MIXED REGENERATOR PLACEMENT AND ROUTING AND WAVELENGTH ASSIGNMENT FOR ENERGY-EFFICIENT OPTICAL TRANSPORT NETWORKS

Invited Paper

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Abstract

We discuss network design algorithms to minimize the power consumption of an optical transport network with joined optimization of mixed regenerator placement and routing and wavelength assignment. The performance of the algorithms is investigated with simulations in various network topologies. Simulation results indicate that the algorithms can effectively reduce the number of O/E/O 3R regenerators, leading to less power consumption on signal regeneration and green network design.

1 Introduction

In the last decade, there has been an exponential growth of Internet traffic [1]. The consequent bandwidth demands have stimulated intensive research on efficient and scalable optical transport networks. In opaque optical networks, network operators relied on optical-electronic-optical (O/E/O) 3R (Reamplification, Reshaping, and Retiming) regenerators at every switching node to maintain transmission performance. However, due to the requirements of high-speed electronics, these devices are usually expensive and power-hungry, especially for data-rates at 10 Gb/s and beyond [2]. To make the development of optical transport networks sustainable, operators have to mitigate their network infrastructure from opaque to translucent for reducing capital expenditures (CAPEX) and operational expenditures (OPEX) [3]. As shown in Fig. 1, translucent optical network design aims to minimize the number of O/E/O 3R in networking systems without compromising transmission performance. To address this and to design scalable translucent networks, previous works have investigated impairment-aware O/E/O 3R placement [4], online and offline joint optimization of 3R placement and routing and wavelength assignments (RWA) [5,6], and translucent-oriented GMPLS control plan [7,8].

Recently, all-optical 2R (Reamplification and Reshaping) regenerators have been demonstrated for operation speed at 40 Gb/s and beyond [9], and commercially available devices have been released [10,11]. Compared to O/E/O 3R, these devices are much more energy-efficient. Besides, they can also achieve wavelength conversion simultaneously with signal regeneration. Therefore, they can partially replace O/E/O 3R in optical transport networks, and improve network energy-efficiency. To explore these benefits, we first developed an analytical model to estimate the bit-error-rate (BER) evolution in a translucent lightpath that involves mixed placement of optical inline amplifiers (1R), all-optical 2R and O/E/O 3R [12,13]. We then proposed several mixed regenerator placement (MRP) algorithms to arrange different types of regenerators in a lightpath, for energy-saving [14], and based on these works we proposed network design algorithms that can optimize MRP and RWA jointly towards minimizing network energy consumption [15]. This paper reviews our research progress on designing energy-efficient optical transport networks with MRP.

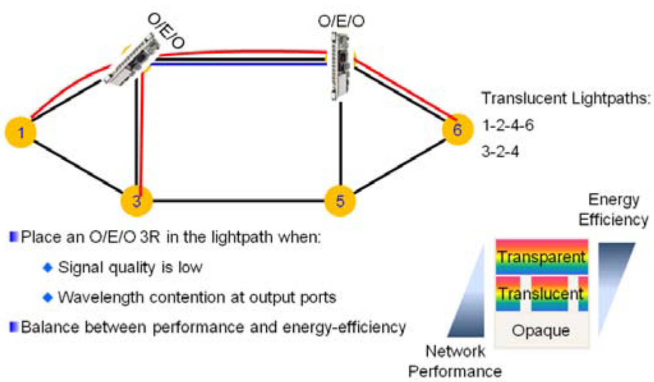

Fig. 1 An example of optical translucent network.

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Fig. 2 shows the proposed configurations of hybrid regeneration site for optical translucent networks. Since all-optical 2R does not have the retiming functionality, we have to have a performance estimation model to evaluate signal quality for this MRP scenario. In [13], we proposed such a model to estimate BER evolution hop-by-hop. Specifically, we considers several imperfections of all-optical 2R, such as degree of regenerative nonlinearity, bandwidth limitation, pattern dependence, timing jitter and etc, and calculates signal's BER increment after each regenerator. The numerical results with this model show a good match with the experimental results, for both all-optical 2R and O/E/O 3R [12]. Therefore, we can estimate the end-to-end BER of a lightpath, as long as the fiber link characteristics, regenerator parameters, and MRP arrangement is known.

With the model discussed above, the energy-efficient lightpath design problem can then be defined as an multi-objective optimization problem, in which we should try to replace as many as O/E/O 3R with all-optical 2R, while keeping the end-to-end BER below a preset threshold. With a periodic arrangement and a exhaustive search algorithm, we designed an effective lightpath design method for MRP in [14]. In addition to lightpath design, translucent network design has also consider the well-known RWA problem and make the MRP scenario useful in WDM network. In [15], we proposed one network design algorithms with joint optimization of MRP and RWA: MRP and maximum segment length wavelength assignment (MSL-WA), and compare it with the traditional first-fit wavelength assignment algorithm in grid and ring topologies. Fig. 3 shows the power consumption comparisons in a (a) ring topology and (b) grid topology [15]. It can be seen that the schemes with MRP (2R&3R-) is much more energy-efficient than the conventional schemes without 2R (3R-).

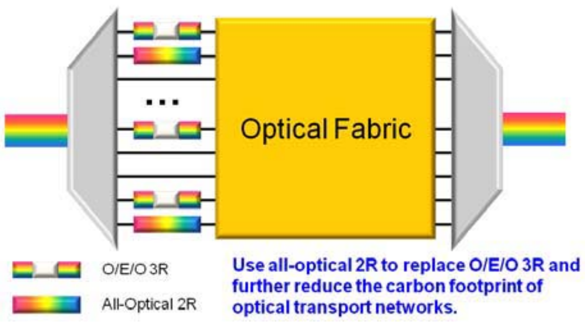

Fig. 2 Hybrid configuration of regeneration site.

3 Summary

We discussed network design algorithms to minimize the power consumption of an optical transport network with joined optimization of mixed regenerator placement (MRP) and routing and wavelength assignment (RWA). The performance of the algorithms was investigated with simulations in various network topologies. Simulation results indicated that the algorithms could effectively reduce the number of O/E/O 3R regenerators, leading to less power consumption on signal regeneration and green network design.

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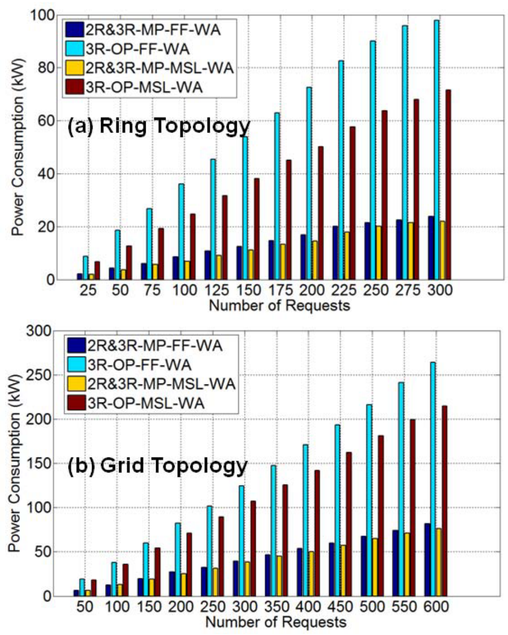

Fig. 3 Comparisons of power consumption in (a) a ring topology and (b) a grid topology ([15])