Pre-Deployment of Regenerators in DWDM Networks and the Impact of Mismatches between Planning and Operation

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Abstract: Pre-deploying regenerators is vital for fast service provisioning in long-haul networks. This paper compares regenerator placement strategies exploiting different degrees of network and traffic information and assesses their sensitivity to planning and operation conditions mismatches.
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1. Introduction

Recent progress in DWDM transport networks, such as the availability of Colorless, Directionless, Contentionless (CDC) ROADMs, coherent transponder technology and advanced control and management planes [1], is setting the stage for fast service set up in these networks, as a limited set of transponders/regenerators can be pre-deployed and configured on demand without constraints related to using a specific wavelength channel and/or direction [2]. This enhanced service provisioning has been envisioned by major carriers, which can benefit not only from the reduced service set up time but also from minimizing the number of truck rolls required to deploy regenerators in long-haul networks [3]. However, 3R regenerators are a very expensive resource. Therefore, the effectiveness of this approach will depend on the matching between the services that need to be established, and how they are routed, during network operation and where the limited set of regenerators have been deployed in advance, since the unavailability of a regenerator at a node can lead to blocking a service or requesting an additional truck roll.

This paper proposes a framework for planning the placement of regenerators in DWDM networks supporting the set up of wavelength services on demand. It includes a set of strategies exploiting different degrees of network and traffic information to characterize stochastically the fitness of each network node as a placeholder for pre-deployed regenerators. The performance of these strategies is compared via network simulation and considering different scenarios regarding the traffic pattern, routing algorithm and path computation metric, forecasted during network planning, and the ones enforced during network operation. The analysis highlights, on one hand side, the importance of embedding more information in the placement process to enhance the success ratio of service set up and reduce the number of pre-deployed regenerators, and on the other hand side, how the extent of these improvements depends on which main traffic and routing assumptions made during network planning hold during network operation.

2. Stochastic-based Framework for Regenerator Placement

Consider a DWDM network with N nodes and L bidirectional fiber links, each carrying W channels. Each node i has a nodal degree $M(i)$ and the architecture depicted in Fig. 1. A set of $n_{TP}(i)$ transponders and $n_{3R}(i)$ 3R regenerators, equipped with line interfaces tunable across the entire C band, will be deployed locally. Assume a total of n_{TP}^{total} transponders and n_{3R}^{total} 3R regenerators are to be pre-deployed in the network, which correspond to a normalized transponder count and a normalized regenerator count as given in (1) and (2), respectively. Each node is assumed to have full add/drop port capacity, that is, the total number of add/drop ports that can be used at node i is given by (3).

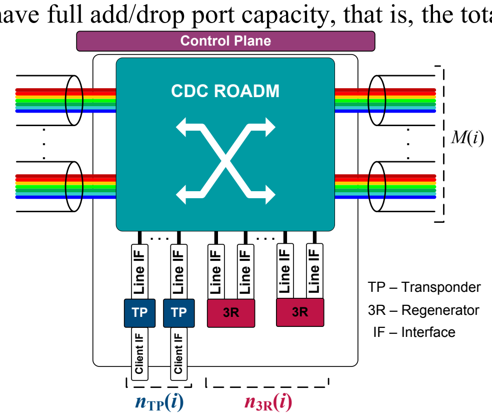


Fig. 1. DWDM node architecture

$$r_{TP} = \frac{\sum_{i=1}^{N} n_{TP}(i)}{\sum_{i=1}^{N} n_{AD}(i)} \quad (1)$$

$$n_{AD}(i) = W \cdot M(i), \quad 1 \le i \le N \quad (3)$$

$$r_{3R} = \frac{\sum_{i=1}^{N} 2 \cdot n_{3R}(i)}{\sum_{i=1}^{N} n_{AD}(i)} \quad (2)$$

$$\Gamma_{net} = \frac{\sum_{s,d} \gamma(s,d) \cdot h(s,d)}{\mu \cdot W \cdot 2L} \quad (4)$$

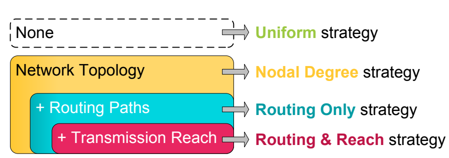


Fig. 2. Information exploited for node fitness computation

The framework for 3R placement comprises two stages, executed sequentially. The first one consists of using a strategy that defines the fitness of each node i as a probability density function, $pdf_{3R}(i)$. Different information can be exploited by these strategies to calculate $pdf_{3R}(i)$, as illustrated in Fig. 2 and detailed in the following expressions.

