Cross Optimization for RWA and Regenerator Placement in Translucent WDM Networks

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Abstract—**Translucency in WDM networks appears as a trade-off between the low cost of full transparency and the high signal quality provided by full opacity. On the one hand, transparent networks undergo various transmission impairments due to optical components deployed in the network. On the other hand, opaque networks remain very expensive due to electrical 3R regeneration (Re-amplifying, Re-shaping, and Re-timing), performed at each network node. Translucent networks use sparse regeneration strategy in order to improve the optical signal budget. In translucent network design, the objective is to judiciously choose the regeneration sites in order to establish a set of traffic demands with an admissible quality of transmission at a minimized network cost. We address the problem of translucent network design by proposing a novel heuristic for routing, wavelength assignment and regenerator placement. Our heuristic, called COR2P for *Cross Optimization for RWA and Regenerator Placement*, aims at minimizing both the number of required regenerators and the number of regeneration sites in the network. The originality of COR2P lies on a CapEx/OpEx perspective for network cost evaluation. Capital Expenditure refers to the network deployment cost while Operational Expenditure refers to the network management and maintenance cost. We introduce an original cost function that contributes to the optimization of CapEx/OpEx expenditures. In this paper, we investigate the impact of different parameters introduced in our heuristic and cost function, such as the ratio of sites chosen *a priori* for regeneration, and the limited size of regenerator pools installed at such nodes. Our simulation results outline that a tradeoff for CapEx and OpEx costs can be achieved by judiciously adjusting these parameters.**

I. INTRODUCTION

Thanks to the development of long-haul and ultra-long-haul optical components, transparent WDM (Wavelength Division Multiplexing) networks are nowadays achievable. However, impairments due to transmission over fiber may significantly affect network performance. Recent research work in the field of optical network planning deals with the problem of Routing and Wavelength Assignment (RWA) considering physical layer constraints. Several studies propose Impairment-Aware RWA (IA-RWA) algorithms for transparent WDM networks whereas others investigate the idea of sparse regeneration in large-scale networks, referred to as translucent networks.

IA-RWA algorithms define the rules and strategies for routing and wavelength assignment in transparent networks, in order to minimize the number of rejected demands due to either capacity or Quality of Transmission (QoT) limitations. In [1], Deng *et al.* study the impact of crosstalk on blocking performance under dynamic traffic pattern. They propose crosstalk-aware algorithms that minimize crosstalk between the new and exiting lightpaths such that blocking probability is minimized. Nonlinear effects have also been considered in [2] where Cardillo *et al.* propose an Optical Signal to Noise Ratio (OSNR) aware algorithm. They show that when transmission impairments come into play, the Best-OSNR algorithm outperforms its traditional counterparts (*e.g.*, first-fit) in terms of blocking probability.

Sparse regeneration technique consists in deploying regenerators at a limited number of nodes to ensure admissible QoT through the network. In [3], Ramamurthy *et al.* show that

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translucent networks can achieve performance measures close to those obtained in fully opaque networks while significantly reducing the network cost. They deal with parse regeneration assuming a limited regeneration capacity. Four regenerator placement algorithms have been proposed, based on either network topology or traffic prediction. These algorithms have been investigated with respect to different network topologies. Simulation results show that for medium-sized networks, the topology-based algorithm yields better results than the signal quality prediction and the traffic load prediction algorithms. However, for large-sized networks, the signal quality prediction algorithm yields the best performance.

In previous work [4], we proposed an algorithm that deals with translucent network design under static traffic pattern. Given that we can deploy a regenerator at any node if necessary, our aim was to minimize both the number of rejected demands and the number of required regenerators. In [5], we investigated the impact of deploying dynamic gain equalizers in the network and we have shown that using an equalization scheme can significantly improve performance through the network. Moreover, QoT-aware wavelength assignment strategies can compensate for the absence of in-line gain equalizers [6].

