Cost-Effective and Reliable Multi-Period Planning for Fixed and Flexible Grid Architectures in Optical Networks

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***Abstract*—This work studies cost-effective and reliable multi-period planning in transparent optical networks using the C-band, considering two different architectures: fixed and flexible grid. We propose two Integer Linear Programming (ILP) formulations for minimum-cost network planning, guaranteeing $1+1$ protection for every demand. The two-stage Sequential ILP optimizes the planning of the working paths of the demands first and then optimizes their protection. The second ILP, referred to as Joint ILP, performs the planning simultaneously for both working and backup paths for every demand. The ILPs minimize the planning costs based on a cost model that considers the equipment cost of establishing a new lightpath and lighting a dark fiber when and where it is necessary for the network. Results showed that over a 4-year planning period, the two methods provided similar costs both for the fixed and the flexible grid architectures but presented a slight difference in the required fibers. For the fixed grid, the Joint ILP needs one more fiber than the Sequential ILP, while for the flexible grid, the number of fibers was the same for both approaches. Overall, the number of required fibers was $5-7$ times lower in the flexible grid compared to the fixed grid, but the costs were $25-55\,\%$ higher for the flexible grid. However, with the expected upcoming maturity of the flexible grid components, the costs reduce to comparable levels with the fixed grid after $2-3$ years.**

***Index Terms*—Network Planning, Transparent Optical Networks, Fixed/Flexible Grid, Reliability, Cost Optimization**

I. INTRODUCTION

The exponential growth of services and connected devices is compelling operators to enhance the capacity of their networks [1]. However, requirements such as reliability must also be met to guarantee the availability of services in the event of failures. It is incumbent upon core network operators to utilize the available resources optimally when configuring protected demands based on the type of grid architecture of the network, aiming at minimum planning costs.

In transparent optical networks, grid architectures define how the spectrum is allocated and managed for transmitting data over optical fibers. Demand routing involves assigning paths to optical signals through a network. In a fixed grid, wavelength channels are pre-defined at standardized intervals (typically 50 GHz or 100 GHz), limiting flexibility and potentially leading to inefficient spectrum usage. On the other hand, flexible grid technology allows for variable channel spacing with finer granularity (e.g., 12.5 GHz slots), enabling more efficient spectrum utilization and higher data rates. Flexible grid networks can dynamically allocate spectrum based on the required bit rate, reducing wasted bandwidth. While this flexibility increases network capacity and adaptability, it also introduces complexity in spectrum management and requires advanced, more costly hardware and signal processing capabilities compared to fixed grid networks.

A core network operator utilizing fixed or flexible grid optical networks in the C-band aims to maximize the number of demands by optimizing spectrum utilization. It has been shown that the C-band is expected to saturate [2]. When planning protected demands, the required spectrum increases by at least a factor of two, and thus, the C-band is expected to saturate at an even faster rate [3]. Several works have studied network planning and topology upgrades to cope with increasing traffic [4], considering spatial division multiplexing (SDM) and ultra-wideband (UWB) upgrades [5]–[8]. However, none of these works have addressed reliability and survivability, which are crucial as the amount of transmitted data radically increases, and a single link failure can lead to tremendous data losses.

The first objective for the operator is to find working and backup paths (WPs and BPs) for each demand that minimize the cost. If no spectrum is available when finding the disjoint WPs and BPs for a demand, lighting a dark fiber is the most cost-effective solution compared to other SDM solutions, such as installing multi-core fibers or using new bands. This work proposes two different planning optimization strategies to minimize the total planning costs using the existing standard single-mode fiber within the C-band: the sequential and the joint approach. In the first case, we formulate a *Sequential Integer Linear Programming (ILP)* problem to optimize the planning of the WPs of all the demands. Then, using the same ILP, we optimize the planning of the BPs given the configured

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WPs and the remaining capacity. In the second case, the *Joint ILP* solves the problem simultaneously by jointly planning the WPs and the BPs. Two cost categories are considered for the minimization of the cost: *1)* the cost of establishing a new lightpath (LP), which includes twice the cost of the transceiver (TRx) and the amplifier at each end node of the demand, and *2)* the cost of lighting dark fiber which includes wavelength selective switches (WSSs), amplifiers at both end reconfigurable optical add-drop multiplexers (ROADMs), as well as the required in-line amplifiers for the optical fibers. We investigate different solutions to protect all the demands in transparent optical networks in the most cost-effective way. We compare fixed and flexible grid solutions, considering the cost of each grid's components. The higher spectral efficiency of the flexible grid allows a significant reduction in the required fibers but at a higher cost. However, as the cost of flexible TRx's matures over the next few years, the cost is expected to fall to a level comparable to the cost of the fixed grid.

