Joint Optimization of Mixed Regenerator Placement and Wavelength Assignment for Green Translucent Optical Networks

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ABSTRACT

We propose network design algorithms to minimize the power consumption of a translucent optical network with joined optimization of mixed regenerator placement and wavelength assignment. The performance of the algorithms is investigated with simulations in ring and grid 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. Among the algorithms, the *maximum segment length wavelength assignment* (MSL-WA) approach further reduces regenerator numbers, with the cost of placement readjustments.

Keywords: Optical regeneration, regenerator placement, translucent optical networks, green networks.

1. INTRODUCTION

Translucent optical network designs try to maintain the end-to-end signal quality with a reduced number of optical-electronic-optical (O/E/O) 3R regenerators [1]. Previous works in [2,3] assume signal quality is independent before and after a regenerator, and only place a 3R at where the signal bit-error-rate (BER) is right below the performance threshold. Our recent work in [4] has shown that this assumption might underestimate the signal degradation when there is no forward-error-correction (FEC) functionality in 3R. Another drawback of previous translucent network designs is that they rely solely on 3R to solve the signal quality and wavelength contention issues. In [5], we proposed to include all-optical 2R in translucent network design and demonstrated that mixed regenerator placement can reduce the cost and power consumption of lightpaths. In this paper, we propose several network design algorithms based on the regenerator placement algorithms in [5], and minimize the power consumption of a translucent optical network with joined optimization of mixed regenerator placement and wavelength assignment. The performance of the algorithms is investigated with simulations in ring and grid network topologies. Comparison study demonstrates that the number of 3R in translucent networks can be effectively reduced with the proposed algorithms, leading to less power consumption on signal regeneration and green network design.

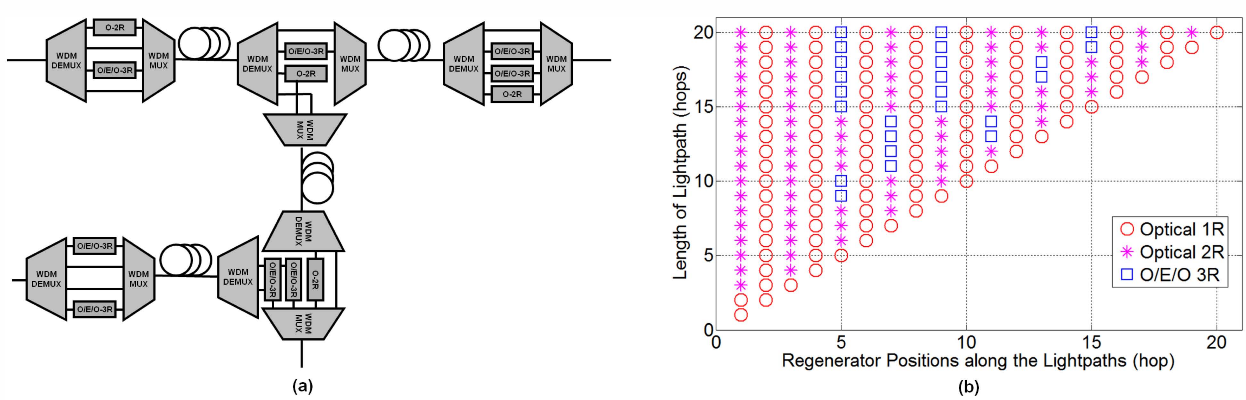

Fig. 1 (a) Translucent optical networks with mixed placement of regenerators, (b) 1R/2R/3R placements for different lightpath lengths.

