Towards Dynamic Network Reconfigurations for Flexible Optical Network Planning

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Abstract: We propose a network reconfiguration heuristic, incorporating provisioning, upgrading, and rerouting of lightpaths for multi-period planning. Using the same physical network infrastructure, we achieve up to 33% increase in network throughput compared to the state-of-the-art.

OCIS codes: All-optical networks (060.1155), Networks (060.4250), Networks, assignment and routing algorithms (060.4251)

1. Introduction

Flexible optical networks harness the advantages offered by software tunable transponders to increase the network throughput without adding additional bands or lighting dark fibers [1]. These new transponders support varying channel configurations in terms of data rate (100-600 Gbps), modulation format (QPSK, xQAM), and forward error correction (FEC). The challenge for planning algorithms is to dynamically allocate lightpaths (LPs) and their configurations to a set of demands, such that the offered traffic is guaranteed, while coping with physical layer constraints. An important metric in allocating configurations to LPs is the minimum receiver sensitivity threshold, which must always be lower than the calculated Generalized Signal to Noise Ratio (GSNR) for all the LPs in the network. The possible impacts of this metric on the flexible optical networks is studied in HeCSON [2]. However, HeCSON does not deal with the multi-period traffic scenarios which need dynamic network reconfigurations. Towards understanding these reconfiguration methods, Cugini et. al. [3] introduced the push pull method, which reconfigures LPs in the network without traffic disruptions, while considering only 100 Gbps QPSK LP configuration in their coherent network deployment. More recently, other works [4, 5] discuss LP upgrade and addition strategies in a multi-period scenario using heuristics and Integer Linear Programming (ILP). However, if an LP cannot be upgraded at its pre-assigned central channel frequency or a new LP cannot be deployed, the requested traffic is either considered blocked, or physical upgrades to the network are suggested. Such upgrades incur higher investments on network operators and should be delayed as much as possible.

Thus, in this work, we propose a heuristic that utilizes three network reconfiguration methods, *LP upgrade*, *LP addition*, and *LP rerouting* to efficiently provision the network and meet the yearly-increasing traffic without any physical network investments.

2. Network Model

Let us define the network, as a graph $G = (N, L)$ with N optical add/drop nodes and L links consisting of single-mode fiber pairs with heterogeneous span lengths. Considering a finite discrete time horizon T, the set of demands per year is defined as $D_t, t \in T$. Each demand $d \in D_t$ is defined as $d_{i,j,t} = (i_d, j_d, r_{d,t})$, where $i, j \in N$ are source and destination nodes, and $r_{d,t}$ is the yearly requested data rate. The value of r is calculated based on the data rate of the previous year and the expected increase, i.e., $r_{d,t} = r_{d,t-1} + \Delta_{d,t}$. A demand may be fulfilled by one or more LPs in the network. To efficiently (i.e., with low over-provisioning) cope with this demand increase per year, three network reconfiguration methods are considered: *i) LP upgrade*: requires to upgrade the LP configuration to a higher data rate, *ii) LP addition*: deploys new LP(s), and *iii) LP rerouting*: reroutes the neighboring LPs such that the released spectrum can be used to upgrade the LP of the considered demand.

Without loss of generality, we assume the cost of these methods increases from the first to the third one. In particular, upgrading an LP from a configuration to another can be achieved by minimal laser downtime. However, adding a new LP requires adding new transponders physically, if not already available; and also longer LP setup time. Further, rerouting is considered to be the most expensive method, since the traffic being carried on the LP will experience a disruption in the order of seconds (if the LP is rerouted to another path) or less (if the LP is reconfigured to a new central channel frequency). In the next section, we show how these methods can be used in a heuristic algorithm to efficiently cope with the yearly traffic increase in a flexible optical core network.

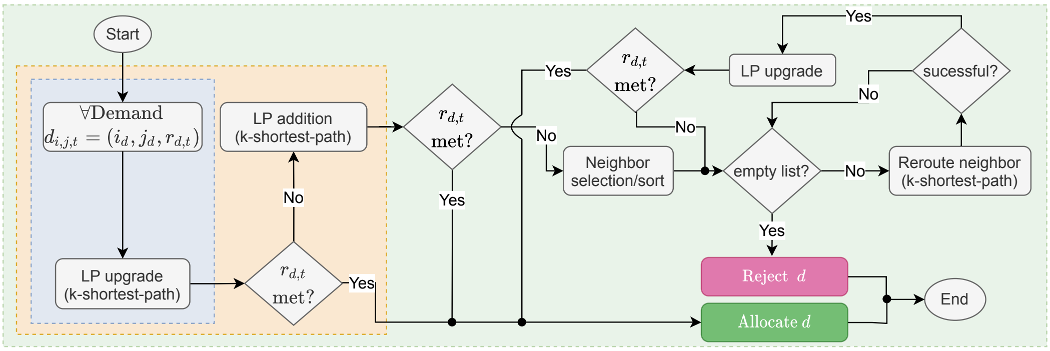


Fig. 1: The heuristic flowchart which shows how the network reconfiguration methods work together to provision for the increased data rate. Approach 1 is shown in blue, 2 in orange, and 3 (our proposed heuristic) in green.