In [7] and [8], Pachnicke *et al.* deal with the problem of translucent network design assuming a fixed number of regeneration sites. They propose a double-stage algorithm for routing and regenerator placement taking into account both linear and non-linear transmission impairments. Their proposal relies on a topology-driven strategy for regenerator placement followed by a constrained-based algorithm for RWA.

In this paper, we propose a novel algorithm for RWA and regenerator placement taking into account transmission impairments. Our proposed algorithm, *Cross Optimization RWA and Regenerator Placement* (COR2P), is a heuristic-based algorithm that aims at minimizing the number of regeneration sites while minimizing the number of regenerators required in the network. Regenerators are used whenever the BER value exceeds a given threshold along a lightpath. In practice, several regenerators may be needed along a lightpath. BER values are estimated using the BER-Predictor tool introduced in [9]. BER estimation is based on the cumulated effect of four transmission impairments, namely Chromatic Dispersion (CD), Polarization Mode Dispersion (PMD), Non-Linear Phase shift (Φ_{NL}), and Amplified Spontaneous Emission (ASE).

The remain of this paper is organized as follows. Section II is dedicated to the description of the COR2P heuristic while Section III summarizes our simulation results. In Section IV, we conclude our paper and provide directions for farther work.

II. TRANSLUCENT NETWORK DESIGN

In translucent WDM network design, nodes equipped with regeneration facilities should be carefully chosen in order to guarantee an acceptable signal quality at destination. Moreover, the number of such nodes should be kept to a minimum in to reduce the network deployment and management costs.

A. Problem Statement

Given

- a physical network topology wherein switching nodes are connected via bidirectional fiber-links;
- a set of wavelengths available per fiber-link;
- a set of Permanent Lightpath Demands (PLDs);
- an admissible BER threshold in the network BER_{th}.

Objective

Our aim is to satisfy the maximum number of PLDs while minimizing network cost. In this work, we consider a twofold network cost, namely the Capital Expenditure (CapEx) cost relative to network deployment and Operational Expenditure (OpEx) cost relative to network management and maintenance. Usually, the CapEx and OpEx costs cannot be minimized simultaneously. In this paper, we try to formulate the global network cost with respect to their relative weights. Consequently, our objective is to minimize the number of required regenerators and to urge their concentration into a reduced number of nodes.

Subject to

a) Quality of transmission requirements: For any lightpath in the network, the corresponding BER value should not exceed the BER threshold. An estimate of the BER is obtained using BER-Predictor developed in previous work [9]. BER-Predictor takes into account the simultaneous effect of four transmission impairments, namely Chromatic Dispersion (CD), Polarization Mode Dispersion (PMD), Amplified Spontaneous Emission (ASE), and Nonlinear Phase Shift (Φ_{NL}).

b) Wavelength continuity constraint: In the absence of any wavelength conversion, a lightpath demand should be routed using the same wavelength along the chosen route. Since electrical regeneration allows wavelength conversion, introducing regenerators slightly relaxes this constraint.

c) Regeneration capacity per site: The number of regenerators we can deploy in a regeneration site is limited to an upper bound $\mathcal{X}$. Such a limitation could be due to supply power constraints or other motivations according to the carrier's strategy.

B. Notations

In this paper, we use the following notations and typographical conventions.

- $\mathcal{G} = (\mathcal{V}, \mathcal{E}, \xi)$ is a symmetrical graph representing the network topology. $\mathcal{V}$ represents the set of nodes and $\mathcal{E}$ represents the set of links. ξ is a cost function $\xi : \mathcal{E} \rightarrow \mathbb{R}^+$ mapping the physical length of the links.
- $N = |\mathcal{V}|$ denotes the number of the network nodes.
- W denotes the number of wavelengths per fiber-link.
- $\mathcal{D}$ is the set of PLDs to be set up in the network.
- A PLD, numbered i and denoted $d_i, 1 \leq i \leq |\mathcal{D}|$, is a connection demand between two nodes in $\mathcal{V}$.
- $\mathcal{P}_i$ is the set of available paths connecting the source node and the destination node of d_i. For each $d_i, 1 \leq i \leq |\mathcal{D}|$, we compute beforehand $\mathcal{K}$-alternative shortest

paths connecting the source to the destination node of d_i according to Eppstein's algorithm [10].

