All-optical SCM-to-TDM label format converters for interoperating optical-label switching networks

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Abstract: We propose and demonstrate all-optical label-encoding format conversion from subcarrier-multiplexing to time-domain-multiplexing for 156.25 Mb/s labels and 10 Gb/s payload. The experiments show error-free operations for with only 0.41 dB normalized power penalty for payload.

OCIS codes: (060.2330) Fiber optics communications, (060.4510) Optical communications

1. Introduction

Recently, there have been intensive research activities on optical-label switching (OLS) technologies [1]. The system demonstrations have included time-domain-multiplexing (TDM) [2], subcarrier-multiplexing (SCM) [3], and orthogonal modulation labeling schemes [4], and comparative studies have addressed advantages and disadvantages of individual labeling schemes [5]. In the future, OLS networks based on different optical labeling techniques may co-exist, and we expect needs to convert or adapt OLS signals between the OLS networks utilizing different label protocols and formats. In this paper, we propose and demonstrate an all-optical label-format conversion technique that achieves conversion of SCM-labeled OLS packets to TDM-labeled ones without involving optical-to-electrical-to-optical (O/E/O) conversion for either the label or the payload. The experimental results show low power penalty label format conversion. The successful experimental results indicate an important step towards realizing seamless interoperability between different OLS systems and networks without requiring complicated O/E/O conversions.

2. Experimental setup

Fig. 1 shows the experimental setup for all-optical SCM-to-TDM label format conversion. The parallel bit-error-rate tester (ParBERT) synchronously generates 156.25 Mb/s labels and 10 Gb/s data payloads in electrical baseband formats. The packetized label and payload produce an OLS packet every 1228.8 nsec. Each payload and label contains 8192 bits (819.2 ns) and 40 bits (256 ns), respectively. For the BER performance measurements, the payload and label both independently utilize 2^{31}-1 pseudo-random-bit-sequences. The SCM transmitter in a two-arm configuration modulates the label and the payload separately before combining them into an optical label switching packet [3]. Here, the distributed-feedback laser diode (DFB-LD) at 1549.19 nm provides CW light to both arms through the 50/50 fiber splitter. The $LiNbO_3$ modulator in the lower arm converts the payload to an optical format. After mixing with a 14 GHz subcarrier, the label drives the $LiNbO_3$ modulator in the upper arm, generating a double-sideband optical SCM signal. FBG1 has a narrow (~0.16 nm FWHM) high reflectivity band (> 99.9 %) peaking at 1549.19 nm. FBG1, together with the isolator, suppresses the optical carrier of the double-sideband SCM signal to avoid coherent crosstalk between the two arms [3]. The SCM label and the payload are then combined with a fiber coupler to form an OLS packet. Fig. 2(a) shows the optical spectrum measured at the output of the SCM transmitter. After being amplified, the OLS packet reaches Label Extractor 1 for label-payload-separation. Fig. 2(b) shows the spectrum of the SCM label after the separation. In the all-optical SCM-to-TDM converter, the SCM label first goes into the SOA (semiconductor optical amplifier) based counter-propagating wavelength converter. Since the SOA only has a low-speed response (< 2.5 GHz) for wavelength conversions, the cross-gain modulation (XGM) effect imprints the label as an optical baseband signal onto the CW light (at 1560.10 nm) from the DFB laser and suppresses the high-frequency subcarrier components [6]. Fig. 2(c) shows the spectrum of the label after the XGM. The spectrum indicates one main component at the baseband and two small (~ 28 dB below the main peak) second-harmonic subcarrier components, which rise from nonlinear wave mixing in the SOA. Since the label after the XGM acquires an inverted logic and a small extinction ratio (3.78 dB), we insert the second wavelength conversion stage employing SOA-MZI (Semiconductor optical amplifier based Mach-Zehnder Interferometer) to invert the polarity again and to improve the extinction ratio. The SOA-MZI improves the label extinction ratio to 7.57 dB and further suppresses the high-frequency components. Fig. 2(d) shows the label spectrum after the second wavelength conversion, and the second-harmonic components are hardly visible in this figure. The all-optical TDM-label rewriter takes the payloads from Label Extractor 1 and the labels from the SCM-to-TDM converter to form TDM-labeled OLS packets. The fiber delay line (170 m) compensates for the label processing delay of the SCM-to-TDM converter and aligns the timing to avoid label-payload collision in the time domain. In the all-optical TDM-label rewriter, a four-port SOA-MZI working in the differential mode builds TDM-labeled OLS packets by converting the labels and the payloads to a new wavelength (1554.60 nm). Fig. 2(e) illustrates the spectrum of the TDM-labeled OLS packets at the output of the TDM-label rewriter. The O/E converter then converts the TDM-labeled packets to an electrical format and forwards them to the BERT for BER measurements. The gating function in the BERT separates the label and the payload in the time domain.

