Optical Regeneration

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***Abstract*—In this technical report, we provide a brief review on our research efforts on optical regeneration. Specifically, our studies tried to tackle the problem of signal quality degradation due to transmission impairments in ultra-high speed optical networks. Optical 3R regeneration (*i.e.*, the Re-amplification, Re-shaping and Re-timing) was investigated, for which we formulated theoretical models, designed and implemented systems, and conducted both numerical simulations and experimental demonstrations. The studies were mainly based on optical devices that leverage semiconductor optical amplifier-based Mach-Zehnder interferometers (SOA-MZIs), but other interesting devices, such as SOA-based asymmetric Sagnac loops, were also considered.**

***Index Terms*—All-optical regeneration, Semiconductor optical amplifier-based Mach-Zehnder interferometer (SOA-MZI).**

I. Introduction

It is known that the major technical difficulty for realizing efficient and scalable ultra-high speed optical communications and networking systems is due to the physical-layer impairments. In order to address this issue, we have considered to leverage the optical regeneration that can re-amplifies, re-shapes and re-times the degraded optical signals through in-line and cascaded operations, *i.e.*, optical 3R regenerator can be realized. In this report, we first describe our efforts to design several optical regeneration systems in Section II. Then, Section III discusses the scalability and cascadability of the proposed systems. Next, the applications of the optical regeneration systems in optical-label switching (OLS) and energy-efficient optical networks are presented in Section IV. Finally, Section V summarizes the report.

II. Design of Optical Regenerators

Fiber transmission and optical switching will impose power losses, waveform changes, and timing jitter on optical signals, and moreover, the negative effects can accumulate when their transmission distances and/or switching hops increase [1–4]. To address these issues, our research designed optical 3R regenerators. The functionalities of re-amplification and reshaping were realized by leveraging the nonlinear power transfer functions of semiconductor optical amplifier-based Mach-Zehnder interferometers (SOA-MZIs) [5, 6] and SOA-based asymmetric Sagnac loops [7]. For the re-timing part, we utilized signal processing with optical filtering and optical-to-electrical-to-optical (O/E/O) based clock re-modulation, and demonstrated all-optical clock recovery and re-timing for various signal formats, including intensity-modulated return-to-zero (RZ), intensity-modulated non-return-to-zero (NRZ), dispersion-uncompensated RZ, and NRZ-DPSK [8].

III. Cascadability of Optical Regenerators

Note that, the whole meaning of using optical regenerators is to decrease the accumulation of bit-errors during signal transmission. Therefore, the cascadability/scalability of optical regenerators is the major metric for performance evaluation. We formulated a theoretical model that can precisely predict the jitter and amplitude noise accumulations in cascaded all-optical regenerators in [9]. Meanwhile, by utilizing the insights obtained with the model, we conducted numerous experiments to evaluate the cascadability of our optical regenerators with both lab fibers [10, 11] and field fibers [12]. The experimental results demonstrated that our proposed optical regenerators can achieve superior cascadability for achieving error-free signal transmissions after more than a million kilometers transmission and/or 10,000 times of cascaded operations.

IV. Applications of Optical Regeneration

Due to the superior performance of our proposed optical regenerators, they can be applied to numbers of optical transmission/networking systems to improve their performance. Hence, in our research, we considered two use cases, *i.e.*, for optical-label switching (OLS) and energy-efficient optical networks. Optical-label switching is a technology that can combine the advantages of both electrical and optical processing to realize highly-efficient optical packet switching. Specifically, the optical packets consists of the labels for control information and the payloads for data transmission, and the low-speed labels are extracted every hop for flexible switching configuration while the high-speed payloads stay in the optical domain for ensuring high-speed data transmission. Optical 3R regeneration can effectively improve the cascadability of OLS routers, which had been verified in our experimental demonstrations [13–15]. Specifically, we use experimental results to confirm that the cascadability of OLS routers can be enhanced to over 1000 hops of cascaded operations.

Meanwhile, due to the fact that optical regenerators can improve signal quality in the optical domain and save energy-hungry O/E/O conversions, they can be incorporated in optical networks to improve their energy-efficiency effectively. By leveraging this idea, we proposed to a mixed regenerator placement scheme to improve the energy-efficiency of translucent optical networks in [16]. Then, based on the scheme, we developed a few time-efficient algorithms to realize joint regenerator placement and routing and wavelength assignment (RWA) for energy-efficient optical networks [17–19]. Moreover, we also tried to balance the tradeoff between energy-efficiency and survivability of such translucent optical networks in [20]. The numerical results suggested that compared with the traditional translucent optical networks that only consider O/E/O regenerators, our proposal that introduces the mixed placement of O/E/O and all-optical regenerators can effectively improved the networks' energy-efficiency while maintaining the signal transmission quality as unchanged.

V. Conclusion

For the topic of optical regeneration, we designed several optical regeneration systems, evaluated their scalability/cascadability experimentally, and considered their applications in optical-label switching (OLS) and energy-efficient optical networks. We have published 23 conference papers and 11 journal papers for the topic. Students and researchers who interested in our work in this area are encouraged to check the full versions of the papers on http://www.zuqingzhu.info.

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