II. PROBLEM DEFINITION

This work investigates optimal multi-period planning to minimize the network cost, taking into account reliability by guaranteeing $1{+}1$ protection for every demand. The problem is studied for fixed and flexible grid architectures and is defined by the following parameters:

- The set of directed network links, $\mathcal{L}$.
- The number of available fibers per directed link, F.
- The number of wavelengths per fiber for the fixed grid architecture/the number of frequency slots per fiber for the flexible grid architecture, W.
- The number of wavelengths (fixed grid)/frequency slots (flexible grid) per directed link, $WLs = F \cdot W$.
- The set of demands, $\mathcal{D}$.
- The set of the demands' bit rates (demand values), DV.
- The set of WPs based on which the demands will be routed, $\mathcal{P}_w$, where $\mathcal{P}_{w_{p,d}}$ is the WP p of demand d.
- The set of BPs based on which the demands will be protected, $\mathcal{P}_b$, where $\mathcal{P}_{b_{p,d}}$ is the BP p of demand d.
- The set of bit rates (capacities) that can be transmitted by all the candidate WPs for all the demands, WPC, where $WPC_{p,d}$ is the bit rate of path $\mathcal{P}_{w_{p,d}}$ of demand d.
- The set of bit rates (capacities) that can be transmitted by all the candidate BPs for all the demands, BPC, where $BPC_{p,d}$ is the bit rate of path $\mathcal{P}_{b_{p,d}}$ of demand d.

Our objective is to minimize the planning costs in each architecture scenario based on the components needed to establish an LP and the required equipment to light an available dark fiber when the spectrum becomes saturated. Towards this aim, the following cost model is defined based on the transmission system of [1] and the node architecture of [9]:

$$Costs = \begin{cases} C^{A} = 2 \cdot C^{TRx} + 2 \cdot C^{Amp} \quad \text{when establishing} \\ \text{a new LP,} \\ C^{B}_{f,ij} = 2 \cdot C^{TE} + \left\lceil \frac{L(i,j)}{L_s} \right\rceil \cdot C^{Amp} \text{ when lighting} \\ \text{a dark fiber on link } (i,j), \end{cases} \tag{1}$$

where:

1) C^{A} includes the cost of a TRx (C^{TRx}) and the cost of an erbium-doped fiber amplifier (EDFA) (C^{Amp}) at the source and the destination node of each demand,
2) C^{TE} is the terminal equipment cost at each ROADM at each end of the link, including one WSS and one EDFA.
3) the term $\left\lceil \frac{L(i,j)}{L_s} \right\rceil \cdot C^{Amp}$ indicates the number of in-line EDFAs required for a lit fiber. $L(i,j)$ is the length of the link (i,j) in kilometers (km), and L_s is the span length of each fiber in km.

III. PROPOSED PLANNING OPTIMIZATION STRATEGIES

Two planning strategies are proposed to optimize the routing and minimize the induced network cost for the fixed and flexible grid for the C-band channel alignment.

1) The *Sequential* approach: For each demand, the K-shortest paths, $K = 3$, are computed based on the link lengths, and an ILP minimizes the cost of the lit fibers and the cost of the working LPs of all the demands. For each found WP, the K-shortest link-disjoint BPs are computed. Then, the same ILP minimizes the protection cost for the configured working LPs.
2) The *Joint* approach: For each demand, the K-shortest paths are computed based on the link lengths, and for each one of these paths, the shortest link-disjoint path is also calculated. Using these K link-disjoint path pairs, an ILP minimizes the cost by choosing the correct pairs of the WPs and BPs to route and protect all the demands.