- $\mathcal{P} = \bigcup_{i=1}^{i=|\mathcal{D}|} \mathcal{P}_i$ is the set of available paths considering all the $\mathcal{K}$-alternative shortest paths computed between all PLDs to be set up.
- p_{ik} denotes the $k^{th}, 1 \leq k \leq \mathcal{K}$ shortest path in $\mathcal{P}_i$ connecting the source node to the destination node of d_i.
- $\mathcal{H}_{ik}$ denotes the number of hops of the path p_{ik}.
- $\mathcal{R}$ is the initial number of regeneration sites in the network while $\mathcal{R}^*$ is the number of effectively used regeneration sites.
- $\mathcal{X}$ is the maximum number of regenerators per regeneration site.

C. *Synopsis of* COR2P

Given a network topology and a set of lightpath demands, COR2P aims to find an RWA solution and places regenerators in appropriate nodes in order to satisfy the quality of transmission requirements. The synopsis of COR2P can be divided in three consecutive steps.

*1) **Step 1 - Preliminary Routing:*** In this step, we only proceed to routing the PLDs taking into account the network resources and wavelength continuity constraints.

First, we compute an estimate of the BER for all paths in $\mathcal{P}$ assuming a flat transmission system, *i.e.* the network elements have a flat spectral response. Afterwards, we sort the PLDs in decreasing order with respect to the BER value on their shortest path. Subsequently, PLDs that are most affected by transmission impairments will be processed first.

Second, we consider the PLDs one by one. We try to find for each PLD d_i, a path-free wavelength in $\mathcal{P}_i$. If no path-free wavelength is available, the processing of this PLD is postponed to Step 3. Such PLDs may be satisfied then thanks to the placed regenerators that relaxed the wavelength continuity constraint.

*2) **Step 2 - Potential Regenerator Placement:*** Our aim in this step is to determine the nodes that are most likely to become regeneration sites. In this respect, each node is assigned a counter reflecting the need for regeneration at its level.

In this step, we consider the lightpaths obtained in Step 1. We follow the signal quality of each lightpath hop by hop. Whenever the signal quality drops, we increment the counter of the preceding node and we restart the quality test from that node. Once all the lightpaths are processed, we sort the network nodes in decreasing order according to their counters. The first $\mathcal{R}$ nodes are qualified as those where regeneration is most likely needed. We recall that $\mathcal{R}$ denotes the initial number of regeneration sites in the network; this number may increase during Step 3.

At this stage, we introduce ρ as the ratio of the initial number of regeneration sites to the number of network nodes. We expect that by judiciously choosing ρ, the number of regeneration sites to be effectively deployed in the network can be reduced.

*3) **Step 3 - Effective RWA and Regenerator Placement:*** In this step, we assume a real transmission system wherein the signal quality depends on the chosen wavelength. We consider first the PLDs that have been routed in Step 1. To each demand an adequate wavelength is assigned according to the Best-BER-Fit (BBF) strategy, introduced in [6].

Given a path and a set of wavelengths, BBF consists in choosing the first wavelength that guarantees the quality of transmission requirements. Subsequently, BBF saves the better suited wavelengths in terms of BER for possible longer PLDs. If no available wavelength can satisfy the quality of transmission requirements, the lightpath requires one or more signal regenerations.

Regenerators are deployed in the network according to an original multi-constraints cost function (detailed in II-D). This function aims not only to optimize the number of deployed regenerators but also to concentrate them in several nodes. In doing so, we reduce the network management cost. PLDs that found no path-free wavelength in Step 1 benefit from the relaxation of the constraint of wavelength continuity using regenerators. Step 3 synopsis is given in Pseudo-Code 1.

Function GET_COST(*path*) detailed in Pseudo-Code 2, tries different places for the regeneration on the *path* and computes the cost related to each combination. It then chooses the *solution* that gives the lowest total cost.

