Novel Strategies for Sparse Regenerator Placement and Allocation in Translucent Optical Networks

Daniel A. R. Chaves, Renan V. B. Carvalho, Caio F. C. L. C. Ayres, Helder A. Pereira, Carmelo J. A. Bastos-Filho and Joaquim F. Martins-Filho

***Abstract*— In this paper we propose one allocation strategy and two strategies for sparse regenerator placement in translucent optical networks, namely Most Used Regenerator Placement (MU-RP) and Most Simultaneous Used Regenerator Placement (MSU-RP). The novel regenerators placement algorithms are compared with other ones presented in literature. They are tested on the proposed regenerator allocation algorithm. We investigate the behavior of the these algorithms under different load values and numbers of translucent nodes. The MU-RP obtained good results in relation to the algorithms presented in literature and the MSU-RP showed the best results in all cases.**

***Keywords*— Optical Translucent Networks, Regenerator Allocation, Regenerator Placement, Sparse Regeneration.**

I. INTRODUCTION

Translucent optical networks are a performance and cost effective alternative to the fully transparent and fully opaque networks [1], [2]. In translucent networks some nodes are transparent and some others have regeneration capabilities. Two strategies are possible to design translucent networks: islands of transparency [3] and sparse regeneration [1], [2]. The islands of transparency are made of several transparent subdomains, which means that the nodes in an given island are transparent and the regeneration capability is provided only in the island boundaries. The sparse regeneration refers to a strategical distribution of the regenerators over the network nodes. In this paper we consider the sparse regeneration approach for translucent optical network design. Two questions naturally arises in this scenario: where to place the regeneration capability in the network and how to use this capability on demand in a network with a dynamic traffic. The algorithm that decides the number of regenerators and in which nodes of the network they should be installed is known as the regenerator placement (RP) algorithm. The algorithm that decides at which nodes in a given route the optical signal must be regenerated is referred as regenerator allocation (RA) [4]. Several heuristics and methaheuristics were proposed to solve both RA and RP problem [4], [5], [6], [7]. Yang *et al.* proposed in [4] four heuristics algorithm for solving the RP problem. We proposed in [5] a RP based on a multi objective genetic algorithm which tries to minimize simultaneously the network cost and blocking probability. Sambo *et al.* proposed in [8] an interesting RA algorithm that uses the minimum number of regenerators in a given route. However it requires a large number of quality of transmission (QoT) evaluations which is a very time consuming process.

In this paper we propose three heuristic algorithms for translucent networks using 3R regeneration: one concerning the RA problem and two others to deal with the RP problem.

Daniel A. R. Chaves, Renan V. B. Carvalho, Caio F. C. L. C. Ayres and Joaquim F. Martins-Filho are with Department of Electronics and Systems, Federal University of Pernambuco, Recife, PE, Brazil. Email: jfmf@ufpe.br.

Daniel A. R. Chaves, Helder A. Pereira and Carmelo J. A. Bastos-Filho are with Polytechnic School of Pernambuco, University of Pernambuco, Recife, PE, Brazil. Email: {darc@ecomp.poli.br, helder.pereira@poli.br, carmelofilho@ecomp.poli.br}

II. OUR PROPOSAL FOR REGENERATOR ALLOCATION

The Regenerator Allocation (RA) algorithm is invoked after the RWA procedure. In this paper we assume a Dikstra's shothest path algorithm for routing and First Fit algorithm for wavelength assignment (WA). Our RA algorithm assumes three possible cases for a given route: the lightpath can be established in all-optical manner, a wavelength conversion is needed to established the lightpath or an electronic regeneration is needed in order to establish the incoming call request. According to the case a different RA strategy is used. The decision of which strategy should be used is performed in the RWA and Regenerator Allocation pre-processing phase. The pseudo code for this phase is shown in Algorithm 1. The first algorithm executed is the routing algorithm which results in a route π ($\pi = \{t_1, t_2, ..., t_Z\}$) composed by Z nodes linking the source node (t_1) to the destination node (t_Z). Then, the WA algorithm (First Fit) is applied to the found route π in order to select an available wavelength. The WA algorithm can succeed or not depending on the wavelength availability in the network. If the WA algorithm succeeds in finding an available wavelength, in the same frequency from source node to the destination node, then the quality of the transmission of the lightpath (QoT) is checked. $QoT(t_x, t_y, \lambda_i)$ is a boolean function which returns 1 if the QoT (in both directions) of the lightpath linking the nodes t_x and t_y in λ_i wavelength is above the minimum threshold and returns 0 otherwise. In the first case, the lightpath is established in all optical manner in route π and wavelength λ_i found by the WA algorithm. Otherwise the function *RA_Impai(x,y,λ_i)* is executed to determine in which nodes that belongs to the route π the signal must be regenerated. If the WA algorithm fails in finding a single available wavelength from source node to the destination node in route π it means that an wavelength conversion is needed in order to establish the call. In this case, we invoke the *RA_Conv(x,y)* algorithm which tries to use the installed electronic infrastructure to perform the wavelength conversion.

