11-HOP OPERATION OF OPTICAL-LABEL SWITCHING SYSTEM WITH ALL-OPTICAL LABEL SWAPPING

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Abstract *This paper discusses multi-hop operation of an optical-label switching system, demonstrating rapid all-optical packet switching with 2R regeneration for the data and optical label swapping for the label.*

Introduction

Optical-label switching technology has the potential to provide low latency and transparency desired for the next generation Internet [1-2]. For network applications, the router must be cascadable. Moreover, data and label regeneration with label swapping capabilities are desired. Recent demonstrations have been limited to single-hop operations with label swapping [3], multi-hop operations without label or data regeneration [4]. This paper discusses an experimental demonstration of multi-hop (up to 11-hop) operation, in an optical packet routing system with 2R regeneration and optical-label swapping.

Experiment Descriptions

Using one optical-label switching router (OLSR) setup, the experiment emulates the multi-hop operation of many routers by sending the output packets of one linecard back to the input of the second linecard to form a loop. Fig. 1 shows the setup. The OLSR consists of an optical-subcarrier multiplexing transmitter (SCM TX), two label extractors (LE), two burst mode receivers (BMRX) for label detection, a switch controller that implements the forwarding table and switching control, two tunable wavelength converters (TWC) consisting of tunable lasers (TLD) and semiconductor optical amplifiers (SOA), a uniform-loss cyclic-frequency arrayed waveguide grating router (AWGR), and a fixed wavelength converter and label rewriting module (FWC & LR) [5]. The Parallel Bit Error Rate Tester (ParBERT) synchronously generates the electrical label at 155Mb/s and payload at 2.5Gb/s. The SCM TX mixes the label with a 14GHz tone, combines it with the payload, and modulates the optical carrier with the combined signal. Hence, the modulator output is a double-sideband optical signal with the payload as the baseband and the label as the subcarrier. The combination of a fiber Bragg grating (FBG) and an optical circulator (OC) 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. Based on the decision, the switch controller sends a control signal to the TLD to tune to the designated wavelength [7]. The TLD generates the probe light for SOA, which converts the payload information onto the new wavelength by cross-gain modulation (XGM). Payloads with different labels are converted onto different wavelengths corresponding to the desired output ports of the AWGR.

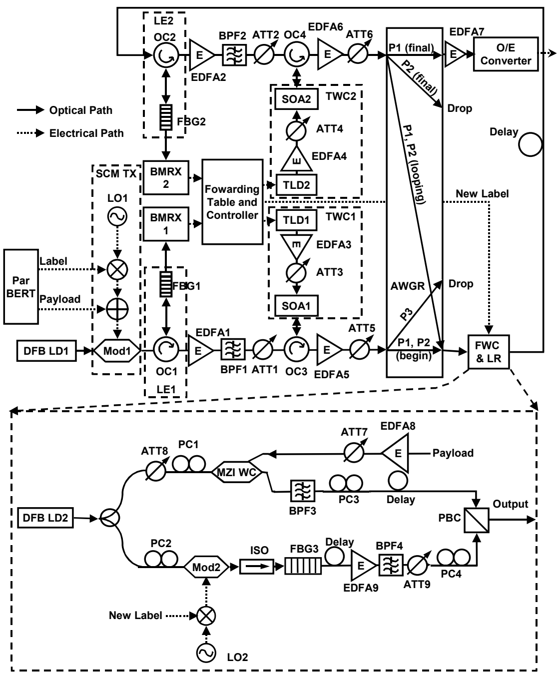
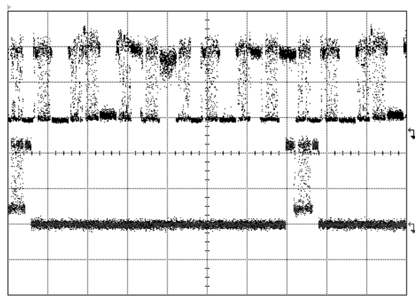