2. NETWORK DESIGN ALGORITHMS

Fig. 1(a) shows the configurations of regeneration sites for our proposed scheme [5]. We place all-optical 2R instead of O/E/O 3R at certain locations to reduce cost and power consumption. Using our algorithm reported in [5], we can

Network Architectures, Management, and Applications IX, edited by Lena Wosinska,
Ken-ichi Sato, Jing Wu, Jie Zhang, Proc. of SPIE-OSA-IEEE Asia Communications and Photonics,
SPIE Vol. 8310, 83100G · © 2011 SPIE-OSA-IEEE · CCC code: 0277-786X/11/$18 · doi: 10.1117/12.904198

obtain the regenerator placements in Fig. 1(b) for lightpaths with lengths up to 20 hops. Here, the signal bit-rate is 40 Gb/s, and the length of fiber link for each hop is 160 km. We assume that the FEC functionality only exists at the end of each lightpath, and the end-to-end BER threshold of a lightpath is 1E-4. Note that as long as the end-to-end BER requirement is satisfied, the regenerator placement for each lightpath length is not unique. Therefore, the placement can be adjusted with certain flexibility for optimizing wavelength assignment.

We consider a WDM network physical topology $G(V,E)$, where V is the node set, and E is the fiber link set. Each link supports wavelength set W. $L_{s,d}$ is the number of lightpath requests from node s to d, $s,d \in V$. The wavelength connection flag is $f_{s,d}^{(u,v)}(w)$. Its value is 1 if wavelength w is used on link (u,v) for a lightpath from node s to d; otherwise, it is 0. The BER threshold is BER_t, and $BER_{s,d,k}$ denotes the end-to-end BER for the *k-th* lightpath from node s to d. $R2_u$ and $R3_u$ denote the number of 2R and 3R at node u, respectively. The power consumption per regenerator is P_{2R} and P_{3R}, for 2R and 3R, respectively. The energy-efficient network design problem is summarized as: choose routing path, place regenerators and assign wavelengths for lightpaths, such that:

$$\sum_{s\in V}\sum_{d\in V}\sum_{w\in W} f_{s,d}^{(u,v)}(w) \le |W|, \forall (u,v) \in E \tag{1}$$

$$BER_{s,d,k} \le BER_t, \forall s \in V, \forall d \in V, k \in [1, L_{s,d}] \tag{2}$$

$$\min(P_{3R}\sum_{u\in V} R3_u + P_{2R}\sum_{u\in V} R2_u) \tag{3}$$

For each lightpath request from node s to d, our network design algorithm first finds N shortest paths $R_{s,d}^{(1)}, R_{s,d}^{(2)},..., R_{s,d}^{(N)}$. The regenerators are then placed for each path using the algorithm in [5]. Here, we consider the *mixed placement of 2R and 3R* (2R&3R-MP) and the *3R-only placement* (3R-OP). After this first-round regenerator placement, we perform wavelength assignment for $R_{s,d}^{(1)}, R_{s,d}^{(2)},..., R_{s,d}^{(N)}$. Note that both 2R and 3R regenerator can work as a wavelength converter. Therefore, we only need to consider the wavelength continuity constraint for the transparent path segments between regenerators. The *first-fit wavelength assignment* (FF-WA) algorithm assigns wavelengths based on local information and can work in a distributed way. However, it may require more regenerators for wavelength conversion when there is wavelength contention inside transparent segments. We only insert 2R for wavelength conversion for 2R&3R-MP approach to save energy. To minimize unnecessary wavelength conversions, we propose a *maximum segment length wavelength assignment* (MSL-WA) algorithm. In this approach, we assign wavelength based on the information of nodes along each transparent segment, test whether there is an available common wavelength for the segment, and readjust regenerator placement along the whole path when wavelength contention is unavoidable. When the wavelength assignment is finished for paths $R_{s,d}^{(1)}, R_{s,d}^{(2)},..., R_{s,d}^{(N)}$, we validate their availabilities by verifying wavelength continuity and recalculating the end-to-end BER. We then choose the path with minimum power consumption from Equ. (3), and commit the regenerator placement and wavelength assignment.