D. *Cost Function*

The global cost of an end-to-end connection is twofold: the network resources cost and the regeneration cost. In order to balance these two costs, we ponderate them by α and $(1-\alpha)$, respectively as depicted in Equation (1).

$$\mathcal{C}_{connection} = \alpha \cdot \mathcal{C}_{resources} + (1-\alpha) \cdot \mathcal{C}_{regeneration} \quad (1)$$

The network resources cost is related to optical channels consumed by the connection and thus, to the number of hops traversed by the connection. We formulate the network resources cost by:

$$\mathcal{C}_{resources} = \frac{\mathcal{H}}{\overline{\mathcal{H}}} \quad (2)$$

where $\mathcal{H}$ is the number of hops of the assigned path and $\overline{\mathcal{H}}$ is the mean number of hops of the $\mathcal{K}$-alternative shortest paths. Equation (2) enables to keep in Equation (1) resources cost and regeneration cost at comparable order of magnitudes.

As aforementioned, the regeneration cost takes into account two aspects, namely CapEx and OpEx. We assume that regenerators are not installed individually but by pool of size $\mathcal{X}$. According to the traffic load, individual regenerators within a pool may be activated or deactivated. The OpEx cost then is relative to the activation or deactivation of a regenerator in a regeneration site. In this paper, only static traffic is considered, traffic demands being satisfied in a cumulated way. In this context, the CapEx cost is constant per regeneration site regardless of the number of activated regenerators in the pool. The rationale of our cost function is to decrease OpEx cost with the number of activated regenerators in the considered

PSEUDO-CODE 1 Synopsis of COR2P-Step 3

```
Let $\Theta$ be the set of demands to be regenerated.
Let $\Delta$ be the set of demands rejected in Step 1.
**Initialization**
$\Theta = \Delta$
$\mathcal{R}$ nodes are considered regeneration sites
**Processing**
for all $d_i \in \mathcal{D} \backslash \Delta$ do
    $\lambda^*$=Get_BBF$^1(p_{ik^*})$ {$p_{ik^*}$ is the path assigned to $d_i$ in Step 1}
    if ($\lambda^* \neq -1$) then
        Assign $\lambda^*$ to $d_i$
        Update network resources
    else
        $\Theta = \Theta \cup \{d_i\}$
    end if
end for
for all ($d_i \in \Theta$) do
    $cost_i = \infty$
    for ($k = 1$ to $k = \mathcal{K}$) do
        $cost_{ik} = Get\_Cost^2(p_{ik})$
        $cost_i = min(cost_i, cost_{ik})$
    end for
    if ($cost_i = \infty$) then
        if ($p_{i1}$ supports no regeneration site) then
            Consider the BBF $\lambda$ wavelength over $p_{i1}$
            Trace the BER relative to $\lambda$ on each node $v_h$ $(2 \leq h \leq \mathcal{H}_{i1})$
            Let $v_{h^*}$ be the node that precedes the deterioration of the BER
            while ($h^* \neq 1$) do
                Estimate $BER_1$ and $BER_2$, BERs relatie to the BBF
                wavelengths at the end of subpaths $(v_1 - ... - v_{h^*})$ and
                $(v_{h^*} - ... - v_{\mathcal{H}_{i1}+1})$
                if (($BER_1 \geq BER_{th}$)&($BER_2 \geq BER_{th}$)) then
                    $d_i$ is blocked
                else
                    if (($BER_1 \geq BER_{th}$)||($BER_2 \geq BER_{th}$)) then
                        $h^* - -$
                    else
                        $v_{h^*}$ is considered a regeneration site
                        A regenerator is deployed in $v_{h^*}$
                        $d_i$ is established
                        $h^* = 1$
                    end if
                end if
            end while
        else
            $d_i$ is blocked
        end if
    else
        Solution of the Get_Cost(path) function provide places to add
        regenerators along with an RWA solution
    end if
end for
```

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[1] Get_BBF($path$) is a function that returns the Best-BER-Fit wavelength, available over the parameter $path$. Get_BBF($path$) returns -1 if no available wavelength guarantees the quality of transmission requirements.