Both *RA_Impai(x,y,λ_i)* and *RA_Conv(x,y)* are recursive function applied to the route π found by the routing algorithm.

Algorithm 1 RWA and Regenerator Allocation pre-processing

Arrival of a call request.
Execute the Routing algorithm which results in a route π ($\pi = \{t_1, t_2, ..., t_Z\}$) composed by Z nodes linking the source node (t_1) to the destination node (t_Z).
Execute the wavelength assignment algorithm in the found π rote.
if There is a single wavelength available λ_i from the source node to the destination node in the route π **then**
    if $QoT(t_1, t_Z, \lambda_i) = 1$ **then**
        Establish the incoming call in route π and wavelenght λ_i. {All-optical lightpath}
    else
        RA_Impai(1,2,λ_i) {Regeneration procedure trigged by QoT level below to the threshold}
    end if
else
    RA_Conv(1,2) {Regeneration trigged by lack of available wavelength}
end if

Algorithm 2 RA_Impai(x,y,λ_i)

if $y = Z$ **then**
    End algorithm.
end if
if $f_y = 0$ **then**
    RA_Impai(x,$y+1$,λ_i).
end if
if ($QoT(t_x, t_y, \lambda_i) = 1$), **then**
    RA_Impai(x,$y+1$,λ_i).
else
    if ($\exists$ k such that $f_k \neq 0$ and $x < k < y$) **then**
        Regenerate the signal at the node t_k closest to t_y such that $f_k \neq 0$.
        RA_Impai(k,$k+1$,λ_i).
    else
        The signal can not be regenerated (*i.e.* the call request is blocked).
        Stop.
    end if
end if

A call for either *RA_Impai(x,y,λ_i)* and *RA_Conv(x,y)* with $x = 1$ (source node) and $y = 2$ (closest node to the source) is used for start the recursive procedure. *RA_Impai(x,y,λ_i)* has three input parameters: the indexes x and y of two nodes in the route π (the sub-route currently under analysis) and the wavelength λ_i found by the WA algorithm. If the *RA_Impai(x,y,λ_i)* is invoked there is a route and a wavelenght available from source to the destination node, however with a QoT below to the minimum threshold. This procedures tries to establish the entire lightpath in the wavelength λ_i found by the WA algorithm (no wavelength conversion is performed). Furthermore, it tries to use regenerators at the furthest possible node from the source node, splitting the lightpath in multiple all-optical segments linked by electronic regenerators in the segment edges. The QoT for each all-optical segment is checked before the lightpath establishment. The pseudocode for *RA_Impai(x,y,λ_i)* is shown in Algorithm 2. In this algorithm f_i stands for the number of not used regenerators at node i.

On the other hand, if *RA_Conv(x,y)* is invoked there is no single wavelength available from source node to the destination node in the same frequency. *RA_Conv(x,y)* has two input parameters: the indexes x and y of two nodes in the route π (the sub-route currently under analysis). The a different wavelength can be assigned for each transparent segment thus no wavelength is given as input parameter. The pseudocode for function *RA_Conv(x,y)* is provided in algorithm 3. This algorithm tries to use regenerators at the furthest possible node from the source node, splitting the lightpath in multiple all-optical segments linked by electronic regenerators in the segment edges. In addition, a wavelength conversion is performed from one transparent segment to the next one. Again, the QoT for each all-optical segment is checked before the lightpath establishment. In this algorithm f_i stands for the number of not used regenerators at node i. The $QoTW(t_x, t_y, \lambda)$ function returns 1 if there is an available wavelength λ between the nodes t_x and t_y, in both directions, that satisfies the QoT requirement, and 0 otherwise.