Strategy	3R Probability Density Function (PDF)
Uniform (Uni)	$pdf_{3R}(i) = 1/N$
Nodal Degree (ND)	$pdf_{3R}(i) = M(i)/2L$
Routing Only (RO)	$pdf_{3R}(i) = T(i) \Big/ \sum_{s,d} \lvert \pi(s,d) \rvert - 2$, where $T(i) = \sum_{s,d} \{1 : i \in \pi(s,d) \setminus \{s,d\}\}$
Routing & Reach (R&R)	$pdf_{3R}(i) = R(i) \Big/ \sum_{s,d} \lvert P_{\min}(\pi(s,d)) \rvert$, where $R(i) = \sum_{s,d} \{1 : i \in P_{\min}(\pi(s,d))\}$

The Uni strategy assigns the same fitness value to every node in the network, considering all of them as equally good candidates to be placeholders of pre-deployed 3Rs, whereas the ND strategy introduces a simple differentiation criterion between nodes by setting the fitness value to be proportional to the nodal degree. The rationale is that nodes with higher nodal degree are expected to be traversed by a larger number of traffic demands, some of which needing 3R regeneration. However, it only hints at the amount of transit traffic demands, neglecting the routing paths that traverse it. The RO strategy more accurately models the average number of transit traffic demands via computing the set of shortest paths between nodes using path computation metric Q, $\Pi_{SP}(Q)$. Node i is a transit node for traffic demands between nodes s and d if it is contained in path $\pi(s, d) \in \Pi_{SP}(Q)$. Finally, instead of estimating fitness solely via the amount of transit traffic demands, the R&R strategy also exploits the transmission reach to pinpoint at which nodes regeneration is expected to be performed. This is achieved by calculating for every shortest path $\pi(s, d)$ all feasible combinations of 3R placements with minimum number of 3Rs and creating the set of transit nodes that are part of at least one of these combinations, $P_{\min}(\pi(s, d))$. Using these sets it is possible to estimate for each node i the total number of paths that traverse the node and are likely to utilize it to realize 3R regeneration.

The second stage comprises the distribution of the set of n_{3R}^{total} regenerators over the nodes as to match as close as possible their target fitness. Ideally, the set of regenerators is distributed across the N nodes such that the expected probability density function is exactly matched, that is, $pdf_{3R}(i) = n_{3R}(i) / n_{3R}^{\text{total}}$ for $1 \le i \le N$. In view of the discrete nature of variables $n_{3R}(i)$, that may not be possible in practice and a heuristic algorithm was devised to distribute the n_{3R}^{total} regenerators as to minimize the difference between the expected probability density function and the real one.

(S1) Initialize the 3R counter of each node i, that is, $n_{3R}(i) = 0$ for $1 \le i \le N$. Initialize the iteration counter, $j = 1$.

(S2) For the placement of the next pre-deployed 3R, select the node i^* with largest deviation from the expected PDF and which still has available add/drop ports to support the additional 3R, that is,

$$i^* = \arg\max_i \left\{ pdf_{3R}(i) - n_{3R}(i) \big/ n_{3R}^{\text{total}} : n_{TP}(i) + 2 \cdot (n_{3R}(i) + 1) \le n_{AD}(i),\ pdf_{3R}(i) \le n_{3R}(i) \big/ n_{3R}^{\text{total}} \right\} \quad (5)$$

