FWM-Based SAC Label Recognition for Optical Packet Switched Networks

S. Alireza Nezamalhosseini[1,2], M. Rezagholipour Dizaji[1], Kerim Fouli[3], Lawrence R. Chen[1], and Farokh Marvasti[2]
[1] Department of Electrical and Computer Engineering, McGill University, Montreal, QC H3A 2A7 Canada
[2]Department of Electrical Engineering, Sharif University of Technology, Tehran, Iran
[3]was with INRS, Montreal, Canada; now with Research Laboratory of Electronics, MIT, Cambridge MA, USA

Abstract: We propose a flexible four-wave mixing-based label recognition technique for low-weight spectral amplitude codes in optical packet-switched networks. We experimentally demonstrate label recognition, packet switching, and error-free transmission.

1. Introduction

The course granularity of wavelength switches in current fiber optic transmission systems and also the fast growth of high-bandwidth applications results in inefficient use of available fiber capacity [1]. Optical packet switching (OPS) is the one solution for providing fine granularity and high bandwidth efficiency as well as high network utilization [2]. In OPS, payloads are optically switched at forwarding nodes based on the optical label (OL) without being processed, and therefore slow and power consuming opto-electronic conversion is avoided [3]. In [4], weight-2 spectral amplitude codes (SAC) were used as the OLs. To recognize the different OLs, a four-wave mixing (FWM) based approach was used whereby the OLs were input in a nonlinear medium (NLM). A proper code design was achieved if for each OL, the two generated FWM idlers were non-overlapping for at least one of the idlers; this unique idler is referred to as the label identifier (LI). An AWG was then used to isolate the LIs after which a suitable control signal would be generated. Owing to the fixed and equal wavelength spacing between AWG outputs, by increasing the number of labels, it becomes more difficult to select wavelengths that will generate unique LIs that can be filtered. We propose a new FWM-based recognition method for SAC OLs in which fiber Bragg gratings (FBGs) are used instead of an AWG. Our approach provides increased freedom in selecting the wavelength set for OLs and makes the code design process less challenging as the interference in the wavelength domain can be avoided more readily compared to AWG-based recognition methods in which equally-spaced wavelengths are generally set by the AWGs. Moreover, our design decreases device footprint since only two photodiodes (PDs) are used regardless of the number of labels, whereas in [4] the number of PDs is equal to the number of possible labels.

2. Label recognition for SAC-labels based on FWM

Fig. 1(a) shows the optical packet format: OLs consist in two wavelength tones selected from a wavelength bin while the payloads are transmitted at a different (but common) wavelength. The labels and payloads are transmitted simultaneously and the packets can have various durations. Label extraction can be easily performed using proper optical filters (Fig. 1(b)). The extracted OL is passed through a NLM (e.g., highly nonlinear fiber (HNLF) or semiconductor optical amplifier (SOA)) to generate two FWM idlers. The output of the NLM reaches the power splitter through the second port of a circulator. In one branch, the output of the NLM is detected using PD1. In another branch, the output of the NLM reaches a set of FBGs with reflection wavelengths corresponding to the LIs. The FBGs are physically separated by short lengths of fiber, X_k. If the input OL generates the kth LI at the output of the NLM, it will be reflected by the corresponding FBG back through the power splitter and the circulator towards PD2, appearing at a delay of τ_k with respect to the signal received by PD1. τ_k, called the characteristic delay, is uniquely associated with the kth LI and is proportional to the sum of length of fibers that the LI passes before getting reflected by its corresponding FBG. LIs will then be detected using a simple electronic processor (EP) by measuring the characteristic delay and a control signal corresponding to the detected label will be generated. Fig. 1(c) shows different characteristic delays for different labels.

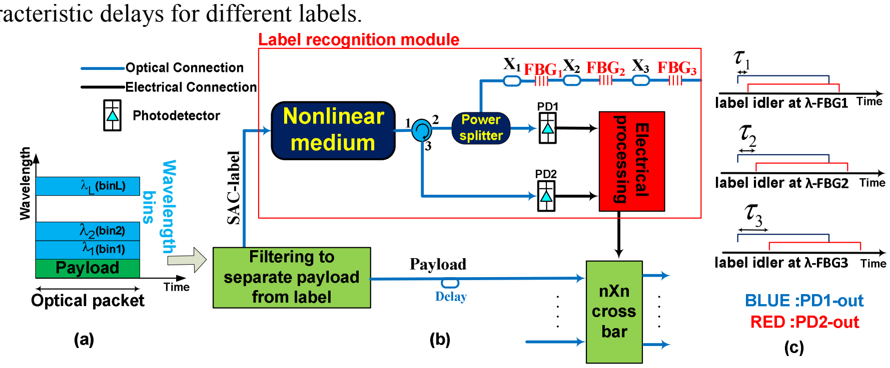

Fig. 1. a) Optical packet with SAC labels, b) structure of the forwarding node, c) different delays between two signals for different labels.

