all-optical label swapping operation of optical label switching routers that make real-time decisions based on the label and the forwarding table. The switching fabric conducts data regeneration and label rewriting.

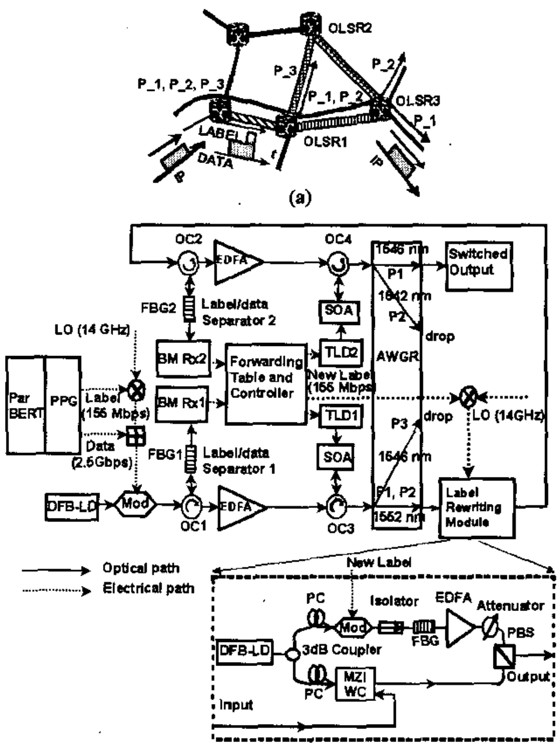
1. Introduction

Optical-label switching technology has made key progress in providing the low-latency and transparent switching desired for the next generation Internet [1-2]. For practical network applications, the optical routing system must be cascadable. Recent demonstrations have been limited to single-hop operations with label swapping [3], multi-hop operations without label or data regeneration [4]. High-performance optical-label switching routers are expected to include data and label regeneration with label swapping capabilities. This paper discusses an experimental demonstration of a cascaded multi-hop optical packet routing system with optical-label swapping. The system includes tunable lasers, wavelength converters, arrayed waveguide grating routers, burst mode receivers, a switch controller with a forwarding table, and an all-optical label-swapping module.

2. Experiments

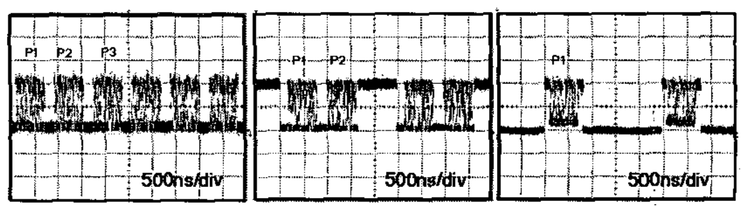
The experiment emulates a network with multiple optical-label switching routers, each providing label-based packet forwarding. Fig 1(a) shows an emulated optical-label switching network consisting of several optical-label switching routers (OLSR). Three types of packets, P1, P2, and P3 with labels L1, L2, and L3 respectively, ingress into the optical label switching networks. The first OLS router (OLSR1) performs the optical-label based forwarding of all three packets. OLSR1 forwards P3 north to a neighboring OLS router (OLSR2) and forwards P1 and P2 east to another neighboring OLS router (OLSR3). The OLSR3 in turn forwards P1 and P2 to two different output ports. For multi-hop scalable OLSR operations, data payload regeneration and label swapping/regeneration are beneficial. Fig 1(b) shows the detailed structure of OLSR and setup for this network emulation. As Fig 1(b) shows, the actual experiment places OLSR1 and OLSR3 on the same optical router system with multiple line cards and replaces OLSR2 with a drop port. The OLSR system consists of an optical-subcarrier multiplexing transmitter (SCM Tx), two optical label/data separators, two burst mode receivers (BMRx1 and BMRx2) for label detection, a field programmable gate array (FPGA) that implements the forwarding table and switching control, two tunable wavelength converters consisting of tunable lasers and semiconductor optical amplifiers (SOAs), a uniform-loss-cyclic frequency (ULCF) arrayed waveguide grating router (AWGR), a label rewriting module [5] and data receivers. The Parallel Bit Error Rate Tester/Pattern generator (ParBERT) synchronously generates the electrical label and payload signals. The $LiNbO_3$ external modulator modulates the continuous wave (CW) light from the distributed feedback laser diode (DFB LD) using a subcarrier multiplexed signal consisting of a baseband 2.5 Gb/s data payload and a 155 Mb/s label modulated onto a 14 GHz subcarrier. Hence, the modulated signal includes a double-sideband subcarrier label 14 GHz away from the center optical carrier frequency. The combination of a fiber Bragg grating and an optical circulator achieves all-optical label extraction [6]. The BMRx asynchronously recovers the label contents from optical domain to electrical domain. The recovered label signal induces the forwarding decision inside the switch controller according to the routing algorithm in the FPGA. Based on the forwarding decision, the switch controller sends a control signal to the tunable laser (TLD) to switch to the designated wavelength [7]. The TLD generates a tunable probe light for the SOA1, which modulates the payload signals onto the new wavelength by cross-gain modulation. Payloads with different labels are converted onto different wavelengths corresponding to the desired output ports of the AWGR.

