Routing and Regenerator Planning in a Carrier's Core ROADM Network

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Abstract: Optimizing routing and regenerator planning in a carrier's inter-city ROADM network provides significant savings. We describe how regenerator site planning and regenerator pre-deployment can be optimized for an inter-city IP over optical network.

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1. INTRODUCTION

Colorless Non-directional Reconfigurable Optical Add/Drop Multiplexers (CN-ROADMs) have been widely deployed in carriers' core optical networks for cost efficiency and agility. The advent of this technology has significant implications for network design and operation. In a network with CN-ROADMs, spare regenerators can be pre-deployed within the nodes to enable fast provisioning of services and dynamic reconfigurations. They also enable recovery from network failures without the need of manual intervention. This dramatically reduces mean time to repair and provides operational savings as well. By deploying regenerators at a *subset* of the network nodes, referred as regenerator sites (RS), we get better sharing of spare regenerators from random demands and improved operational efficiencies by requiring fewer truck rolls. In our prior work [1], a new routing-constrained regenerator location problem is defined. We showed that this problem is NP-hard and presented a heuristic solution which can be tuned to accommodate different priorities or cost metrics. Our results with various network topologies, reach distances, and cost metrics show that this heuristic gives near-optimal solutions in most studied cases. In this paper, in addition to bandwidth-on-demand wavelength services that require pre-deployed regenerators, we also consider the requirements of upper layer networks, such as a Layer-3 (IP/MPLS layer) backbone network. With advances of SDN control in the core network, network operators can utilize the agility of the underlying ROADM network and set up new Layer-3 links or increase capacity on existing links upon traffic surge and/or failure. In this paper, we consider such a SDN-controlled dynamic IP over Optical network, and optimize the regenerator site planning and regenerator pre-deployment for both layers' demands.

2. PROBLEM DEFINITION AND HEURISTIC ALGORITHM

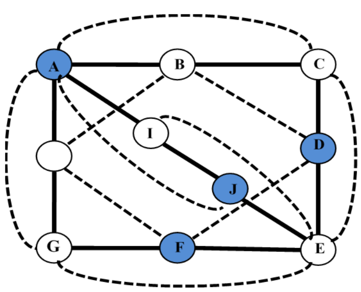

Fig. 1: Solid lines represent original edges, and dotted lines represent augmented edges for reach equal to 2.5 times the link length. Filled circles represent regenerator locations obtained for min-regenerator.

In [1], we considered the constrained-routing regenerator location problem (CRLP) that entails minimizing the number of RS with constraints on circuit routing. For example, we can constrain circuits to use only paths with the minimum number of regenerators, or minimum distance paths, or minimum cost paths where the cost is the sum of regenerator and wavelength-km costs. In this work we extend the CRLP heuristic in a multi-layer network scenario, considering network carrier constraints and restoration design

Formally: we are given a network topology with link distances and a reach distance (maximal optical distance without requiring regenerator). We are also given a set of constraints that restricts the set of paths between any node pair. The goal is to find a minimum set of RS such that between each node pair, at least one constrained route is reachable using the regenerators in RS.

Having a generalized definition of constraints allows us to consider different design priorities and cost metrics. Fig. 1 shows a simple network with 10 nodes and 11 links. We assume that the optical reach is equivalent to 2.5 hops. If the RS selection is not restricted by any routing constraints, i.e., the only requirement is availability of a path with no requirement of it being min-distance or min-regenerator, we can place all regenerators at just three RS, *A, E, I*, since a path between any node pair can be constructed using this subset. Similarly, if paths are required to be min-hop, we need to place regenerators at five locations: *A, C, E, G, I*. For CRLP with the freedom of having multiple candidate min-regenerator paths, we have a bit more freedom to select routes and we need only four locations: *A, J, D, F*. We have proven that CRLP is NP-hard by reduction from a vertex cover problem [1]. Our heuristic algorithm started by determining a core set of RS that must be included in any solution. E.g., if the requirement is to have a min-cost path, we must include a RS that belongs to (and requires regeneration at) *every* min-cost path for a given demand. Because leaving this site out of the solution will break the constraint of providing min-cost path for this demand. Then we iteratively considered each demand and tried to reuse as many of the previously selected RS as possible. We also extended the algorithm to deal with more general constraints, e.g., instead of requiring min-cost paths allow paths whose cost is within (say) 5% of optimal cost. Our performance evaluation demonstrated our heuristic's close-to-optimal performance in [1] for the cases we evaluated.