[2] Pseudo-code of the Get_Cost($path$) function is provided.

site. For instance, maintaining x regenerators at 2 distinct regeneration sites does not imply the same cost for maintaining x regenerators in a single pool.

Let $v_i \in \mathcal{V}$ be a regeneration site used by a connection, its regeneration cost $\mathcal{C}_R(v_i)$ takes into account the CapEx/OpEx duality as follows:

$$\mathcal{C}_R(v_i) = \begin{cases} \mathcal{C}_O \cdot e^{-\frac{1}{\mathcal{X}}} + \mathcal{C}_C & \text{if } v_i \text{ is a new site,} \\ \mathcal{C}_O \cdot e^{-\frac{x_0+1}{\mathcal{X}}} & \text{if } 1 \leq x_0 < \mathcal{X}, \\ \infty & \text{if } x_0 = \mathcal{X} \end{cases} \qquad (3)$$

PSEUDO-CODE 2 Synopsis of Get_Cost ($path$)

```
**Initialization**
Let $\mathcal{H}$ be the number of hops of $path$
Let $s$ and $d$ be the source and destination of $path$
Let $\mathcal{N}_R$ be the number of regeneration sites over $path$
**Processing**
$minCost = \infty$
for ($k = 1$ to $k = \mathcal{N}_R$) do
    Consider the $k$-combinations from the set of $\mathcal{N}_R$ sites
    for ($c = 1$ to $c = C_k^{\mathcal{N}_R}$) do
        Consider the combination $C_{kc}$, with $n_1, n_2, \ldots n_k$ used as regen-
        eration sites over $path$
        Find a set of BBF free wavelengths $\{\lambda_p : p = 1...k+1\}$ over the
        subpaths of $path$ delimited by $n_i$, $1 \leq i \leq k$. These wavelengths
        should provide good QoT.
        if (Such set exists) then
            Compute the cost $Cost_{kc}$ relative to the use of $path$ with the
            combination $C_{kc}$ of regeneration sites, using the Cost Function
            { Equation (1) }
        end if
        if ($Cost_{kc} < minCost$) then
            $minCost = Cost_{kc}$
            Store this "solution"($path$, $C_{kc}$, $\{\lambda_p : p = 1...k+1\}$)
        end if
    end for
end for
Return "solution"
```

where $\mathcal{C}_O$ and $\mathcal{C}_C$ are the unitary OpEx and CapEx costs respectively. In the first case, we consider the installation of a first isolated regenerator in a new regeneration site. In this case, the cost $\mathcal{C}_C$ illustrates the carrier's investment to install a regeneration pool at node v_i. The cost $\mathcal{C}_O$ corresponds to the cost to manage a single active regenerator at a node. The second case refers to the activation of a new regenerator in a site already equipped with x_0 active regenerators. The higher x_0, the lower $\mathcal{C}_C$. The third case corresponds to the case where all an infinite regeneration cost since the maximum number of regenerators $\mathcal{X}$ is already reached in v_i. Equation (3) depicts the fact that the higher the number of regenerators in a site, the lower its maintenance cost.

The regeneration cost of an end-to-end connection is the sum of the cost of each regeneration site used on the path. From Equations (2) and (3), Equation (1) can be developed as follows:

$$\mathcal{C}_{connection} = \alpha \cdot \frac{\mathcal{H}}{\overline{\mathcal{H}}} + (1 - \alpha) \cdot \sum_i \mathcal{C}_R(v_i) \qquad (4)$$

such that v_i is a regeneration site used by the connection.

III. SIMULATION RESULTS

In this section, we investigate different parameters of COR2P via numerical simulations. First, we aim at concentrating the regenerators in a limited number of regeneration sites. Second, we elaborate the results of the first phase in order to dimension the regenerator pools in the sites.