3. Network Reconfiguration Heuristic

The flowchart of the heuristic is depicted in Fig. 1. The algorithm is triggered yearly, in a demand-by-demand manner. For each demand $d_{i,j,t}$, if the sum of configured data rate of the deployed LP(s) is lower than the total increased traffic $r_{i,j,t}$, the heuristic efficiently determines the required reconfiguration methods to fulfill it. It starts with *LP upgrade* which has the lowest reconfiguration cost, which is realized by using HeCSON [2]. At this step, considering the spectrum occupancy and GSNR along each k-shortest-path of $d_{i,j,t}$ (where the LPs can be currently deployed), the *LP upgrade* method checks if the deployed LPs can be upgraded to a new channel configuration higher data rate. If possible, one or more LPs of the current demand are upgraded until the increased requested data rate $r_{d,t}$ is met. If neither enough frequency slots are available, nor the required GSNR can be guaranteed, the heuristic moves to the second reconfiguration method, *LP addition*.

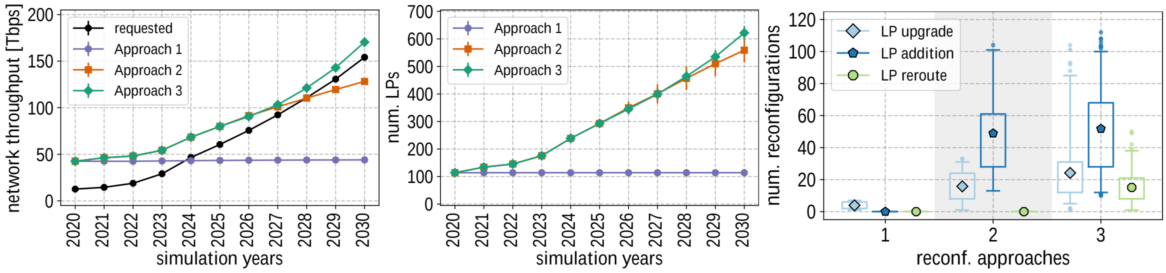
In *LP addition* method, new LPs can be deployed at any of the k-shortest paths of $d_{i,j,t}$, considering the physical and neighboring channel constraints. Given the complexity of this problem, *LP addition* method uses an ILP formulation to find such LPs on different k-shortest-paths, such that the number of new deployed LPs are minimized for each demand. In case enough LPs cannot be deployed to meet the required data rate, the third reconfiguration method is considered, which is *LP rerouting*.

In *LP rerouting*, the first step is to select the currently deployed LPs of $d_{i,j,t}$. Generally, the more LPs are rerouted (removed) from the links with high channel utilization, the more likely it is to release the resources required for LPs of $d_{i,j,t}$ to be upgraded. Thus, for each of these LPs, their neighboring LPs are listed and decreasingly ordered based on the channel utilization of the links that they are using. Thereafter, we reroute the neighboring LPs one by one to a k-shortest-path between i and j, considering the spectrum occupancy and minimum GSNR requirements. After each successful reroute, we try to upgrade the LP of $d_{i,j,t}$ (whose neighbor has been moved) to a higher data rate. If the upgrade is successful and leads to meeting the requested traffic $r_{d,t}$, the algorithm allocates the resources to demand $d_{i,j,t}$ and stops. Otherwise, if the rerouting of all the neighboring LPs cannot satisfy the $r_{d,t}$, the request of demand d is blocked.

4. Evaluation and Results

In this section, we present the simulation scenario, followed by a discussion on the results. The proposed heuristic is evaluated for $T = 10$ years, for two topologies, Nobel-Germany ($|N| = 17$, $|L| = 26$, and $|D| = 136$), Germany50 ($|N| = 50$, $|L| = 88$, and $|D| = 662$), and Abilene-USA ($|N| = 12$, $|L| = 15$, and $|D| = 66$) networks [6,7]. However, due to similar behavior of the approaches and lack of space, only the results from Nobel-Germany are presented. The traffic model for the initial year is taken from our previous work [4]. In order to model the uncertainty of the traffic increase, we extend [4] by considering a $\pm 15\%$ onward from the second planning year. Each link consists of a single fiber pair and the transponders are equipped to handle 26 different configurations for the C-Band [2].