Algorithm 3 RA_Conv(x,y)

if $y = Z$ **then**
    End algorithm.
end if
if $f_y = 0$ **then**
    RA_Conv(x,$y+1$).
end if
if ($\exists$ λ such that $QoTW(t_x, t_y, \lambda) = 1$), **then**
    RA_Conv(x,$y+1$).
else
    if ($\exists$ k such that $f_k \neq 0$ and $x < k < y$) **then**
        Regenerate the signal at the node t_k closest to t_y such that $f_k \neq 0$.
        Assign the wavelength λ such that $QoTW(t_x, t_k, \lambda) = 1$ using FF
        RA_Conv(k,$k+1$).
    else
        The signal can not be regenerated (*i.e.* the call request is blocked).
        Stop.
    end if
end if

III. Sparse Regenerator Placement Proposals

We propose two dynamic traffic based regenerator placement algorithms. The regenerators are placed at the network node in a shared pool manner as in [4]. We used the transitional weight idea shown in [2], however with different weights. In both algorithms, the decision about the number of regenerators that should be installed in each node is based on offline simulations. We assume that the load distribution information along the network is available. The offline simulation consists in the execution of a large set of dynamic call requests in a fully opaque network (*i.e.* with unlimited regeneration capabilities per node). The number of times that the signal requires electronic regeneration in a given node during the offline simulation is used as information for placement decision. The offline simulation is, in fact, performed only for regenerator placement decision, and not for network performance evaluation, which is performed after the placement decision. The goal is to find the bottleneck nodes in terms of regeneration, by considering no constraints. We named the first algorithm as Most Used Regenerator Placement (MU-RP). The pseudocode for MU-RP is provided in Algorithm 4. It places the same number X of regenerators in the N more requested nodes for regeneration during the offline simulation. The X and N are input parameters for MU-RP.

Algorithm 4 MU-RP(N,X)

Set $R_i \leftarrow 0$ for each node in the network.
Start an offline simulation (dynamic traffic).
for Each call request **do**
  Find a route. Run the RA algorithm.
  if The RA decides regenerate the signal at the node i **then**
    $R_i \leftarrow R_i + 1$.
  end if
end for
Place X regenerators in the N nodes that have the higher values of R_i.

We named the second algorithm as Maximum Simultaneously Used Regenerator Placement (MSU-RP). It distributes R regenerators over the network based on the maximum instantaneous number of regenerators used in each node during the offline simulation. R is an input for MSU-RP instead of X and N. The MSU-RP can be implemented using the pseudocode shown in Algorithm 5, where r_i is the current number of regenerators used at node i, n is the total number of nodes in the network and the function $ROUND(w)$ returns the nearest integer to w.

Note that, if we choose the N and X parameters for algorithm MU-RP, we can perform a fair comparison between MU-RP and MSU-RP by selecting, as the input parameter for MSU-RP, $R = NX$. In such case, the total number of regenerators placed in the network by both algorithms are the same. We used this strategy to perform comparison between the algorithms.

IV. Simulation Results

The MU-RP and MSU-RP algorithms obtain a solution for the number of regenerators that is placed in each network node. By using this solution found (*i.e.* a translucent network), the network blocking probability is evaluated. The default parameters used in our simulations are: Fiber loss coefficient $\alpha = 0.2$ dB/km, maximum percentage of pulse broadening due to PMD and residual dispersion $\delta = 10\,\%$, transmitter linewidth $\Delta\lambda_{\mathrm{Tx}} = 0.013$ nm, the first wavelength