3. Heuristic Results

We evaluate our heuristic using the Coronet CONUS topology [2], depicted in Fig. 2, comprising of 75 nodes and 99 links. We parameterize the cost of a circuit as $c_r \times$*number of regenerators in path* + $c_m \times$*length of the path*, where c_r (c_m) are unit regenerator (wavelength-km) costs. Four different sets of parameters were considered: min-regenerator route ($c_r = 1$; $c_m = 0$), min-distance route ($c_r = 0$; $c_m = 1$), min-cost route ($c_r = 1000$; $c_m = 1$), and min-distance min-regenerator (MDMR) route ($c_r = 1$; $c_m = 1000$). The goal is to minimize the number of RS such that each node pair is able to pick a path according to the selected constraints.

Reach distance	Min-Distance	Min-Regeneration	Min-cost	MDMR
1500	24	37	41	34
1800	21	29	32	29
2000	19	21	28	25
2200	15	17	23	19

Table.1: Number of RS for different reach distances and various routing schemes

Table.1 summarizes the total RS for various reach metrics and the routing schemes [1]. We see that a min-distance path is not necessarily a min-regenerator path and vice-versa. However, in a carrier-grade network all the service paths are preferred to be on shortest-path. By modifying the weights, as explained in the previous paragraph, - we select the min-distance path with the minimum number of regenerators (Min-distance-min-regenerator, MDMR). For the rest of the paper, we use a reach distance of 2000 km, MDMR routing scheme and all possible 2775 node pairs. In Fig. 2 the circle locations indicate 25 RS obtained for MDMR routing scheme. Details of the heuristic algorithm are explained in [1]. There exists a reachable path between every-node pair (i.e. any-to-any traffic) in Fig. 1 using the constrained routing (MDMR).

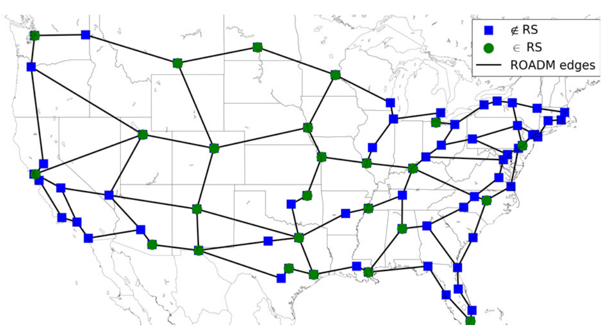

Fig.2: CONUS network topology, with 25 RS using MDMR routing for 2000 km reach distance.

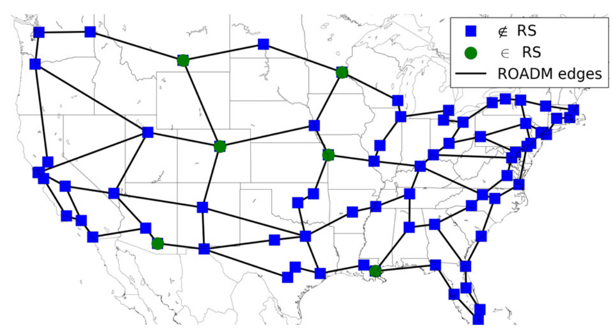

Fig.3: ROADM topology and RS for Layer-3 demands. The RS indicated here are the subset of RS from Fig.2