A. Simulation assumptions

In our simulations, we consider the 18-node NSFNet illustrated in Figure 1. The network is assumed to be deployed using Standard single-Mode Fibers (SMF) covering the C-band with 100 GHz spacing, *i.e.* providing $\mathcal{W} = 40$ wavelengths

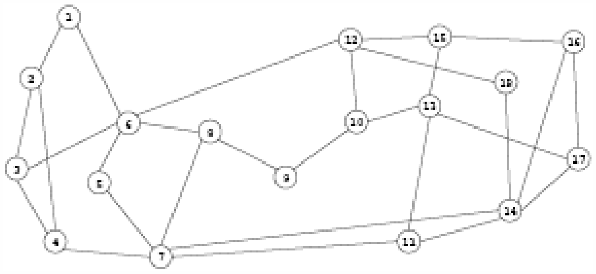

Fig. 1. The American 18-nodes NSF backbone network topology.

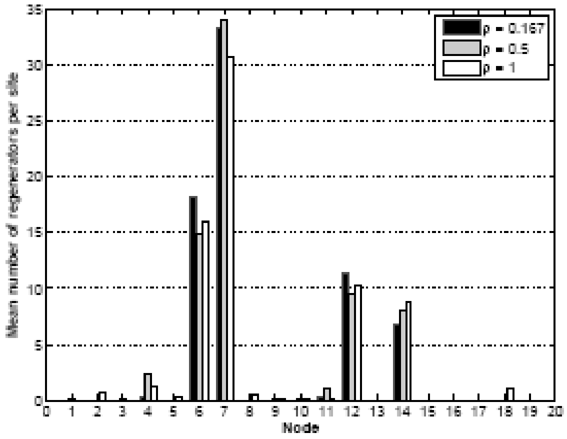

Fig. 2. Regenerator distribution for a traffic load of 400 PLDs.

on each fiber-link. In order to recover the fiber losses, double-stage Erbium-Doped Fiber Amplifiers (EDFA) are deployed every 80 km. Chromatic dispersion is compensated with Dispersion Compensating Fibers (DCF) which are deployed at the amplification sites. Further details about the transmission system assumptions are given in [9]. In this paper, we consider a BER threshold of 10^{-5} corresponding to a Q-factor of 12.5 dB assuming FEC (Forward Error Correction) at destination. According to the statement of different carriers, there is not an explicit way to evaluate the OpEx cost. Subsequently, the ratio $\mathcal{C}_C/\mathcal{C}_O$ may vary according to the type of equipment and the maintenance policy. Without loss of generality, we have fixed in our simulations this ratio to 1.

Simulation results are obtained considering static traffic matrices randomly generated according to a uniform distribution. For each considered traffic load, we deal with 10 different matrices. Hence, each result represented in this paper is the mean value of 10 simulations.

B. Regeneration Concentration

As mentioned in Section II-C1, COR2P chooses $\mathcal{R}$ transparent network nodes to be equipped with a pool of regenerators. Parameter ρ represents the ratio of $\mathcal{R}$ to the number of network nodes. Additional pools of regenerators may be coupled to other transparent nodes if necessary. Therefore, the number of effective regeneration sites $\mathcal{R}^*$ is not necessarily equal to the number of prefixed sites $\mathcal{R}$. In this section, we investigate the impact of different values of ρ on the global network cost.

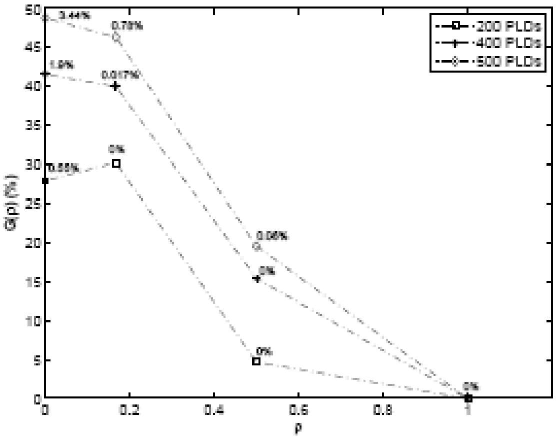

Fig. 3. Gain in the number of regeneration sites.