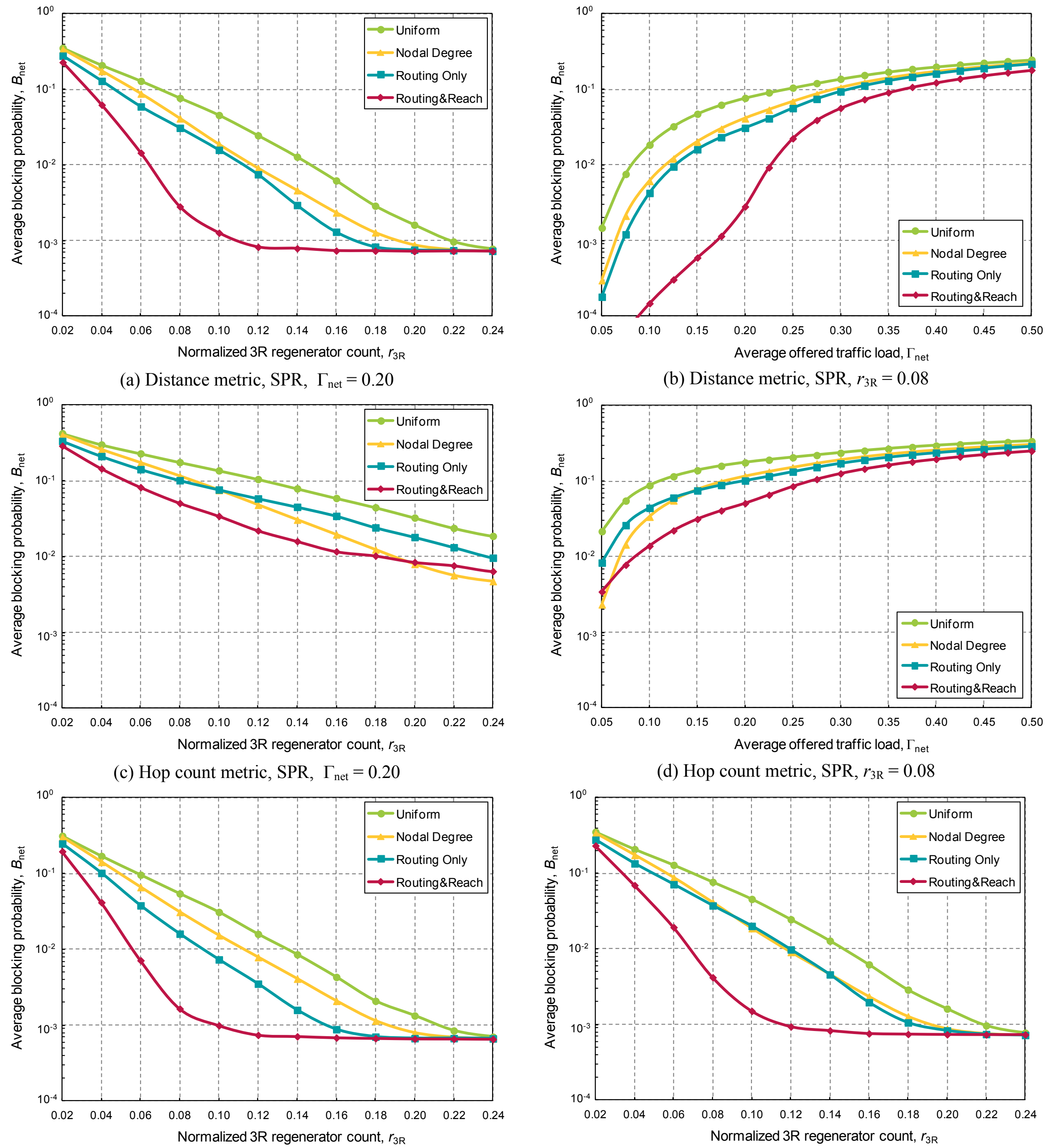
Update the number of pre-deployed 3Rs at node i^*, $n_{3R}(i^*) \leftarrow n_{3R}(i^*) + 1$.

(S3) If there are unplaced 3Rs, that is, $j < n_{3R}^{\text{total}}$, increment the iteration counter, $j \leftarrow j + 1$, and repeat **(S2)**.

3. Results and Conclusions

The continental US CORONET CONUS topology [3], with $N = 75$, $L = 99$, $W = 96$, channel data rate $\mu = 100$ Gb/s and $r_{TP} = 0.20$, is used in the performance evaluation via network simulation. The pre-deployed transponders are uniformly distributed over the 75 nodes. The regenerator count r_{3R} is varied between 0.02 and 0.24. Only half of the node pairs exchange traffic and demand duration and interarrival time are exponentially distributed. The average offered traffic load normalized to the network capacity is given by (4), where $\gamma(s, d)$ and $h(s, d)$ are the traffic load and hop count in the shortest path between s and d, respectively. Network planning assumes distance is the path computation metric. For simplicity, optical performance is modelled via a maximum reach of 2000 km and a 60 km penalty per node traversed [2]. The average blocking probability is computed from 10 independent simulation runs.

The first two plots in Fig. 3 show the blocking performance when during network operation distance is also the path computation metric, only shortest path routing (SPR) is used and the node pairs exchanging traffic were known during planning. The results highlight the benefits, in terms of lower demand blocking, (b), and smaller number of 3Rs needed to attain a given performance, (a), from using more information in the 3R placement stage. For instance, for $\Gamma_{net} = 0.20$, minimizing blocking requires a regenerator count of 24% if Uni strategy is used. This figure drops to around 20% or 18% if ND or RO strategies are used instead. Moreover, the highest 3R savings are achieved with R&R, enabling to reduce this value to 12%. The second set of plots, (c) and (d), show the impact of using during operation a different path computation metric (hop count), that is, for some node pairs demands are always routed via a different path from that assumed in planning. As a consequence, using RO and R&R instead of the simpler ND strategy can even lead to worst performance, albeit R&R still outperforms RO. In the last set of plots the planning assumptions are challenged in two different ways: during operation fixed alternate routing with 3 paths (FAR-3) is used, meaning that when the shortest path is not available demands can be routed via one of other two, (e); during planning the node pairs exchanging traffic are unknown, leading to the assumption that all of them exchange traffic, (f). The results suggest that R&R preserves most of the 3R savings in both scenarios, whereas RO does not provide improvements compared to ND when the traffic pattern is unknown during planning. Overall, it is concluded that R&R is the best performing regenerator placement strategy especially if the routing paths to be used more often are known in planning. Moreover, if no reliable information is known in advance, ND is a better design option than Uni.



(e) Distance metric, FAR-3, $\Gamma_{net} = 0.20$ (f) Distance metric, SPR, $\Gamma_{net} = 0.20$, unknown traffic pattern

Fig. 3. Performance of the regenerator placement strategies in CORONET

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