The Sequential and Joint ILP formulations are presented below; the same formulations are used both for the fixed and the flexible grid using the respective parameters for each architecture. The following decision variables are used:

- $\delta^{w}_{wl,p,d}$ is 1 if for demand $d \in \mathcal{D}$, the WP $p\,(\mathcal{P}_{w_{p,d}})$ and wavelength/frequency slot $wl \in \{1, ..., W\}$ are chosen, 0 otherwise.
- $\delta^{b}_{wl,p,d}$ is 1 if for demand $d \in \mathcal{D}$, the BP $p\,(\mathcal{P}_{b_{p,d}})$ and wavelength/frequency slot $wl \in \{1, ..., W\}$ are chosen, 0 otherwise.
- $x_{wl,ij}$ is 1 if the wavelength/frequency slot $wl \in \{1, ..., W\}$ on the directed link (i,j) is used, 0 otherwise.
- $y_{f,ij}$ is 1 if the fiber $f \in \{1, ..., F\}$ on the directed link (i,j) is used, 0 otherwise.

The objective minimizes the cost of the equipment for the chosen LPs and the lighting of dark fibers. We start with the Sequential ILP, for which the first stage is the optimization of the cost induced by the working LPs for all the demands. The objective is defined as:

$$\text{minimize} \left(\sum_{f=1}^{F} \sum_{(i,j) \in \mathcal{L}} C^{B}_{f,ij} \cdot y_{f,ij} + \sum_{d \in \mathcal{D}} \sum_{wl=1}^{WLs} \sum_{p=1}^{K} C^{A} \cdot \delta^{w}_{wl,p,d} \right), \tag{2}$$

and falls under the following constraints:

$$x_{wl,ij} = \sum_{d\,\in\,\mathcal{D}} \sum_{p=1}^{K} \delta^{w}_{wl,p,d} \cdot I((i,j) \,\in\, \mathcal{P}_{w_{p,d}}) \qquad \forall\,(i,j) \in \mathcal{L},\, \forall\, wl = \{1, ..., WLs\}, \tag{3}$$

$$\sum_{wl=1}^{WLs} \sum_{p=1}^{K} \delta^{w}_{wl,p,d} \cdot WPC_{p,d} \geq DV_d \quad \forall\, d \in \mathcal{D}, \tag{4}$$

$$y_{f,ij} \geq \frac{\sum_{wl=(f-1)\cdot W+1}^{f\cdot W} x_{wl,ij}}{W} \qquad \forall f = \{1, ..., F\},\, \forall\,(i,j) \in \mathcal{L}. \tag{5}$$

Constraint (3) guarantees wavelength/frequency slot continuity for every working LP and that each wavelength/frequency slot can be used only once on each directed link. Constraint (4) chooses the LPs for every demand so that their total capacity is at least equal to each demand value. Finally, constraint (5) defines how many fibers will be needed for each link.

For the second stage of the Sequential ILP, which aims to minimize the protection cost of the found working LPs, we make the following adaptations:

1) The optimization will not be performed on the set of demands but on the set of the resulting working LPs from the first stage of the ILP, $WLPs$. Therefore, the set $\mathcal{D}$ will change to the set $WLPs$ in the objective and all the constraints. Basically, the idea is that we now treat the configured working LPs as demands throughout the entire ILP formulation for the protection optimization.
2) In the objective and all the constraints, $\delta^{w}_{wl,p,d}$ will be substituted by $\delta^{b}_{wl,p,d}$.
3) In constraint (4), $WPC_{p,d}$ will be substituted by $BPC_{p,d}$ and the demand value of demand d, DV_d, will be substituted by the capacity of the already configured working LP wlp, $WLPs\_C_{wlp}$.

For the Joint approach, the objective changes as follows:

$$\text{minimize} \left(\sum_{f=1}^{F} \sum_{(i,j)\,\in\,\mathcal{L}} C^{B}_{f,ij} \cdot y_{f,ij} + \sum_{d\,\in\,\mathcal{D}} \sum_{wl=1}^{WLs} \sum_{p=1}^{K} C^{A} \cdot (\delta^{w}_{wl,p,d} + \delta^{b}_{wl,p,d}) \right), \tag{6}$$

and the constraints are defined below:

$$x_{wl,ij} = \sum_{d\,\in\,\mathcal{D}} \sum_{p=1}^{K} \delta^{w}_{wl,p,d} \cdot I\left((i,j) \,\in\, \mathcal{P}_{w_{p,d}}\right) + \sum_{d\,\in\,\mathcal{D}} \sum_{p=1}^{K} \delta^{b}_{wl,p,d} \cdot I\left((i,j) \,\in\, \mathcal{P}_{b_{p,d}}\right) \qquad \forall\,(i,j) \in \mathcal{L},\, \forall\, wl = \{1, ..., WLs\}, \tag{7}$$

