All-optical sub-carrier label-swapping with 2R regeneration

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Abstract: We propose and demonstrate an all-optical sub-carrier label-swapping subsystem with 2R regeneration and wavelength conversion. The experimental results show error-free operation as well as regenerating operation with negative power penalty.

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1. Introduction

Label-swapping technology is important for providing scalability in multi-protocol label switching (MPLS) and optical-label switching (OLS) networks. Optical sub-carrier multiplexing (SCM) is an attractive label-encoding scheme for accommodating both the sub-carrier label and the baseband data payload on the same optical wavelength channel but on separate modulation frequencies. Compared to bit-serial time-domain label-encoding techniques, SCM techniques facilitate the label swapping based on frequency-dependent separation of the label and the data payload. Optical-label swapping techniques reported to date involve relatively complex single side-band transmitters [1], nonlinear optical schemes with bulky fiber spools [2], or overmodulating schemes with inter-modulation penalty [3]. This paper proposes and demonstrates an all-optical label-swapping technique with 2R regeneration and no inter-modulation effect. The experiment shows error-free operation with negative power penalty.

2. Experiments

Fig. 1 shows the experimental setup for regenerative all-optical label swapping. It consists of two stages: the first stage performs label extraction of the incoming optical packet. The second stage performs label rewriting and 2R regeneration for data payload. Inside the left dashed-line box of Fig. 1 is a transmission line module consisting of two erbium-doped fiber amplifiers (EDFAs), one optical attenuator and a 75km SMF-28 fiber acting as the noise and dispersive element to test the regeneration capability of the label-swapping module. The parallel bit error rate tester (ParBERT) synchronously generates the electrical label and data payload signals. The SCM transmitter generates the optical packets using double-side band (DSB) SCM with a 14 GHz sub-carrier. A packet consists of a set of time-overlapping label and data payload. The label bit rate is 155 Mb/s while the data payload bit rate is 2.488Gb/s. The packet duration is 619.4 ns (1536 bit payload and 96 bit label), with 206.5 ns guard time between packets. The data payload contains a $2^{15}-1$ pseudo-random bit sequence (PRBS). The fiber Bragg grating 1 (FBG 1) has a sharp (~10 GHz FWHM) high reflectivity band (>99.9%) peaking at the same wavelength (1550.75 nm) as the wavelength of the SCM transmitter. Therefore, the FBG 1 reflects the baseband data payload signal and transmits the label signal, thus achieving all-optical separation and extraction of the label in label extractor 1 [4]. The transmitted label signal reaches the optoelectronic receiver for bit-error-rate (BER) performance measurements of the label. At the same time, the reflected data payload signal goes to the label-rewriting module after being amplified by an EDFA. The dashed-line box at the bottom right of Fig. 1 illustrates the schematic diagram of the optical-label rewriting module. It consists of a distributed feed-back laser diode (DFB LD2), a LiNbO$_3$ modulator, a 1x2 fiber coupler, two polarization controllers (PCs), a semiconductor optical amplifier based Mach-Zehnder interferometer wavelength converter (MZI WC, Alcatel 1901-ICM), an isolator, a FBG, an EDFA, an attenuator, and a polarization beam combiner (PBC). This setup achieves 2R regeneration of the data payload on one arm and sub-carrier modulation of the new label on the other arm, both onto a new wavelength. The DFB LD2 provides continuous-wave (cw) light to both arms through a 1x2 fiber coupler. The center wavelength of the DFB LD2 inside the label-rewriting module is 1555.73 nm. 50% of the cw emission travels to the SOA-based MZI WC to be used as a probe beam for wavelength conversion by cross-phase modulation driven by the data payload signal obtained by removing the label from the incoming packet in label extractor 1. The other 50% of the cw emission is modulated by the SCM signal containing the new label information generated by the switch controller (in this case ParBERT). In order to avoid interference with the data payload and the unwanted baseband cw component of the SCM, the setup includes FBG3 with peak reflectivity centered at 1555.73 nm, rejecting the baseband signal and allowing only the DSB SCM label signal to transmit. The isolator prevents feedback into the DFB LD2. The PBC ensures that the two optical signals from the two arms are combined together without any undesired coherent interference. The two PCs are
adjusted to achieve high throughput and optimum performance. Fig. 2 (i) and (ii) show the optical spectra measured at the input port (i) and at the output port (ii) of the MZI WC respectively. They contain only the baseband data payload. Fig. 2 (iii) shows the optical spectrum of the new label without baseband cw component measured at port (iii). Fig. 2 (iv) shows the final output spectrum measured at port (iv), and the result is a combination of the baseband signal containing the data payload and the SCM signal containing the new label. This combined signal is sent to label extractor 2, which has the identical structure as label extractor 1 except for the FBG2 peak wavelength (1555.73 nm) in order to achieve the BER measurement on the new label and the regenerated data.

Fig. 1 Schematic diagram of the experimental setup for regenerative all-optical label swapping
Two sets of accumulated packet-by-packet BER measurements were carried out for the setup with and without the transmission-line module shown in Fig. 1. Fig. 3 (a) shows the BER and eye diagrams of the label and payload without the fiber-transmission-line module. The label-swapping system imposes essentially no power penalty on either the label or the payload. Fig 3(b) shows the results for the second set of measurements where the transmission-line module was included to purposely inject deteriorated label and data payload signals to test the regeneration capability. The 25 dB attenuation in addition to the 75 km SMF fiber transmission followed by the EDFA resulted in the degraded extinction ratio of 8 dB for the data payload, which improved to greater than 13 dB after the 2R regeneration. As Fig 3 (b) indicates, the label-swapping system achieved a 3dB negative power penalty for the data payload and a 2.5 dB negative power penalty for the label for this set of measurement. The 2R regeneration effect for the data and the label rewriting effect for the label are clear in this measurement.
3. Summary
We proposed and demonstrated an all-optical label-swapping system with 2R regeneration and wavelength conversion. The all-optical label-swapping system achieves zero penalty for a high-quality input signal, and negative penalty for a deteriorated input signal for both labels and data payloads. The error-free, regenerating capabilities of the demonstrated all-optical label-swapping system imply its application in a scalable optical-label switching network.

4. References

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