

# Traffic Grooming for Clonal Selection Routing over Dynamically Wavelength-Routed Switched Networks

Michael Taynnan Barros<sup>†</sup>, Paulo Ribeiro L. Júnior<sup>‡</sup> and Marcelo S. Alencar<sup>‡</sup>

Institute for Advanced Studies in Communications (Iecom)

<sup>†</sup>Systems and Computing Department - DSC

<sup>‡</sup>Electrical Engineering Department - DEE

Federal University of Campina Grande (UFCG), Campina Grande, Brazil

Email: {michel.taob,paulo,malencar}@iecom.org.br

**Abstract**—Traffic grooming is a promising technique to reduce the blocking probability in all-optical networks, in the context of the RWA problem (Routing and Wavelength Assignment). Routing with clonal selection algorithms is also an interesting approach for the same propose. In order to create a robust mechanism to optimize the establishment of connections, this paper proposes a performance evaluation combining the aforementioned techniques and the traditional OSPF protocol. The analysis contemplates the variation of wavelength assignment heuristics in sparse networks with a highly dense traffic. The results show that the proposed approach obtained a blocking decrease of almost 60%.

## I. INTRODUCTION

The next generation network is characterized by many users and applications. The Internet users has almost 5,6 billion users and 50 billion entities (e.g., computers programs, sensors, actuators, etc.) [1]. Therefore, the next generation of optical networks (WDM or DWDM) requires a provision for high quality of service (QoS), directly related with low transmission delay, large bandwidth, high availability (resource oriented performance) and low blocking probability (traffic oriented performance). In those networks the users are connected by lightpaths, chosen by the selection of a set of physical links between the source and destination edge nodes, and the reservation through signalling of a particular wavelength on each link [2].

A unique feature of optical WDM (Wavelength Division Multiplexing) networks is the tight coupling between routing and wavelength selection. Therefore, to establish an optical connection, one must deal with both routing (selecting a suitable path) and wavelength assignment (allocating an available wavelength for the connection). The resulting problem is referred to as the routing and wavelength assignment (RWA) problem [3], and it is significantly more difficult than the routing problem in other networks. The additional complexity arises from the fact that routing and wavelength assignment is subject to the following constraints: a lightpath must use the same wavelength on all the links along its path from source to destination nodes and all lightpaths using the same link

(fiber) must be allocated distinct wavelengths. This constraint is called wavelength continuity constraint.

Routing and wavelength assignment is an important problem for the control plane of WDM networks and has received intensive attention from the research community. Several RWA algorithms have been developed for static routing, in which case the demand of traffic does not change or it changes during large time intervals.

To maximize the network throughput in optical communications the traffic grooming technique was presented in [4]. This approach consists of grooming streams in one single wavelength, because the bandwidth request of a traffic stream can be much lower than the capacity of a lightpath. The difficulty of this technique is on the equipment, which requires the integration of new hardware in the edge node of an all-optical network. But, for the next generation networks, this approach is important for the bandwidth provision and management, blocking minimization and the dynamic service requirement, which are directly correlated with the QoS.

This paper presents a novel approach to routing in optical networks for the minimization of blocking, called Clonal Selection Adaptive Routing Algorithm (CSA). This algorithm was developed based on the optimization algorithm Clonal Selection, using the mutation phase, based on the Genetic Adaptive Routing Algorithm (GARA) [5], applied to IP networks. The main goal of this new algorithm is to achieve a performance similar or above the performance of the adaptive last used routing algorithm with traffic grooming, without the need to adjust the hardware or the need for wavelength converters.

To combine two promising approaches to minimize the blocking effect (CSA algorithm and the traffic grooming technique) the objective of the paper is evaluate the effect of different wavelength assign algorithms and the traffic grooming mechanism over the clonal selection routing. The results show the performance contribution to the blocking probability minimization for the CSA. Also the wavelength assignment heuristics do not show difference of performance

in the variation of load, only a small difference in the variation of number of wavelengths. The CSA presents the same effect of traffic grooming in the traditional approach. The traffic grooming technique proves to be a promising technique to improve the performance gain in the next generation of all-optical networks.

The remaining of the paper is organized as follows. Section II shows the related work. Section III presents a formulation of routing and wavelength assignment. Section IV presents the proposed CSA algorithm. The wavelength assignment heuristics are presented in Section V. The traffic grooming technique is shown in Section VI. Section VII presents the simulation environment and Section VIII conveys the analysis of the results. Section IX summarizes the paper.

## II. RELATED WORK

Routing in dynamic WDM networks has been studied in the literature. In Mokhtar and Azizoglu [6] an analytical model was developed to evaluate the blocking performance of various routing algorithms, including adaptive unconstrained routing which does not restrict the path selection to any pre-defined set of routes. Bhide *et. al.* [7] and Dante [8] present new weight functions that exploit the correlation between blocking probability and the number of hops involved in a connection setup to increase the performance of the network.

Other approaches, based on adaptation of optimization algorithms, have been presented in the literature. Sinclair [9] presented a hybrid algorithm (which involved genetic algorithm – GA) for the RWA problem, but the genetic operators do not adapt well to the network condition and restrictions. The article [10] presented a joint routing and dimensioning technique that used GA, the proposal is not to solve the RWA problem directly.