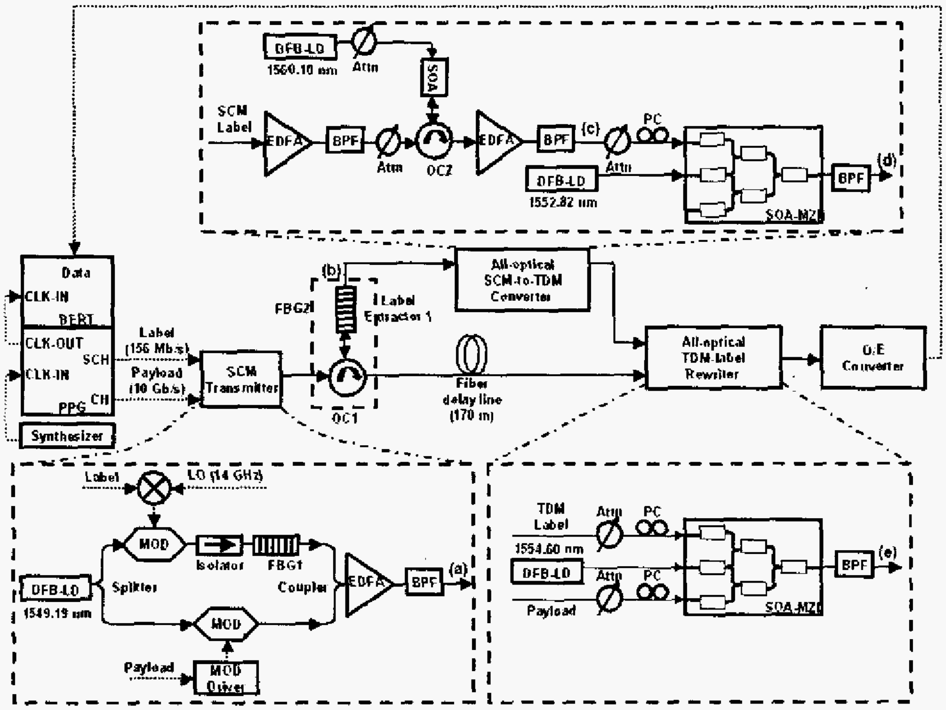

Fig. 1. Experimental setup of all-optical SCM-to-TDM label format conversion
(PPG: Parallel Pattern Generator; BERT: Bit Error Rate Tester; LO: Local Oscillator; DFB-LD: DFB Laser Diode; Mod: $LiNbO_3$ Optical Modulator; OC: Optical Circulator; FBG: Fiber Bragg Grating; EDFA: Erbium Doped Fiber Amplifier; BPF: Optical Band-pass Filter; Attn: Optical attenuator; PC: Polarization Controller; SOA: Semiconductor Optical Amplifier; SOA-MZI: Semiconductor Optical Amplifier based Mach-Zehnder Interferometer Wavelength Converter)

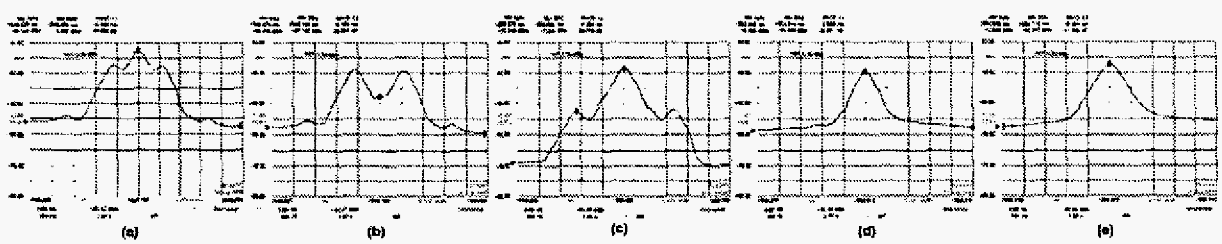

Fig. 2. Optical spectra (measured in 1 nm wavelength span and 0.06 nm resolution bandwidth) of (a) output of the SCM transmitter, (b) SCM label after Label Extractor 1, (c) label after the XGM wavelength conversion in the SCM-to-TDM converter, (d) label after the SOA-MZI in the SCM-to-TDM converter, (e) output of the TDM-label rewriter

3. Experimental results and discussion

Fig. 3(a) shows the packet sequence of the SCM-labeled OLS packets after Label Extractor 1. The timing relation illustrates that the label and the payload are overlapping in the time domain. Fig. 3(b) is the zoom-in view of the bit-patterns of the label and the payload. Fig. 3(c) shows the packet sequence of the TDM-labeled OLS packet after the TDM-label rewriter. The labels sit on the guard-time between payloads, and there is no label-payload collision. The amplitudes of the label and the payload are also aligned. Fig. 3(d) is the zoom-in view of the bit-patterns of the label and the payload.