3. Experimental setup and results

The setup is shown in Fig. 2. At the packet generator, two packets are generated. The packet durations are 1 μs, and 0.5 μs with 0.25 μs gap between them. Two separate laser sources both tuned to the same wavelength (λ_3) are modulated by 2^{15}-1 PRBS to generate 10 Gb/s NRZ-OOK data signals, representing the payload bits. The labels are modulated at the packet rate and are ON for the time duration of their corresponding payloads. The payloads and labels are coupled to form the packets (Fig. 2, point A). After propagating through a 50 km dispersion compensated link, at the forwarding node, the payload is filtered out by a notch filter. The FWM idlers are produced after the OL is passed through a HNLF, see Fig. 3(a). The electrical outputs of the two PDs are received by the EP, which contains two slow analog comparators with 150 MHz bandwidth followed by a complex programmable logic device (CPLD). By measuring the amount of delay between these two signals, the OL can be recognized. Upon recognition of the label, a control signal of duration equal to the packet is generated by the EP to drive MZM5 which emulates an optical switch to switch one of the two packets (Fig. 2, points E and F). Fig. 3(b) shows the BER versus the average received power for the two payloads after being switched. Label recognition is performed without any errors and error-free transmission is achieved.

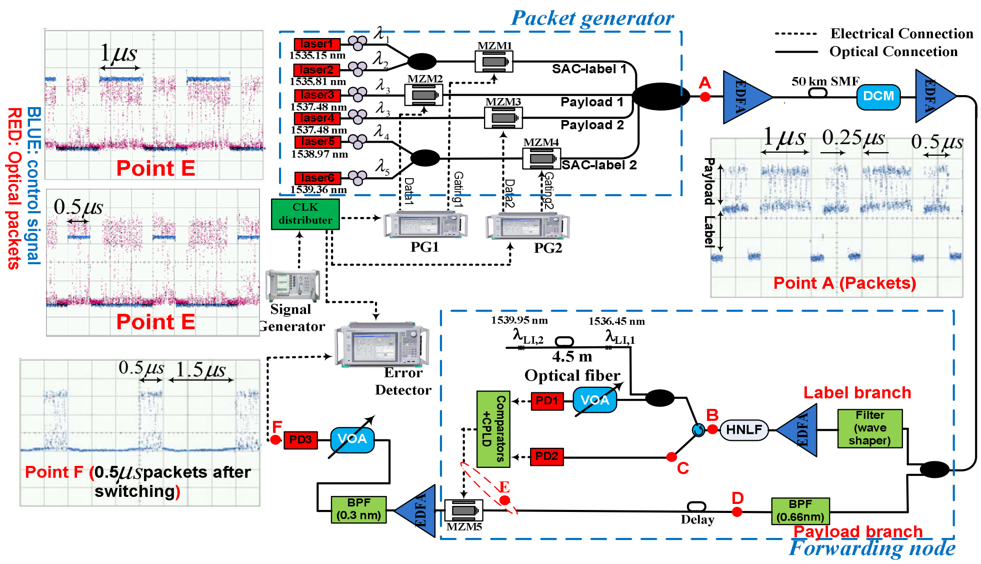

Fig. 2. Experimental setup of the packet switching with SAC-labels, with insets showing the recorded waveform at various points. MZM: Mach Zehnder Modulator, EDFA: Erbuim-doped fiber amplifier, DCM: dispersion-compensating module, VOA: Variable Optical Attenuator.

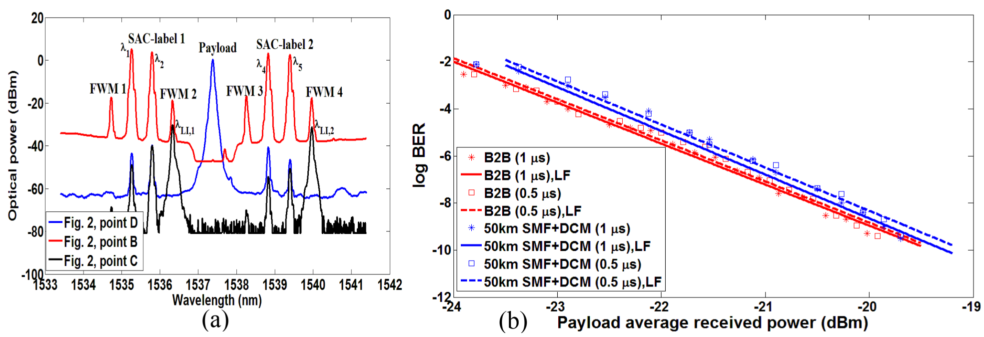

Fig. 3. a) Optical spectrum analyzer traces of SAC labels and their FWM idlers, as well as the extracted payload, and FWM idlers reflected back by FBGs, b) BER versus average received power for back-to-back, and after 50 km of SMF with DCM. LF: Linear fitting.

4. Conclusion

We have demonstrated a flexible FWM based recognition technique for SAC labels. We have experimentally verified successful forwarding of packets after transmission over a 50 km dispersion compensated link. Further details regarding scalability and latency will be discussed at the meeting.

References

[1] G. Cincotti *et al.*, Proc. OFC'05, paper PDP37.

[2] M. J. O'Mahony *et al.*, IEEE Communication Magazine, Vol. 19, 128-135 (2001).

[3] S. J. Ben Yoo, Journal of Selected Topics in Quantum Electronics, Vol. 17, 406-418 (2011).

[4] J. B. Rosas-Fernández *et al.*, Journal of Selected Topics in Quantum Electronics, Vol. 14, 868-878 (2008).