$$BPC_{p,d} \sum_{wl=1}^{WLs} \delta^{b}_{wl,p,d} \geq WPC_{p,d} \sum_{wl=1}^{WLs} \delta^{w}_{wl,p,d} \qquad \forall\, p \,\in\, \{1, ..., K\},\, \forall\, d \in \mathcal{D}, \tag{8}$$

with the constraints (4) and (5) included as well. Constraint (7) guarantees wavelength/frequency slot continuity for the working and backup LPs, along with restricting the utilization of a wavelength/frequency slot on link (i,j) to occur at most once. Constraint (4) chooses the required number of working LPs for every demand, and based on this, constraint (8) chooses the correct backup LPs for all the demands by occupying at least as much capacity for the BPs as needed for the WPs. Finally, constraint (5) holds the same role as in the formulation of the Sequential ILP.

It is important to note that regarding the flexible grid architecture, the two developed ILP formulations provide correct results for the routing and the spectrum assignment under the fundamental assumption that the configurations that can be assigned to the LPs for each demand require only one frequency slot. As a configuration, we define the triplet of modulation format, data rate, and maximum optical reach, which can be assigned to an LP based on its length. In the context of this work, each configuration is defined for a single frequency slot (Table II). This way we do not need to account for the spectrum contiguity constraint, which enhances the flexibility of spectrum utilization and the efficiency and simplicity of our optimization strategy.

IV. NUMERICAL RESULTS

For the evaluation of the proposed planning optimization approaches, we use NSFNET, which has 14 nodes and 42 directed links. The set of demands consists of $\frac{N\cdot(N-1)}{2}$ directed demands acquired from SNDlib [10] (where N the number of nodes) with normalized values in Gbps, as shown in Table I. The methods are used for a 4-year planning, where the traffic is increased by $35\,\%$ each year [7], [11], and are evaluated in terms of cost and number of necessary fibers per link. Regarding the number of fibers, only one fiber per link is considered available in year 0, which is increased by one only in case the optimization problem is infeasible. This helps to keep the search space of the ILPs as small as possible. For the fixed grid, $W = 80$ wavelengths per fiber are available in the C-band with 50 GHz spacing [12], and for the flexible grid, with 12.5 GHz spacing [13], we consider $W = 320$ frequency slots. In order to define the capacities of the candidate LPs according to their length, we consider 5 different modulation formats with the respective achieved data rate and maximum reach (configurations) for a single frequency slot of bandwidth equal to 12.5 GHz, presented in Table II. To cope with the path lengths of the demands in NSFNET, we used the values for transmission with BER $= 4.7 \cdot 10^{-3}$ (before forward error correction) in the C-band from Table 4 of [13]. In the fixed grid, TRx's can transmit only at a single value, so we choose this value as the standard capacity for every LP based on the maximum pre-computed path length of NSFNET. Regarding the applied cost model, the normalized cost values of the fixed and the flexible grid components are summarized in Table III based on [14], and the span length for each fiber is $L_s = 100$ km as in [13].

TABLE I
DEMAND VALUE NORMALIZATION

SNDlib val.	$1-50$	$51-100$	$101-150$	$150-200$	≥ 200
Norm. val. (Gbps)	100	200	300	400	500

TABLE II
CONFIGURATIONS FOR A SINGLE FREQUENCY SLOT [13]

Modulation	Bit Rate (Gbps)	Maximum Reach (km)
BPSK	23	10300
QPSK	46	5200
16QAM	92	1400
64QAM	140	300
256QAM	186	100

TABLE III
NORMALIZED COST VALUES OF THE NEEDED COMPONENTS [14]

Component	Normalized Cost Value
Fixed Grid TRx	5
Flexible Grid TRx	17
Amplifier (EDFA)	0.6
Fixed/Flexible Grid WSS (1×20)	3

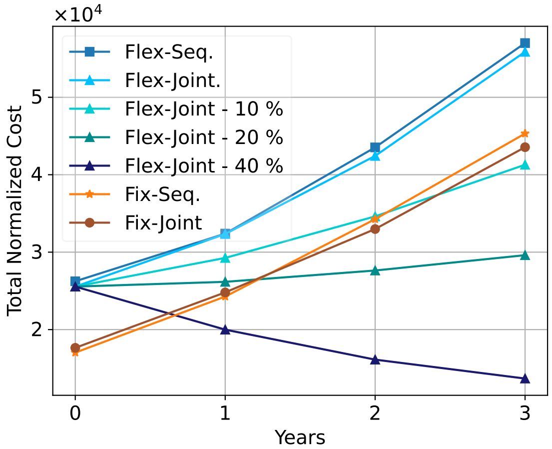

Fig. 1. Total normalized costs for a 4-year planning.