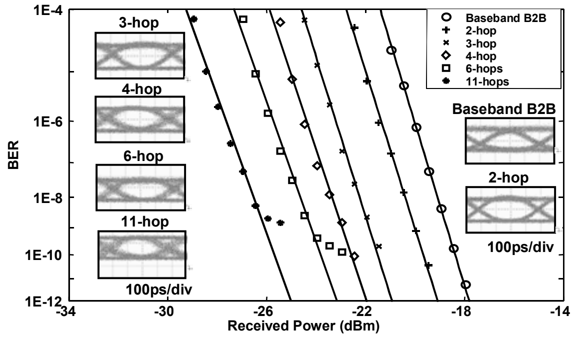
Fig. 1. Experimental setup.
ATT: Attenuator; AWGR: Arrayed Waveguide Grating Router; BMRX: Burst Mode Receiver; BPF: Band Pass Filter; FBG: Fiber Bragg Grating; LE: Label Extractor; LO: Local Oscillator; Mod: Modulator; MZI WC: Mach Zehnder Interferometer Wavelength Converter; OC: Optical Circulator; ParBERT: Parallel Bit Error Rate Tester; PBC: Polarization Beam Combiner; PC: Polarization Controller; SCM TX: Subcarrier Multiplexing Transmitter; SOA: Semiconductor Optical Amplifier; TLD: Tunable Laser Diode; TWC: Tunable Wavelength Converter.

In the experiment the ParBERT generates repeated patterns of packet 1 (P1), packet 2 (P2), packet 3 (P3) with different labels (L1, L2, L3). Each packet is about 614.4ns long with a 204.8ns guard time. The bit pattern is truncated 2^{15}–1 PRBS. The label contains destination information as well as a time-to-live (TTL) field that decides how many loops the packet should travel. L1 and L2 have the same TTL values. The TTL field of L3 is not used. According to L1, L2 and L3, the switch controller tunes the wavelength of TLD1 to λ1 (1544.3nm), λ1 (1544.3nm), and λ2 (1555.6nm), respectively. Thus P1 and P2 are converted to λ1, while P3 is converted to λ2. After the AWGR, P3 is dropped while P1 and P2 go to the FWC & LR module. The switch controller generates new labels L1' and L2' with the TTL fields decreased by 1. The new label mixes with the 14GHz subcarrier and drives the modulator in the FWC & LR. At the same time, payload P1 and P2 are regenerated to the fixed wavelength (1555.7nm) in the SOA-based Mach-Zehnder Interferometer wavelength converter (MZI WC) by cross-phase modulation (XPM). The converted payloads and the new labels form packets. The packets travel to line card 2, where by similar process the switch controller sends control signals to TLD2 according to the new labels. L1' and L2' cause the packets to be converted to λ1' (1548nm) if the TTL fields are greater than 0, or λ1'' (1552.2nm) and λ2'' (1563.6nm) otherwise. As a result, when the TTL fields are greater than 0, P1 and P2 continue to the FWC & LR to form a loop. At the same time the ParBERT only sends in P3 to avoid packet collision in the loop. When the TTL fields decrease to 0, P1 goes to the final output for BER measurements and P2 is dropped. At the same time the ParBERT resumes sending P1 and P2 to start a new round. Thus by using different TTL values, the experiment demonstrates 2, 3, 4, 6, and 11-hop operations.

Fig. 2 shows the experimental results. Fig. 2 (a) shows the packet waveforms for the 6-hop case. The top trace is from the tapping of EDFA2. The logic inversions from loop to loop is due to the XGM wavelength converter. The bottom is the final output of P1. Packet-by-packet bit error rate measurements take place on the final output of P1 for each hop count. Fig. 2 (b) shows the BER curves. The insets show the payload eye diagrams of the final output (P1), all with clear openings. The six curves are for back-to-back, after 2, 3, 4, 6, and 11 hops, respectively. Comparing with back-to-back, all other BER curves show unreasonable negative power penalties. This is due to the average power change resulted from the packet dropping and XGM-induced logic inversion. After the normalization of the received power, the penalties for 2, 3, and 4 hops are 0.2 dB, 0.1 dB and 0 dB, respectively, which are negligibly small. Error floors appear at BER=1E-10 for 6 hops and BER=1E-9 for 11 hops due to the accumulated timing jitter of XGM based wavelength converters and imperfect match in the looping delay. XPM-based wavelength converters and 3R regeneration could eliminate the timing jitter and improve the system performance, thus remove the error floor.



(a)



(b)

Fig. 2 Experimental results. (a) Waveforms of packets for the 6-hop case. Top: Tapping of EDFA2. Bottom: Final output (P1). (b) Packet-by-packet bit error rate test result. B2B: Back-to-back.

Conclusions

We demonstrate more than 10-hop cascaded operation of an optical packet switching system with optical-label switching and 2R regeneration. High-extinction ratio, clear-eye patterns, and regenerating performance imply prospects for future applications.

References

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