To evaluate the reconfiguration methods, we consider three approaches: *Approach 1)* includes the *LP upgrade* method, *Approach 2)* considers the *LP upgrade* and *LP addition* methods [4], and *Approach 3)* combines the three *LP upgrade*, *LP addition*, and *LP rerouting* methods. For clarification purposes, these approaches are shown in blue, orange, and green color in the flowchart (see Fig. 1). The simulation tool is implemented in Java, and the simulations have been performed on a machine equipped with Intel Core i7-6700HQ @2.60 GHz, 16 GB of RAM, running Ubuntu 18.04. The results are gathered from running the simulation for 100 random demand variations. We evaluate the simulations firstly by comparing the total provisioned throughput by each approach against the requested data rate (see Fig. 2a). On the one hand, it can be seen that the *LP upgrade* method cannot cope with the requested traffic after 2024, leading to network under-provisioning. The reason is that mostly, the LPs cannot



(a) Total throughput (b) Total deployed LPs (c) Number of network reconfigurations

Fig. 2: Ten-year planning results for the Nobel-Germany network.

be upgraded to a higher data rate, due to violation of minimum GSNR requirement on longer paths. On the other hand, having both *LP upgrade* and *LP addition* (i.e., Approach 2) increases the throughput of the network as required up to 2028. In this approach, when the LP data rate cannot be upgraded, the set up of new LPs allows offering the required traffic. Also, in Fig. 2c, it can be seen that *LP addition*, can actually lead to having also more LP upgrades, both resulting in an increase of the total throughput. Nevertheless, this combination fails after 2028. This is due to the fact that the channels are greedily occupied, which prevents adding/upgrading more LPs in the future. Ultimately, by utilizing the rerouting beside the *LP upgrade* and *LP addition* (i.e., Approach 3), it can be observed that the network throughput is increase up to 33% compared to Approach 2 (52% and 59% in case of Abilene-USA and Germany50 networks, respectively). In more detail, as Fig. 2c shows, by rerouting a few LPs, more LPs can be upgraded and provisioned, leading to higher throughput. Interestingly, Fig. 2b shows that by benefiting from rerouting, Approach 3 is able to cope with traffic requests by only deploying 3% more LPs compared to Approach 2, while using the same physical infrastructure. This fact indicates that Approach 2 and 3 result in comparable operational expenditure (OPEX). For example, the number of active transponders are a power-hungry resource in the network [8] are only increased by 3% to satisfy the incoming traffic.

Further, Fig. 3 shows the reconfigurability of LPs in the network, based on their data rate. It can be seen that generally, the LP configurations with lower data rates are easier to reconfigure. Although *LP upgrade* seems to be the cheapest reconfiguration method, however, to offer more throughput, the rerouting method shows promise.

Finally, we note that the runtime of our heuristic is in order of minutes for a 10-year scenario, i.e., around 1 and 3 minutes for Nobel-Germany and Abilene-USA networks, respectively. This shows that our heuristic can be utilized in online planning tools.

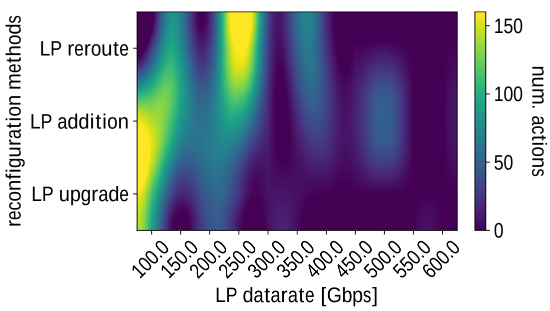


Fig. 3: The distribution of number of reconfigurations of all LPs deployed in Nobel-Germany network based on their data rate.

5. Conclusions

This work presented a heuristic for dynamic network reconfiguration problem in a multi-period planning scenario. The simulation results indicated that our heuristic can increase the throughput for Nobel-Germany network up to 300% and 33% as compared to Approach 1 and 2, respectively. At the same time, Approach 3 deploys only 3% more LPs on average compared to Approach 2, resulting in comparable OPEX. Additionally, our results showed that the rerouting method performs better on LPs with low data-rate. Therefore, it is evident that greedily upgrading LPs to high data rates can reduce the benefits of this method. Hence, opposed to intuition, the *LP upgrade* method is not as efficient, since it can lead to a lower number of rerouting possibilities, and lower overall throughput. Crucially, a trade-off between reconfiguration cost and the achieved throughput in flexible optical networks can be an interesting research direction for future work.

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