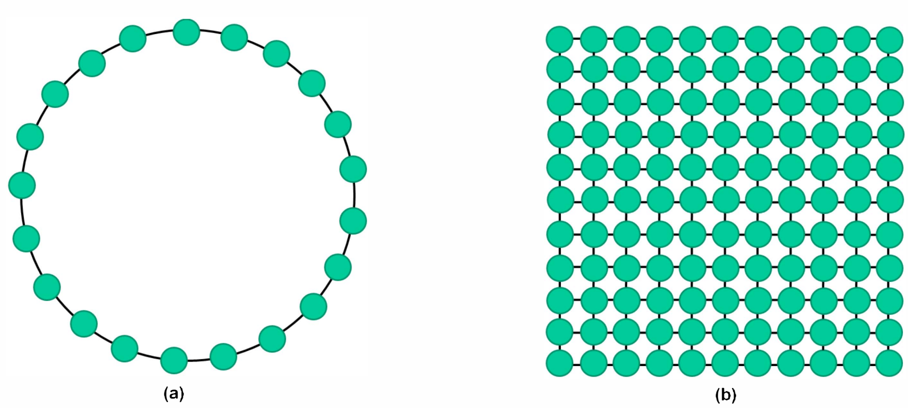

Fig. 2 (a) Ring network topology, (b) Grid network topology.

3. SIMULATION RESULTS

In order to evaluate the performance of the proposed network design algorithms, we perform simulation experiments for two network topologies: a ring network with 21 nodes in Fig. 2(a), and a grid network with 121 nodes in Fig. 2(b). We assume that the signal bit-rate is 40 Gb/s, and the length of fiber link between two adjacent nodes is 160 km in both topologies. Each link in Fig. 2 represents one pair of fiber between two nodes, and each fiber link supports 40 wavelengths. The power consumption of an O/E/O 3R is set as 150 W [6], and that of an all-optical 2R is set as 20 W [7]. The number of shortest paths N is set as 2 in the simulations. The lightpath requests are generated by picking up the source and destination nodes randomly. Fig. 3 and 4 show the number of regenerators required for different volumes of lightpath requests in the ring network. For each data point, we simulate 16 times and average the results for statistical accuracy. The simulation results show that the 2R&3R-MP approaches require much less O/E/O 3R regenerators comparing to the 3R-OP ones, and the MSL-WA algorithm effectively reduces the number of 2R and 3R regenerators in the network. Fig. 3 also shows that the number of 3R regenerators are almost identical for 2R&3R-MP-FF-WA and 2R&3R-MP-MSL-WA. This is due to the reason that we only place 2R for wavelength conversion in 2R&3R-MP approaches. Fig. 5 and 6 show the number of regenerators required for different volumes of lightpath requests in the grid network. The similar trend can be seen from the results. Fig. 7 and 8 show the regenerator power consumption for different network design approaches in the ring and grid networks. The power consumption results verifies that our network design algorithm with mixed regenerator placement can save energy effectively and achieve green design.

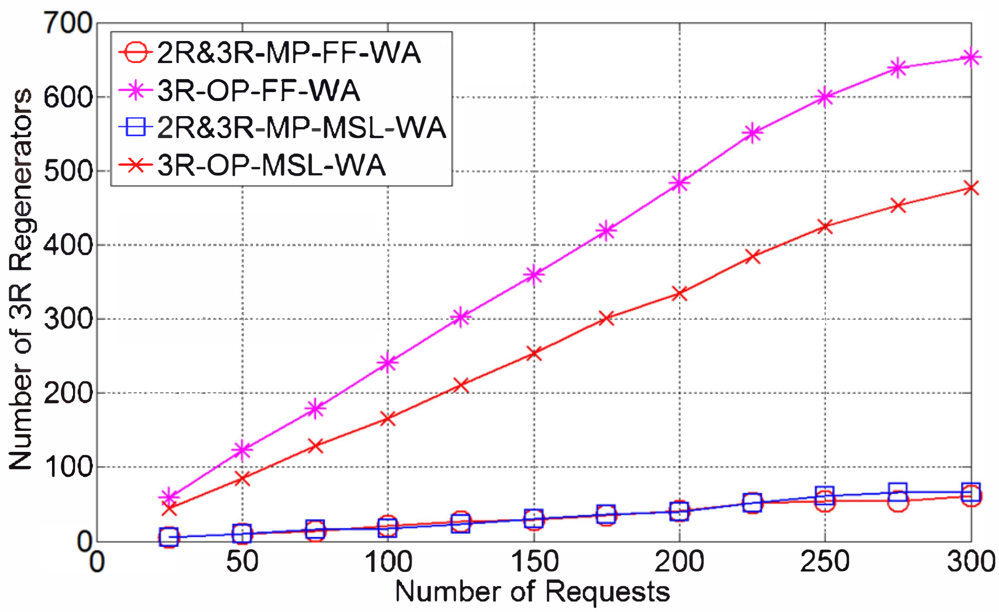

Fig. 3 Average number of 3R regenerators and needed in ring network.