The ParBERT generates repeated patterns of packet 1 (P1), packet 2 (P2), and packet 3 (P3) with different labels (L1, L2, L3). Fig 2(a) shows the three packets. The optical labels L1, L2 and L3 cause the wavelength of the TLD1 to be switched to $\lambda 1$ (1552nm), $\lambda 1$ (1552nm), and $\lambda 2$ (1546 nm) respectively according to the forwarding table. The tunable wavelength converter will convert P1 and P2 to wavelength 1552 nm and P3 to 1546 nm according to the optical-label based forwarding decision. After routing through the AWGR, P3 will be dropped and P1 and P2 go to the label-swapping module as shown in Fig 2 (b). This represents the OLSR1 in the emulated network. The switch controller generates new labels for payload P1 and P2 and drives the modulator inside the label-rewriting module with a 14 GHz carrier frequency. At the same time, payload P1 and P2 will be regenerated to the fixed wavelength (1555.7nm) in the SOA Mach-Zehnder Interferometer wavelength converter (SOA-MZI WC). The packets with the regenerated label and payload transmit to label / data separator 2. The BMRx2 recovers the new label contents and sends them to the switch controller. Again, according to the label contents, the switch controller sends control signals to the TLD2 to switch to the correct wavelengths. The new labels L1'



(b)

Fig. 1. (a) A schematic of the emulated network, and (b) an experimental setup for the multi-hop emulation of this network. ParBERT: Parallel Bit Error Rate Tester; PPG: Pattern Generator, LO: Local Oscillator; Mod: Modulator; FBG: Fiber Bragg Grating; BPF: Band Pass Filter; OC: Optical Circulator; BM Rx: Burst Mode Receiver; SOA: Semiconductor Optical Amplifier; LO: Local Oscillator; MZI WC: Mach Zehnder Interferometer Wavelength Converter; TLD:Tunable Laser Diode; AWGR: Arrayed Waveguide Grating Router; PC: Polarization Controller; PBS: Polarization Beam Splitter



(a) (b) (c)

Fig. 2. Scope traces showing (a) the incoming P1, P2 and P3, (b) P1 and P2 sent to the second hop after dropping P3, and (c) P1 at the final destination output after two-hop OLSR.

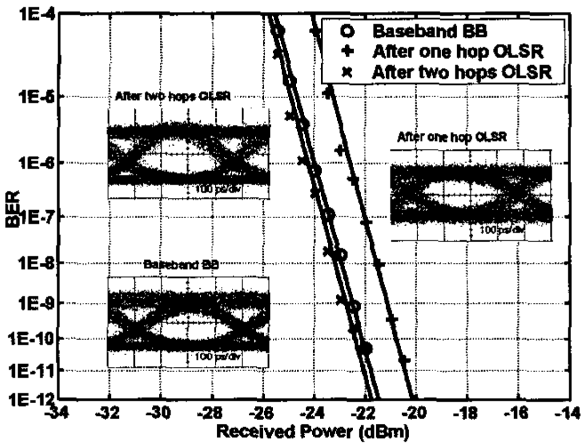


Fig. 3. BER test results of the cascaded OLSR
(Insets: eye diagrams of the baseband payload and signals after OLSR)

and L2' cause the wavelength of the TLD2 to be switched to λ1' (1546nm) and λ2' (1542nm) respectively. TLD2 drives the SOA2 that converts the payload signal onto the desired wavelength by cross-gain modulation. P1 converted to 1546 nm will be routed to the destination port. Fig 2(c) shows P1 on the destination port. P2 converted to 1542 nm will be dropped after AWGR. The switched data payload P1 goes to the data receiver for BER measurements. Here the switching with new labels L1' and L2' emulates the OLSR3 in Fig 1 (a).

Packet by packet bit-error-rate measurements took place on the P1 at each hop. Fig. 3 shows the measured data. Each packet is 600ns long with a 200ns guard time, thus each packet period is 800ns. The bit pattern was $2^{15}-1$ pseudo-random bit sequence (PRBS) truncated into the packets. The three curves in Fig. 3 are for the optical baseband back-to-back and the payload signals after one and two hop OLSR, respectively. The signal after one hop shows about 0.7 dB power penalty compared to the baseband payload signal. However, a negative power penalty about 0.2 dB at BER=1e-9 appears after 2 hop OLSR, which is mainly due to the 2R regeneration in the SOA-based MZI WC and the decrease of the received average power after two packet-dropping. The eye diagrams of the switched payload are shown as the insets in Fig. 3. All eye diagrams show clear openings. The signal-to-noise ratio was higher for the second hop compared to the first hop due to the 2R regeneration of MZI WC. Also the XGM based SOA wavelength converters invert the logic of the signal which leads to the change of the average power of signal. This results in a higher average power for the first hop. For the second hop the second XGM wavelength converter will invert the logic back to normal. For these reasons, the power received by the date receiver corresponds to different ratios of the real packet power for the 1-hop operation and the 2-hop operation. The combination of the 2R regeneration and the optical power change leads to the negative power penalty for the 2-hop operation.