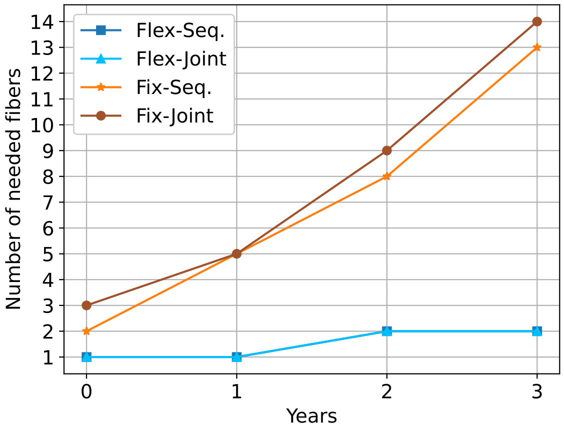

Fig. 2. Number of required fibers for a 4-year planning.

Fig. 1 depicts the total normalized cost for the Sequential and Joint approaches, both for the fixed and flexible grid scenarios, along with the total costs for the Joint approach in the flexible grid when a reduced flexible TRx cost by $\{10, 20, 40\}\,\%$ is considered. Results show that the Sequential and the Joint ILPs perform very closely, with the Joint approach being slightly cheaper most of the time. The total cost for the fixed grid scenario is much lower than for the flexible grid, approximately by $25-55\,\%$; the highest difference occurs at year 0, and it gradually decreases to $25\,\%$ at the end of year 3. Although the spectrum can be utilized more efficiently in the flexible grid, i.e., fewer LPs are required to satisfy the demands compared to the fixed grid, the cost is higher due to the expensive flexible TRx's. Based on the values of Table III, the flexible TRx cost is 3.4 times higher than the fixed TRx cost. Despite this critical cost difference and the fact that the TRx's costs mainly drive the total cost, the flexible grid architecture induces only up to 1.6 times higher cost. However, as the years go by, the maturity of the flexible TRx's is expected to increase, resulting in lower costs for the components. For that reason, we investigate the total network planning cost considering three different reducing factors for the flexible TRx's cost, i.e., 10, 20, 40 %, and we present only the results of the Joint approach given that it performs close to the Sequential one. Fig. 1 proves that a $10\,\%$ reduce factor shows comparable cost with respect to the fixed grid cost after 3 years, while a $20\,\%$ factor leads to a lower cost already on the second year of planning (year 1). For $40\,\%$, the cost difference becomes extreme but proves further the spectrum utilization efficiency that the flexible grid offers.

Fig. 2 presents the number of needed fibers per approach and grid architecture. The flexible grid network requires only two fibers over the 4-year planning, with the extra fiber added in year 2. Both the Sequential and the Joint ILP induce the same number of necessary fibers. On the other hand, in the fixed grid, the Sequential approach always needs fewer (or equal) fibers than the Joint one; the Joint approach needs 1 more fiber every year, except for year 1. This means the Sequential approach utilizes lit fibers more efficiently for the fixed grid scenario. The Joint approach seems to be more restrictive in the sense that $K = 3$ specific path pairs need to be chosen for every demand, which proves to be a limiting factor for the fixed grid architecture. However, an essential aspect of the Joint approach is that it can always protect demands since the routing of the Sequential one may prohibit finding a link-disjoint BP for some demands. Moreover, it is proved that for the fixed grid architecture, $13-14$ fibers are needed over the 2 fibers required in the flexible grid network. As mentioned previously, the total cost is driven by the cost of the TRx's needed for the LPs. The cost of the in-line amplifiers is ~ 8 and ~ 28 times lower than the cost of the fixed and the flexible TRx, respectively [5], [9], [14], which makes the cost of lighting a dark fiber comparable to the cost of establishing an LP in the network. This is the reason why

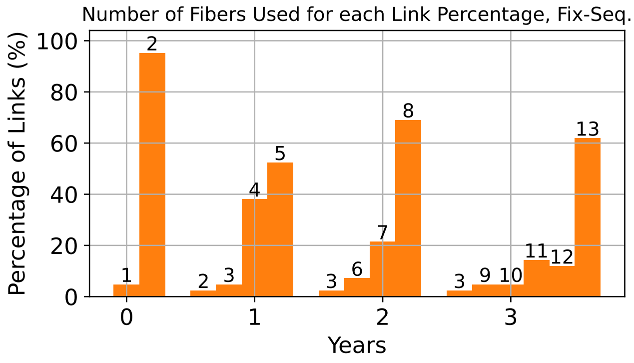

Fig. 3. The number on each bar shows how many fibers each percentage of links uses for the Sequential approach in the fixed grid.