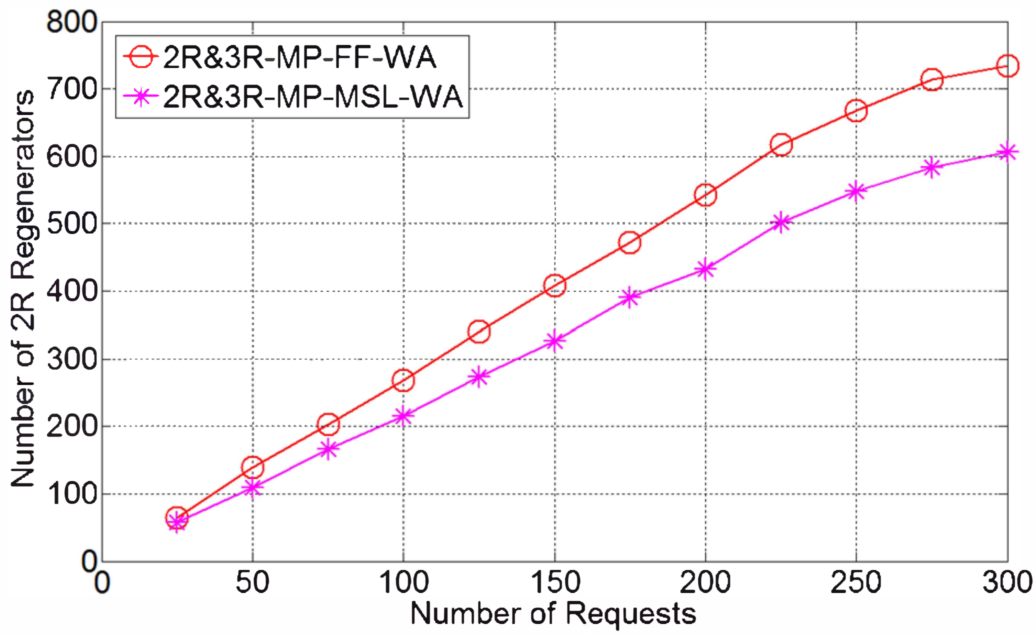

Fig. 4 Average number of 2R regenerators needed in ring network.