3. Summary

We have demonstrated for the first time, to our knowledge, the error-free multi-hop cascaded operation of an all-optical label routing system with optical label swapping. The experiment emulated optical packet switching through 2 hops in the network. Experiment results show regenerating optical label switching with label swapping and 2R packet regeneration. The two-hop routing OLSR system demonstrates negative power penalty of 0.2dB at BER=1e-9 for data packets.

4. References

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FS2 **10:45 AM**

Optical Label Swapping and Packet Transmission Based on ASK/DPSK Orthogonal Modulation Format in IP-over-WDM Networks

N. Chi, L. Xu, L. Christiansen, K. Yvind, J. Zhang, P. Holm-Nielsen, C. Peucheret, C. Zhang, P. Jeppesen, *Research Center COM, Technical University of Denmark, Lyngby, Denmark, Email: nc@com.dtu.dk.*

We demonstrate all-optical label swapping based on SOA, EAM and HNLF for a two-level optically labeled packet using orthogonal ASK/DPSK modulation format. The ASK/DPSK packet is successfully transmitted over 80 km NZDSF.

1. Introduction

All-optical label switching is of increasing interest in future packet-switched WDM networks because individual packets can be switched through an optical network element without being converted from optical to electronic format [1]. Although the optical wavelength can serve as an optical label in the MPλS scheme [1], a second level of optical label is still necessary for provisioning, maintaining, and restoring switched light-paths. This second level optical label can be realised by sub-carrier modulation [2] or by an orthogonal modulation format combining amplitude shift keying (ASK) and differential phase shift keying (DPSK) modulation on a single carrier [3].

The structure of the optical label switching system for the ASK/DPSK packets is illustrated in Fig. 1. At the edge router the DPSK labels are added to the optical packets without modifying the ASK payload. The intermediate routers perform routing and forwarding operations within the local access networks or metropolitan networks by wavelength conversion and DPSK label swapping. However at the core router, switching is based on larger granularity such as wavelength, therefore only wavelength swapping is required but the DPSK label is preserved.

In this paper we demonstrate all-optical label swapping and packet transmission for a 10 Gbit/s ASK payload with 2.5 Gbit/s DPSK label. In the intermediate node, two-level optical label (wavelength label and DPSK label), are swapped using electro-absorption modulators (EAM) or semiconductor optical amplifiers (SOA), and in the core node the wavelength label is swapped while the DPSK label is entirely replicated through the four-wave mixing (FWM) effect in a highly-nonlinear fibre (HNLF). The transmission properties of the ASK/DPSK packet over 80 km non-zero dispersion shifted fiber (NZDSF) are also investigated. The successful label swapping and transmission experiment clearly demonstrate the feasibility of this combined modulation format scheme.

2. Optical label processing/swapping

The experimental setup is shown in Fig. 1(a). The signal source is a wavelength tunable external cavity laser (TL) working at 1552.5 nm. In the edge router, the optical carrier is first intensity modulated at 10 Gbit/s by a chirp-free Mach-Zehnder modulator. The DPSK label at 2.5 Gbit/s is then impressed by the subsequent phase modulator, thus making the optical packets ready for transmission. As we have reported before [4], a limited extinction ratio of 3-4dB for the payload is used in order to detect the DPSK label.

2.1 Intermediate node function: λ-label as well as DPSK label swapping

Both the λ-label and the DPSK label are swapped at the intermediate nodes so that an appropriate optical path can be built-up in the transmission fiber link. The DPSK label can be erased by an intensity-sensitive wavelength converter that copies the payload information onto a new wavelength while omitting the phase information of labels. In our experiment we erase the DPSK label by cross-gain modulation (XGM) -based wavelength conversion in a SOA. A narrow fiber Bragg grating is deployed directly after the SOA to overcome pattern dependence and to remove the frequency chirp [5]. Because the chirp induced by EAM-based wavelength conversion is negligible [6], the phase of the probe and pump signals is not affected in the wavelength conversion process. Therefore the DPSK label can be inserted by phase-modulating a new lightwave and then copying the payload onto it through cross-absorption modulation in an EAM. The SOA and the EAM used in our experiment were kindly provided by GIGA-Intel. At the receiver side, the ASK/DPSK packet is split into two parts after a 3dB coupler, so that the ASK payload and the DPSK label can be detected separately. The DPSK label is demodulated using a one bit delay fibre interferometer before direct detection. Fig. 2(a) shows the BER performance and the eye diagrams of the converted payload and the new label.