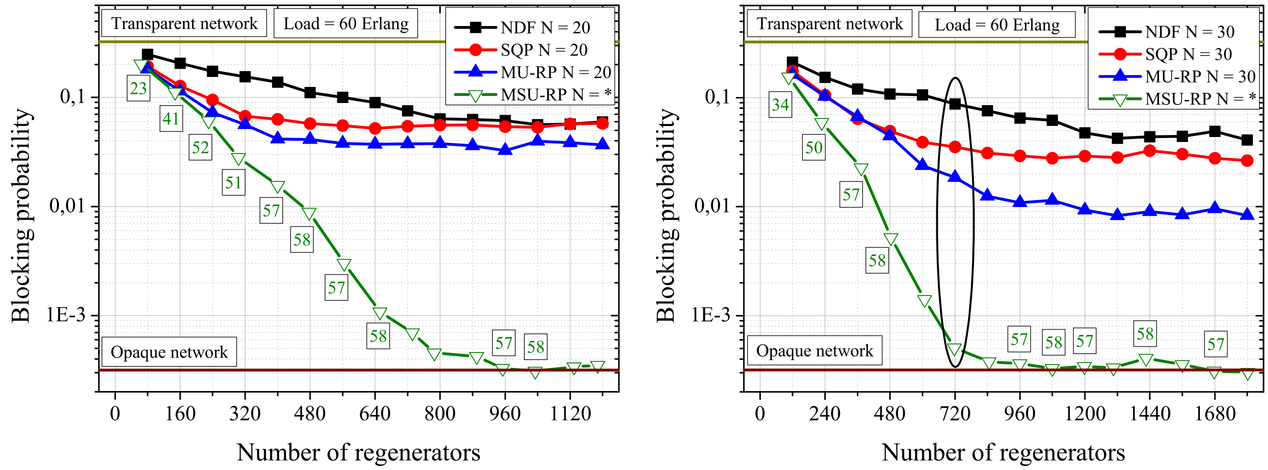
Algorithm 5 MSU-RP(R)

Set $R_i \leftarrow 0$ for each node in the network.
Start an offline simulation (dynamic traffic).
for Each call request **do**
  Find a route. Run the RA algorithm.
  if The RA decides regenerate the signal at the node i **then**
    $R_i \leftarrow max(R_i, r_i)$
  end if
end for
Place $ROUND(R \cdot R_i / \sum_{i=1}^{n} R_i)$ regenerators at node i.

of the grid $\lambda_{\mathrm{i}} = 1528.77$ nm, zero dispersion wavelength for transmission fiber $\lambda_0 = 1450$ nm, zero dispersion wavelength for transmission fiber $\lambda_{0\mathrm{RD}} = 1528.77$ nm, switch isolation factor $\varepsilon = -38$ dB, optical filter bandwidth $B_{\mathrm{o}} = 100$ GHz, transmission bit rate $B = 40$ Gbps, compensating fiber dispersion coefficient D_{DCF} (@1550 nm) $= -110$ ps/km.nm, PMD coefficient $D_{\mathrm{PMD}} = 0.04\,\mathrm{ps}\backslash\sqrt{\mathrm{km}}$, transmission fiber dispersion coefficient D_{Tx} (@1550 nm) $= 4.5$ ps/km.nm, amplifier noise figure (NF) $= 5.5$ dB, multiplexer loss $L_{\mathrm{Mx}} = 2$ dB, demultiplexer loss $L_{\mathrm{Dx}} = 2$ dB, optical switch loss $L_{\mathrm{Sw}} = 2$ dB, amplifier output saturation power $P_{\mathrm{Sat}} = 20$ dBm, transmitter optical power $P_{\mathrm{in}} = 3$ dBm, compensating fiber slope S_{DCF} (@1550 nm) $= -1.87$ ps/km.nm^2, transmission fiber slope S_{Tx} (@1550nm) $= 0.045$ ps/km.nm^2, number of wavelengths in an optical link $W = 36$, transmitter optical signal-to-noise ratio $\mathrm{OSNR_{in}} = 40$ dB and optical signal-to-noise ratio threshold for QoS criterion $\mathrm{OSNR_{Th}} = 20$ dB. Each lightpath is evaluated using the QoT estimator proposed by Pereira *et al.* in [9]. The QoT estimator evaluates the optical signal-to-noise ratio (OSNR) and pulse broadening of the optical signal [9]. The signal can be regenerated in a given node of the network only if both OSNR is above a threshold and the pulse broadening is below a predefined value. We assume the same node architecture simulated in [4], where a shared bank of regenerators are available in some networks nodes.

We compare our proposals with other two RP algorithms: SQP and NDF [4]. The proposed RA algorithm is used for all RP algorithms including SQP and NDF. The topology used for the simulation is shown in Fig 1, which has 61 nodes.