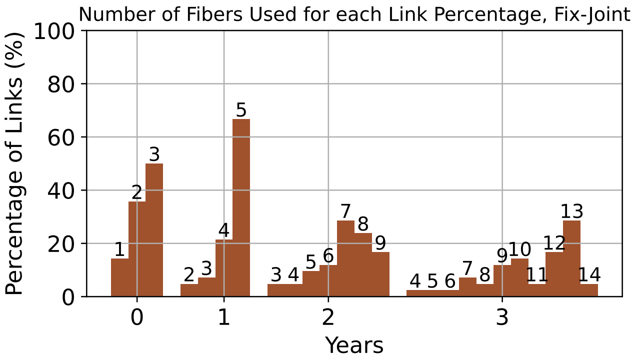

Fig. 4. The number on each bar shows how many fibers each percentage of links uses for the Joint approach in the fixed grid.

the fixed grid presents much lower planning costs despite the 7 times more fibers that it needs compared to the flexible grid. This is also one of the reasons why we choose to add only one extra fiber per link in the network if the optimization problem is infeasible. Moreover, this explains why, in the fixed grid network, the Joint approach provides almost the same cost as the Sequential approach, even though it requires one more fiber as the years go by.

In Figs. 3 and 4, we analyze the number of fibers the directed links need each year in the fixed grid for the Sequential and Joint approach, respectively. Fig. 3 shows that, for the Sequential approach, $\sim 95\,\%$ of the directed links require 2 fibers for the planning of year 0, while $\sim 5\,\%$ need only 1. For the same year, the Joint approach needs overall 3 fibers, with $\sim 50\,\%$ of the links requiring 3 fibers, $\sim 35\,\%$ needing 2 fibers and $\sim 15\,\%$ needing only 1 fiber. The same distribution pattern can be observed for the rest of the years. At each year of the Sequential approach, the by far highest percentage of links requires the maximum number of needed fibers. On the other hand, the Joint approach presents a more uniform distribution of how many links need how many fibers. This proves further that the routing and protection strategy of the Joint approach is more restrictive in the fixed grid and that the Sequential approach utilizes the available resources in a more efficient way, resulting in the need for one less fiber. The respective figures for the flexible grid were omitted due to space constraints and because both approaches presented almost the same results regarding fiber usage with respect to link distribution. At the first 2 years, $100\,\%$ of the links required 1 fiber for both approaches. At the end of year 3, for the Sequential approach $98\,\%$ of the links needed 2 fibers, while for the Joint approach $95\,\%$ of the links required 2 fibers.

In Figs. 5 and 6, we present the cumulative distribution of utilized wavelengths for the fixed grid and the cumulative distribution of utilized frequency slots for the flexible grid over all links and across the years for the two optimization strategies. The dashed lines indicate the number of fibers needed according to the maximum number of utilized wavelengths/frequency slots. For both network architectures, the Sequential and the Joint planning approaches utilize resources in a very similar manner, with the Joint ILP always presenting the highest number of utilized wavelengths/frequency slots over the years. The mean value of the distribution is almost the same every year and in every different optimization approach-year-architecture scenario. Focusing on the fixed grid network, for the year 0, Fig. 5 shows that the maximum utilized wavelengths by the Sequential ILP were 160, while for the Joint ILP, they were slightly higher, around 180. This shows that for the Sequential approach, the 2 fibers, which provide $2 \times 80 = 160$ wavelengths, were borderline enough to plan year 0. On the other hand, the Joint approach shows that very few links require more than 160 wavelengths and, thus, raise the need for a third fiber. Therefore, the fact that $\sim 50\,\%$ of the links need 3 fibers in year 0 (Fig. 4) is caused by the lack of resources on a much smaller subset of links, and not on all this $50\,\%$ of the links. In year 2, the two approaches need the same number of fibers, and the cumulative distribution of the wavelengths used is almost identical. In year 3, Fig. 5 shows how the Sequential approach needs one less fiber than the Joint approach again and that the fibers are more heavily loaded, which proves that the Sequential approach utilizes resources more efficiently in the fixed grid network. Fig. 6 proves that for the flexible grid architecture, where the same number of fibers was needed for both approaches, the cumulative distribution is almost the same for the two ILPs, with the Joint ILP presenting a higher maximum number of utilized frequency slots over the years compared to the Sequential ILP.