Fig. 4 shows the BER measurement results and the eye-diagrams. The eye-diagrams of the labels were taken after an OC-3 electrical low-pass filter. The BER measurements indicated no detected error-floor above 1E-13 for both the labels and payloads. The system power penalties at 1E-9 for the label and the payload are 1.16 dB and 1.49 dB, respectively. However, these power penalties do not indicate true system penalty, since we measured the average receiver power before the O/E converter in the setup and separated the TDM label and the payload after the O/E converter. Both the TDM label and the payload contributed to the average receiver power, although only one of the two contributions should have been included. True system penalty estimations require average power normalization steps. The estimations of true penalty based on duty cycles and extinction ratios of the label and the payload indicate that the TDM label contributes 1.08 dB to the payload penalty and that the true payload penalty should be approximately 0.41 dB. Since the input SCM-label is a carrier-suppressed double-sideband signal while the output TDM-label is an optical baseband signal, the true label penalty estimation procedure is quite complicated and is beyond the scope of this paper.

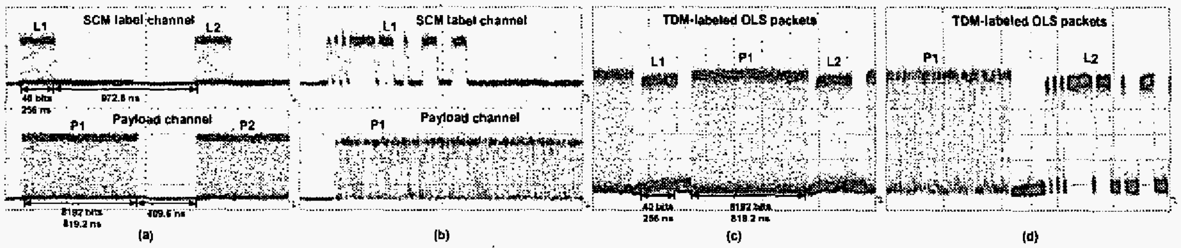

Fig. 3. Packet sequences of (a) SCM-labeled OLS packets (200 ns/div), (b) zoom-in view of SCM-labeled OLS packets (50 ns/div), (c) TDM-labeled OLS packets (200 ns/div), (e) zoom-in view of TDM-labeled OLS packets (50 ns/div)

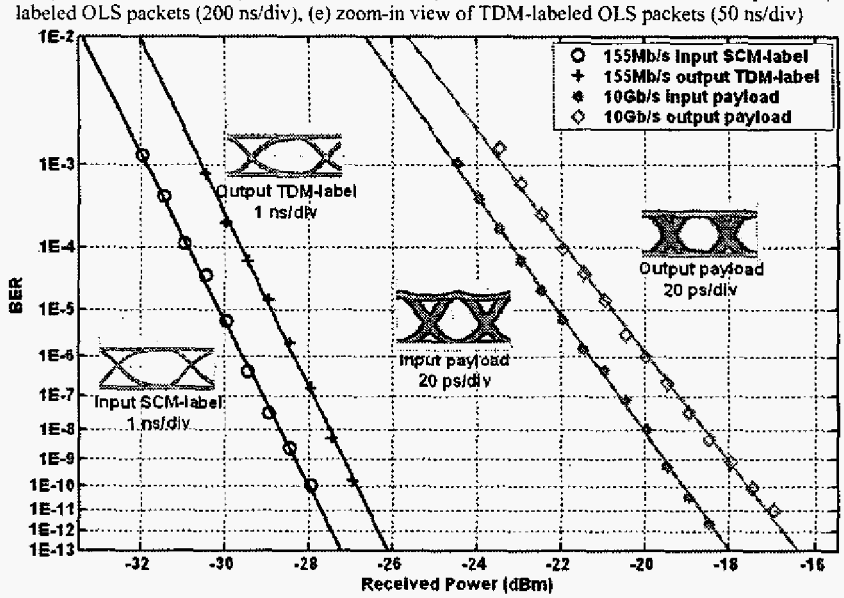

Fig. 4. BER measurement results for the label and the payload before and after the labeling format conversion operation

4. Summary

We proposed and demonstrated an all-optical SCM-to-TDM label format conversion technique for 10 Gb/s OLS networks. The system achieves error-free operations on both the label and the payload with less than 0.5 dB penalty on the payload.

5. References

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