In the following simulations, we choose $\alpha = 0.1$ in order to favor regenerators concentration (see Equation (1)). The value of $\mathcal{X}$ is set to 100. Traffic loads varying from 100 to 500 PLDs are taken into account. For each traffic load, three different values of ρ are considered: 0.167, 0.5 and 1. For these values, the global number of regenerators installed in the network remains roughly the same. It is worth noting that when $\rho = 1$, the network is not opaque since optical signals are not systematically regenerated at each node.

Figure 2 illustrates the distribution of regenerators over the sites for a traffic load of 400 demands under different values of ρ. Each bar represents the mean number of regenerators used in the corresponding site. We observe that the sites with predominant use (sites $6, 7, 12$ and 14) have the highest nodal degrees and longest average distance with their first neighbors. In addition, we notice that the higher ρ, the higher $\mathcal{R}^*$.

Let us consider the case $\rho = 1$ (*i.e.*, Steps 1 and 2 of COR2P are shunted) as a reference case. In Equation (5), $G(\rho)$ is defined as the gain in the number of effective regeneration sites with respect to our reference case.

$$G(\rho) = \frac{\mathcal{R}^*_{\rho=1} - \mathcal{R}^*_{\rho}}{\mathcal{R}^*_{\rho=1}} \tag{5}$$

In Figure 3, we present the gain introduced in Equation (5). Our concern is to find the best value of ρ that leads to the optimum number of regeneration sites with regard to a certain blocking ratio ($< 1\%$). We consider three traffic loads: 200, 400, and 500 PLDs. In the figure, we have coupled to each value of $G(\rho)$ the corresponding blocking ratio. For traffic loads of 400 and 500 PLDs, the optimum value of ρ is 0.167 corresponding to $\mathcal{R} = 3$. Lower numbers of effective regeneration sites can be achieved with $\rho = 0$ at the price of unacceptable blocking ratios. Under 200 PLDs, $\rho = 0.167$ enables the highest gain with null blocking ratio.

Figure 4 depicts the impact of α (Equation (1)) over the effective number of regeneration sites for a traffic load of 400 demands. We considered $\rho = 0.167$ and $\rho = 1$ (the

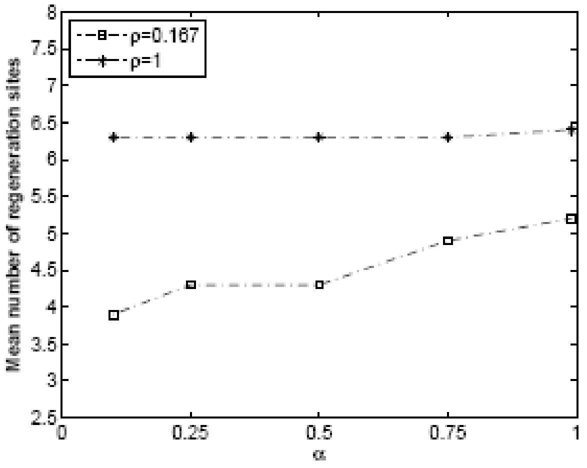

Fig. 4. Effective number of regeneration sites w.r.t. α.

TABLE I
IMPACT OF $\mathcal{X}$ ON $\mathcal{R}^*$ AND $\mathcal{X}^*$.