Regarding the computational time of the ILPs, all of them were run on a PC with a CPU model of Intel(R) Core i7-4790; in each architecture scenario and for each year, the computational time was, in the worst case, $8-10$ hours. The highest execution times occurred during the planning of the last year for the fixed grid architecture. Although the flexible grid offers 4 times more frequency slots and, thus, increases the search space of the ILP, the optimal results were provided in much less time than the ones for the fixed grid, ~ 2 hours at the worst case, because of the availability of higher capacities for the candidate LPs. Moreover, as the years and the number of fibers increased, no significant differences were observed in the execution time of the ILPs. This is because we always

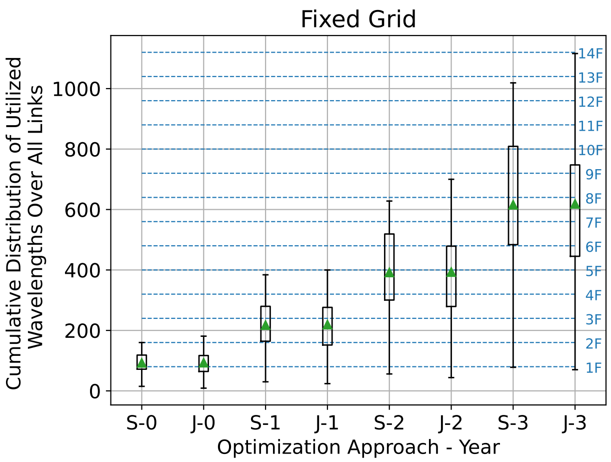

Fig. 5. Cumulative distribution of utilized wavelengths over all links for each year in the fixed grid optical network.

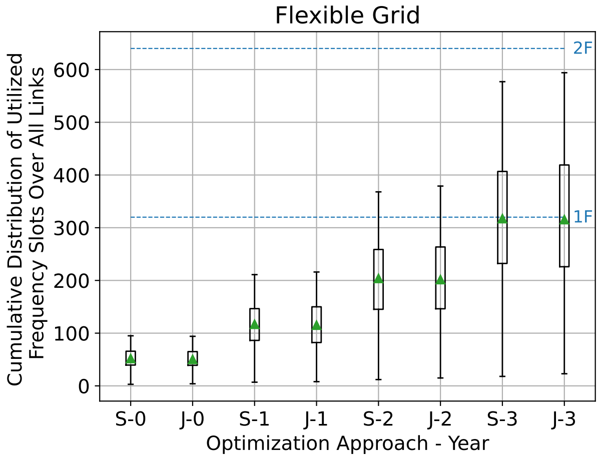

Fig. 6. Cumulative distribution of utilized frequency slots over all links for each year in the flexible grid optical network.

restrict the number of fibers per link to the minimum number the ILP needs to solve the problem. We note that for the execution of the ILPs, we allow a small optimality gap of up to $3\,\%$, which we do to further reduce the running time, given that the results are reliable at this stage. However, since this is a static network planning problem, the execution time of the ILP does not stand as a problem.

V. CONCLUSIONS

This paper investigates optimal and reliable multi-period planning for optical networks' fixed and flexible grid architectures. It aims to minimize the network equipment cost of establishing LPs and lighting dark fibers by proposing two different ILPs to perform the routing and guarantee $1+1$ protection for the demands over a 4-year planning period with increasing traffic. The Sequential ILP performs the planning as a two-step process by first optimizing the WPs and then the BPs, while the Joint ILP chooses the WPs and the BPs simultaneously. The two proposed methods induce similar costs among each other for the fixed and flexible grid, with the flexible grid presenting $25-55\,\%$ higher costs than the fixed grid. However, the fixed grid required $5-7$ times more fibers, where the Joint approach proved to need one more fiber than the Sequential one. The cost difference between the fixed and the flexible grid is expected to reduce as the flexible TRx's will reduce their costs thanks to the maturity of the technology in the next couple of years.

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