Fig. 2 shows the results obtained, concerning to the topology shown in Fig. 1, for the blocking probability as a function of the number of regenerators placed in the network. Note that the figure shows the blocking probability levels for an all-optical and an opaque network. The results were obtained for two different numbers of translucent nodes ($N = 20$ and $N = 30$), which is equal for all RP algorithms, except for MSU-RP. For NDF, SQP and MU-RP algorithms the number of translucent nodes are input parameters. On the other hand, the MSU-RP algorithm determines itself the number of translucent nodes. The number of translucent nodes found by the MSU-RP algorithm for each simulated point in Fig. 2 is indicated inside the rectangle aside the symbol. For the the simulated points that have no indication aside the MSU-RP algorithm found $N = 58$. The simulation were performed at a network



(a) (b)

Fig. 2

BLOCKING PROBABILITY AS A FUNCTION OF THE NUMBER OF REGENERATORS FOR THE DIFFERENT RP ALGORITHMS, FOR TOPOLOGY SHOWN IN FIG. 1, CONSIDERING DIFFERENT LOADS AND NUMBERS OF TRANSLUCENT NODES: (A) LOAD = 80/,ERLANGS AND $N = 20$, (B) LOAD = 80 ERLANGS AND $N = 30$. IN THE CASE OF THE MSU-RP, THIS VALUE IS SHOWN INSIDE THE SQUARES FOR EACH SOLUTION.

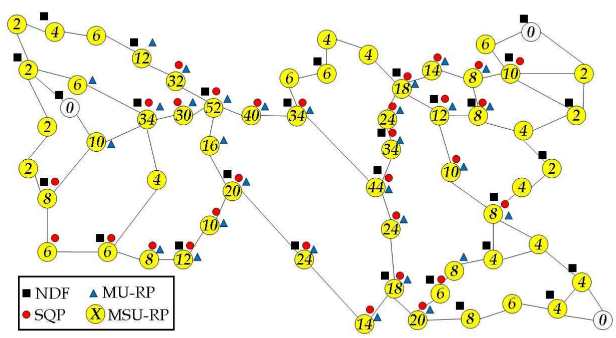


Fig. 1

NETWORK TOPOLOGY (THE LINK LENGTHS ARE SIMILAR TO ONES USED IN [4]) WITH RP ALGORITHMS RESULTS.

load 60 Erlang.

Fig. 2 shows that the NDF had the worst performance in all cases. MU-RP outperforms SQP in the two investigated scenarios. MSU-RP outperforms all other RP algorithms. All investigated algorithms shown a saturation level in the blocking probability for a given number of regenerators placed. This indicates that there is an ideal number of regenerators to be placed in the network. The placement of more regenerators beyond this number results in no reduction in the blocking probability which only contributes to increases the network cost. In all the investigated scenarios, the MSU-RP was the only algorithm able to reach the blocking probability level achieved by an equivalent opaque network. In addition, we observe that MSU-RP algorithm reaches the opaque network blocking level placing only 960 regenerators, for $N = 20$, and 840 regenerators for $N = 30$. The opaque configuration requires 5472 regenerators in this network. Therefore, the MSU-RP algorithm found a placement solution which requires only 17.5% (for $N = 20$) and 15.3% (for $N = 30$) of the required number of regenerators for an opaque network and yet delivering the same network performance achieved by the opaque case.

The regenerators placement found by each RP for the solutions highlighted in Fig. 2(b) are illustrated in Fig. 1. In Fig. 1 each node selected as translucent by NDF algorithm is marked with a small black square, the translucent nodes selected by the SQP are marked with a red circle and the translucent nodes selected by MU-RP are marked with a blue triangle. Note that the algorithms NDF, SQP and MU-RP placed 720 regenerators equally distributed in 30 nodes over the network, which means 24 devices in each selected node. The numbers inside the yellow circle which represents the network nodes are the number of regenerators placed by the MSU-RP algorithm in each network node. Remember that, as for the three other algorithms the MSU-RP algorithm places a total of 720 regenerators in the network as well.