	Traffic load (PLDs)	$\mathcal{X}$	Mean $\mathcal{R}^*$	Max $\mathcal{X}^*$
$\rho = 0.167$	400	50	4.9	30
		75	4.9	30
		90	4.9	31
		100	3.9	33
	500	50	5.2	47
		75	5.2	48
		90	5.2	48
		100	5.2	44
$\rho = 1$	400	30	6.5	25
		40	6.5	26
		50	6.5	26
		100	6.4	26
	500	30	8.3	25
		40	7.9	26
		50	7.9	26
		100	7.9	26

optimum and worst scenarios in terms of the number of effective regeneration sites and w.r.t. an acceptable blocking ratio). For $\rho = 1$, all network nodes are regenerating, thus the CapEx cost related to the installation of a pool of regenerators does not exist, which explains how α barely impacts the number of effectively used regeneration sites. On the other hand, for $\rho = 0.167$, the concentration due to the value of α is eminent. Small values of α, *e.g.*, $\alpha = 0.1$, concentrate better the regenerators because the CapEx cost of installing new regeneration pools weighs more than it does when α takes bigger values. Indeed, the values of α and ρ jointly affect the concentration of regenerators in a limited number of regeneration sites.

C. Regenerators Pool Dimensioning

In the previous section, we found that whatever the value of ρ, COR2P concentrates regenerators in less than half of the network nodes. In addition, we have noticed that $\rho = 1$ and $\rho = 0.167$ lead to the highest and lowest mean numbers of effective regeneration sites $\mathcal{R}^*$, respectively. In this section, we investigate the optimum size of regeneration pool to be deployed in these sites. We choose the value of α to be 0.1.

Let $\mathcal{X}_i^*$ be the number of regenerators effectively used in site i and $\mathcal{X}^* = \max\{\mathcal{X}_i^*\}$ be the number of regenerators to be deployed in each site. Table I presents $\mathcal{X}^*$ and $\mathcal{R}^*$ with respect to parameter $\mathcal{X}$ attributed to each regeneration site under COR2P. For $\rho = 1$, regeneration is potentially distributed over all the nodes of the network. Hence, PLDs have further regeneration possibilities than the case of $\rho = 0.167$ where regeneration is more limited. In this respect, the number of required regenerators per site should be less for $\rho = 1$ than for $\rho = 0.167$, which justifies the different ranges for the values of $\mathcal{X}$.

From Table I, we conclude the following:

- For $\rho = 1$, and for a traffic load of 400 demands, 7 regeneration sites holding 25 regenerators each, are sufficient to guarantee the demands' establishment whereas 8 regeneration sites holding 26 regenerators each, are required for 500 demands.
- For $\rho = 0.167$, 5 regeneration sites holding 30 regenerators each are sufficient to guarantee the 400 demands' establishment. For the same value of ρ, 6 regeneration sites holding 44 regenerators each, are needed to establish 500 demands.

Choosing a lower number of sites holding a larger number of regenerators or, inversely, a higher number of sites holding a smaller number of regenerators depends on the carrier's strategy.

IV. CONCLUSIONS AND PERSPECTIVES

In this paper, we have proposed a new IA-RWA algorithm called COR2P for translucent networks design. Our algorithm aims at minimizing both the global number of regenerators and the number of regeneration sites in the perspective of CapEx and OpEx costs. Both linear and non-linear transmission impairments are considered for QoT evaluation. Our strategy for regenerator placement is based on an *a-priori* choice of potential regeneration sites considering the most restrictive lightpaths. We have investigated the impact of the number of potential sites on the number of effective regeneration sites given by COR2P. Accordingly, we propose a network dimensioning solution that provides, for a given traffic load, the required number of regeneration sites and the size of the regenerator pool. In this respect, two cases are considered. In the first case ($\rho = 0.167$), our concern is to maximize the regeneration concentration which leads to the least number of regeneration sites. Nevertheless, this case eventually induces a higher size of regenerators pool than the second case ($\rho = 1$) that deploys regenerator pools of smaller size in a higher number of sites. Therefore, COR2P can provide carriers with an appropriate solution according to their strategy.

Future work will consider comparison between COR2P and other regenerator placement algorithms proposed in literature. The impact of $\mathcal{C}_C/\mathcal{C}_O$ will be considered in order to respond to different carriers expectations. In addition, we intend to extend our model to the context of scheduled traffic considering activation/deactivation of the lightpaths.

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