In Fig. 2 the selected RS provides a reachable path for all possible node-pairs. The rest of the discussion is based on multi-layer network scenario [3] in which a Layer-3 network is overlaid on the ROADM topology. We consider a Layer-3 topology using fewer than 50% of the nodes in the ROADM layer and goal is to determine RS selection for 10% of node-pairs in Fig. 2 corresponding to the end points of Layer-3 links. Layer-3 link demands are routed on the ROADM layer and have to be reachable with the given set of constraints. Our heuristic algorithm for these specific Layer-3 link demands (a subset of any-to-any traffic) requires 6 RS. Note that not all Layer-3 demands require regenerators. For the Layer-3 topology used in the experiment, our heuristic results show that nearly 12% of the Layer-3 demands require at least one regenerator. Assuming, one wavelength connection per Layer-3 link demand, our results indicate a total of 9 regenerators will be needed. In most carriers' networks, the Layer-3 router locations are co-located with the underlying ROADM topology's nodes. Given this criterion, employing the heuristic algorithm to choose RS

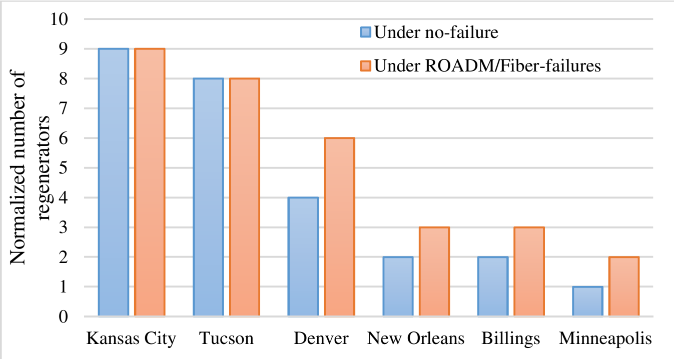

Fig.4: Total regenerators needed under no-failure and regenerators using Layer-3 restoration.

for a specific Layer-3 topology might not be the best approach. For instance, traffic growth can cause changes to the Layer-3 topology and the RS originally selected will no longer be an optimal solution. Instead, if we select the best subset of RS from all-to-all traffic demands, we can assert that RS selection is immune to changes in the Layer-3 topology. We modified the algorithm such that, all nodes that are not part of the RS for all-to-all traffic (square blue boxes in Fig. 2) are excluded from being a potential RS. Therefore, we select the best minimum set of RS from the 25 locations, such that there exists a reachable-path on the ROADM layer for all the Layer-3 link demands. Fig. 3 shows the 6 RS (subset of 25 RS from Fig. 2) indicated in green circles.

Fig. 4 shows the (normalized) number of regenerators at each site for the 188 Layer-3 link demands considered in the study. Under a no-failure scenario, the total number of regenerators at a RS is calculated as the sum of all the Layer-3 demands that use the RS in the ROADM layer routing path. From Fig. 4 under no-failure scenario, (normalized) our heuristic requires 26 regenerators in the network.

However, the no-failure case is too simplistic –as failure restoration is an important consideration in the design and planning of the network. In this paper we assume that all single failures (or outages) including router/fiber-span failures are restored by dynamically requesting capacity on a subset of surviving Layer-3 links from the ROADM layer. This restoration provides the benefits of faster-provisioning and spare reuse. For each failure, we tally the number of demands on each Layer-3 link and the number of regenerators required at each RS for these demands. Then we take the maximum number of regenerators at each RS across all failures. Fig. 4 shows that under failures the total number of regenerators is 31, indicating a significant reuse of pools at each site.

4. CONCLUSION

The advent of CD-ROADM technology has significant implications for network design and operation. In this paper, we consider a SDN-controlled dynamic IP over Optical network, and optimize the regenerator site planning and regenerator pre-deployment for both layers' demands. We designed heuristic algorithms to account for various routing schemes and demonstrated significant savings from regenerator site selection and sharing across demands and failure scenarios.

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5. REFERENCES

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