The translucent networks found by each RP for the solutions highlighted in Fig. 2(b) (with the regenerator distribution shown in Fig. 1) were simulated for a variant network load. This result is shown in Fig. 3. Fig. 3 shows the blocking probability as function of network load. The algorithms NDF, SQP and MU-RP placed 720 regenerators equally distributed in 30 nodes over the network, this is 24 devices in each selected node. MSU-RP utilized 58 nodes with a total of 718 regenerators. We can note that our proposes, MU-RP outperforms NDF and SQP; and MSU-RP outperforms all other RP algorithms for all load values.

V. CONCLUSIONS

In this paper we proposed two heuristic algorithms to tackle the regenerator placement problem based on the network traffic and one heuristic algorithm for the regenerator allocation

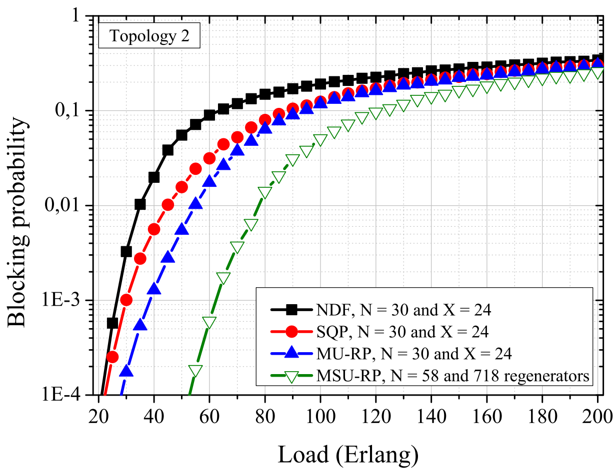


Fig. 3

RESULTS CONSIDERING THE RP ALGORITHMS FOR THE HIGHLIGHTED POINTS IN FIG. 2(B). BLOCKING PROBABILITY AS A FUNCTION OF NETWORK LOAD

problem. The results show that our proposals outperform two other algorithms found in the literature. In the investigated scenario, the proposed MSU-RP algorithm designs a translucent network with the blocking probability level of the opaque network using only about of 15% to 17% of the number of regenerators required in the opaque network scenario.

REFERENCES

[1] B. Ramamurthy, H. Feng, D. Datta, J. Heritage, and B. Mukherjee, "Transparent vs. opaque vs. translucent wavelength-routed optical networks," in *Optical Fiber Communication Conference – OFC*, vol. 1, 1999, pp. 59–61.

[2] G. Shen and R. S. Tucker, "Translucent optical networks: the way forward [topics in optical communications]," *IEEE Communications Magazine*, vol. 45, no. 2, pp. 48–54, February 2007.

[3] E. Karasan and M. Arisoylu, "Design of translucent optical networks: Partitioning and restoration," *Photonic Network Communications*, vol. 8, pp. 209–221, 2004.

[4] X. Yang *et al*. "Sparse regeneration in translucent wavelength-routed optical networks: Architecture, network design and wavelength routing", Phot. Net. Comm., **10**(1) 39–53 (2005).

[5] D. Chaves, C. Ayres, R. Carvalho, H. Pereira, C. Bastos-Filho, and J. Martins-Filho, "Sparse regeneration placement for translucent optical networks using multiobjective evolutionary algorithms considering quality of service and capital cost," in *Microwave and Optoelectronics Conference (IMOC), 2009 SBMO/IEEE MTT-S International*, November 2009, pp. 417 –422.

[6] Y. Ye, T. Y. Chai, T. H. Cheng, and C. Lu, "Dynamic routing and wavelength assignment algorithms in wavelength division multiplexed translucent optical networks," *Computer Communications*, vol. 29, no. 15, pp. 2975–2984, 2006.

[7] Y. Ye, T. Chai, T. Cheng, and C. Lu, "Algorithms for the design of WDM translucent optical networks," *Opt. Express*, vol. 11, no. 22, pp. 2917–2926, 2003.

[8] N. Sambo *et al*. "Accounting for Shared Regenerators in GMPLS-Controlled Translucent Optical Networks", J. Lightwave Technol., **19**(27) 4338–4347 (2009).

[9] H. A. Pereira *et al*. "OSNR model to consider physical layer impairments in transparent optical networks", Phot. Net. Comm., **18**(2) 137–149 (2009).