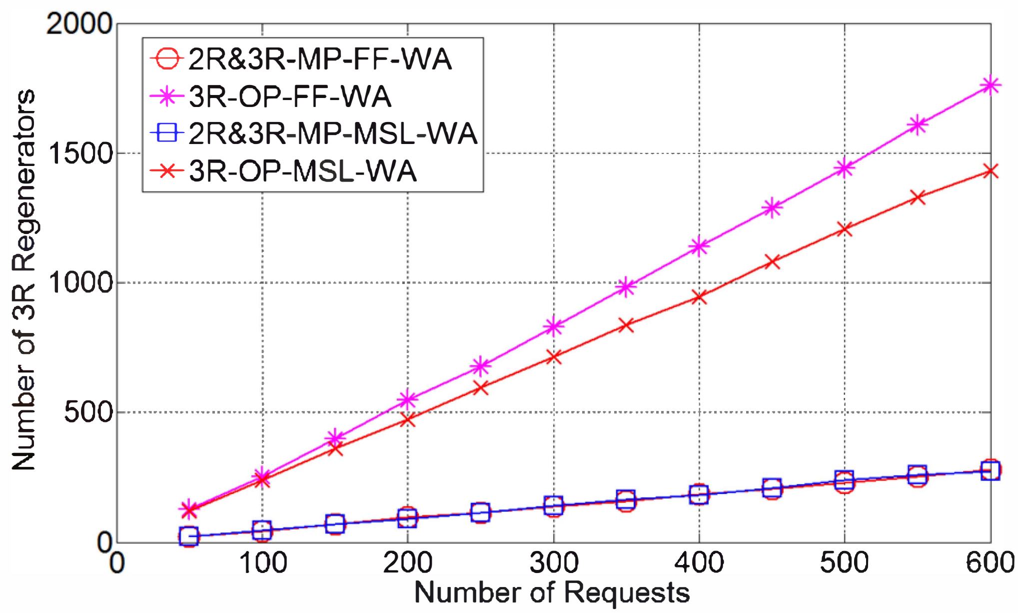

Fig. 5 Average number of 3R regenerators needed in grid network.

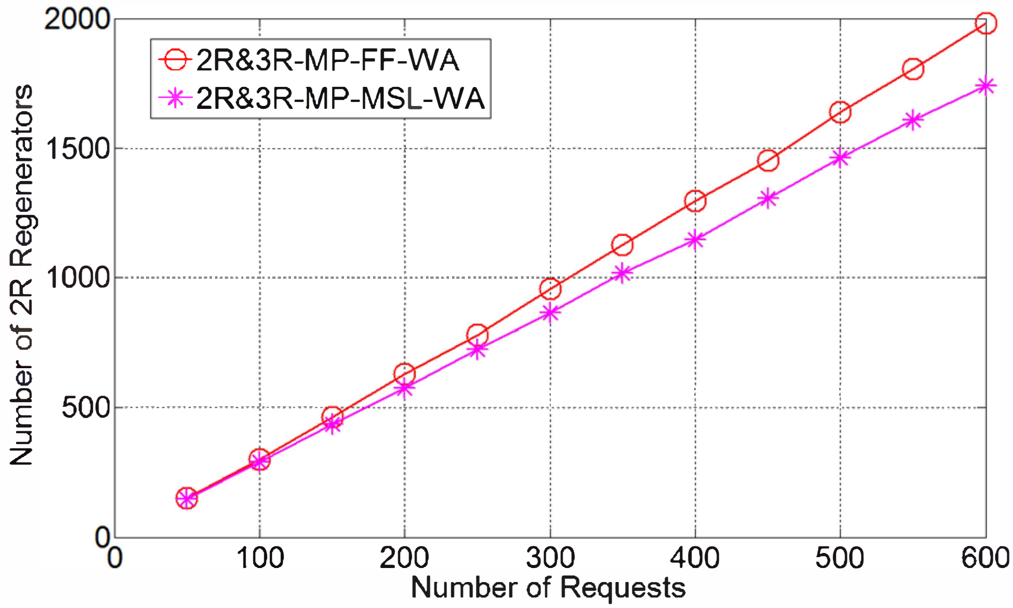

Fig. 6 Average number of 2R regenerators needed in grid network.

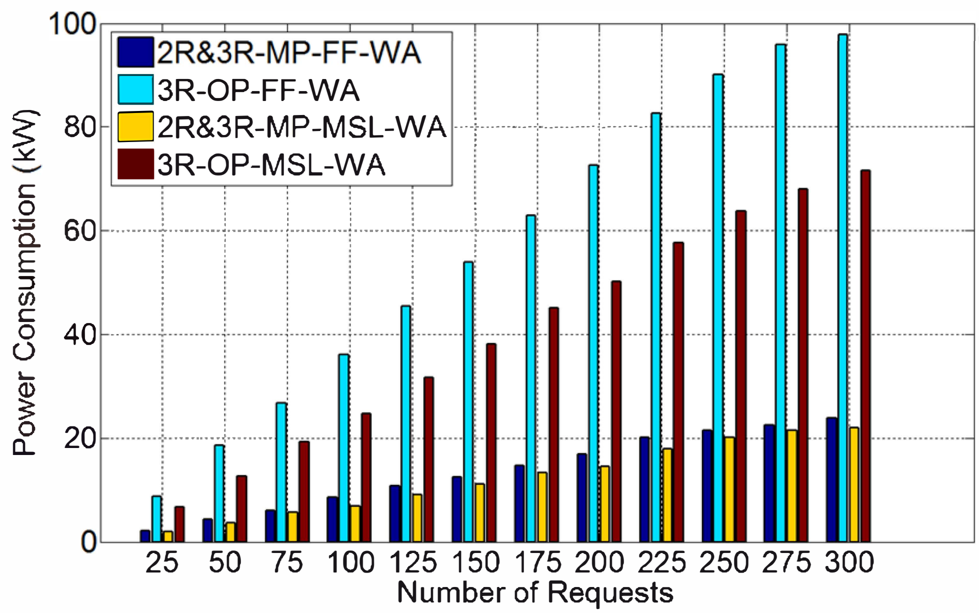

Fig. 7 Comparisons of regenerator power consumption for different design approaches in the ring network.

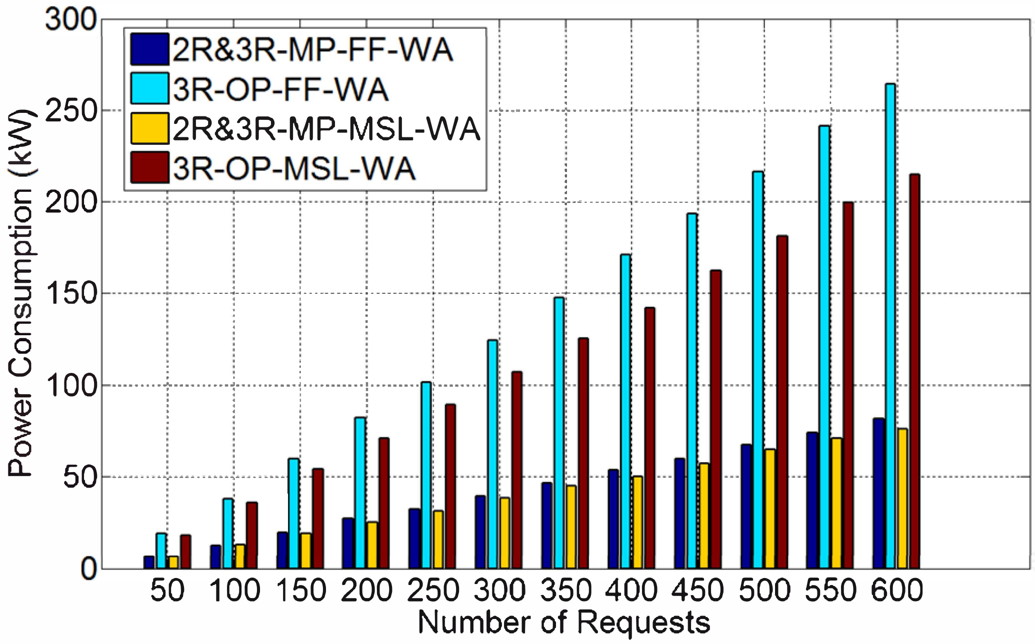

Fig. 8 Comparisons of regenerator power consumption for different design approaches in the grid network.

4. SUMMARY

We proposed two network design algorithms, 2R&3R-MP-FF-WA and 2R&3R-MP-MSL-WA, to minimize the power consumption of a translucent optical network with joined optimization of mixed regenerator placement and wavelength assignment. Simulation results indicated that the algorithms can effectively reduce the number of O/E/O 3R regenerators, comparing to the counterparts that only involve 3R placement. Between these two algorithms, the MSL-WA approach further reduced the number of regenerators, with the cost of possible regenerator placement readjustments. Simulations with ring and grid network topologies verified that the 2R&3R-MP-MSL-WA approach obtained the best design in terms of energy-saving, achieving green translucent optical networks.

ACKNOWLEDGMENTS

This work is supported by the Fundamental Research Funds for the Central Universities under Project WK2100060006.

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