The blocking performance in grooming networks with shortest-path routing has been studied by Thiagarajan and Somani [11], considering the approach of traffic grooming in dynamic networks. Also, the throughput performance of the traffic grooming approach has been studied by Bhattacharya *et. al.* [12], showing that not only the blocking is affected by this technique. A direct application of the traffic grooming strategy can be found in [13], the authors present a novel path computation as a part of the traffic grooming technique. This approach is interesting but to integrated the path computation process for routing wavelengths will be required in the design of the traffic grooming equipments.

## III. THE ROUTING AND WAVELENGTH ASSIGNMENT FORMULATION

The RWA problem can be formalized as follows. Consider a network with  $K$  links and  $W$  wavelengths. The status of the  $i$ -th link,  $1 \leq i \leq K$ , at time instant  $t$  can be specified by the column vector

$$\sigma_t^{(i)} = \begin{bmatrix} \sigma_t^{(i)}(1) \\ \sigma_t^{(i)}(2) \\ \vdots \\ \sigma_t^{(i)}(W) \end{bmatrix}, \quad (1)$$

in which,  $\forall j$  such that  $1 \leq j \leq W$ ,  $\sigma_t^{(i)}(j) = 1$  if the wavelength  $j$  is used by a lightpath in the time instant  $t$ , in link  $i$  and  $\sigma_t^{(i)}(j) = 0$  if this wavelength is available. Therefore, the network status is described by the matrix

$$\sigma_t = \begin{bmatrix} \sigma_t^{(1)}(1) & \sigma_t^{(2)}(1) & \cdots & \sigma_t^{(K)}(1) \\ \sigma_t^{(1)}(2) & \sigma_t^{(2)}(2) & \cdots & \sigma_t^{(K)}(2) \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_t^{(1)}(W) & \sigma_t^{(2)}(W) & \cdots & \sigma_t^{(K)}(W) \end{bmatrix}. \quad (2)$$

Given a request for optical connections establishment in a time instant  $t$  between the source and destination nodes, the function of the RWA algorithm is select a path  $E$ , composed by links  $(e_1, e_2, \dots, e_n)$ , such that  $\sigma_t^{(e_l)}(j) = 0$  for all  $l = 1, 2, \dots, n$ . Such consideration satisfies the wavelength continuity restriction.

The blocking probability ( $B_R$ ) is the QoS (Quality of Service) metric in optical networks to evaluate performance of routing algorithms. It computes the percentage of rejected connections. The computation of the  $B_R$  is done by the control plane, as follow

$$B_R = \frac{\sum CR_X}{\sum CR} \quad (3)$$

in which  $\sum CR_X$  is the number of rejected connection requests due to wavelength unavailability and  $\sum CR$  is the total number of connection requests at the simulation run.

The minimization of  $B_R$  for a given  $E = (e_1, e_2, \dots, e_n)$  reflects the performance of a RWA algorithm. Finally, the objective of a RWA algorithm is presented in the Table I.

TABLE I  
OBJECTIVE OF A RWA ALGORITHM

Find:	$E = (e_1, e_2, \dots, e_n)$
Minimizing:	$B_R$
Over:	$\sigma_t$
Subject to:	$\sigma_t^{(e_l)}(j) = 0 \forall l = 1, 2, \dots, n$ Two lightpaths must not be assigned the same w on a given link

## IV. CLONAL SELECTION ADAPTIVE ROUTING ALGORITHM

Clonal selection algorithms (CS) are optimization techniques based on the artificial immune systems. The techniques form a class of algorithms inspired by the clonal selection theory of acquired immunity. The theory of acquired immunity explains how the B and T lymphocytes improve their response to antigens over time, called affinity maturation. CS establishes

the idea that only those cells that recognize the antigens are selected to proliferate. The selected cells are subject to a maturation process, which improves their affinity to the selective antigen. These techniques are used in applications in engineering and science, the major focus are pattern recognition problems [14].

Based on the genetic mutation technique found in the IP routing protocol GARA, this paper presents the CSA, which adapts the two phases involved in RWA (the route selection and wavelength assignment). The proposed approach is a stochastic method which produces adaptive routes, not necessarily the shortest path, computed in real time. When the blocking decreases the number of stabilized connections increases. This improves the routing performance of the network. Therefore, the objective of CSA is to minimize the blocking probability.

The clonal selection algorithm is used to justify the extensive use of the mutation process. The used CS chooses randomly a number of individuals of a population, in a process called Roulette Wheel Selection (RWS). After that, the mutation process is applied in all selected individuals. The best mutated individual, evaluated by a fitness function, is selected. The pseudo code of the proposal is presented in the Algorithm 1.

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**Algorithm 1: CSA**

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```
PossibleRoutes = Dijkstra( $\sigma_t, s, d$ )
route = roulette(PossibleRoutes, OccupationMatrix,
NumberofWavelengths)
ClonesPopulation = {0 ... numberofclones}
for  $i$  in ClonesPopulation do
   $\lfloor$  ClonesPopulation[ $i$ ] = RouteMutationProcess(route)
BestRoute = fitness(ClonesPopulation)
return BestRoute
```

---

The presented algorithm is the main contribution of this paper, in which the fitness function is new as is the application of this specific optimization technique to this problem. The parts of the algorithm are described in the following.

The fitness function used by the clonal selection algorithm in CSA is

$$f(E, G) = \frac{\sum_{i=0}^K \sum_{j=0}^W G[\sigma_t^{(i)}(j)]}{|E|}, \quad (4)$$

in which  $E$  is the set of links (route) and  $G$  is the graph that represents the network. The calculated function is the sum of all free wavelengths normalized by the number of links for a given route. The result of the computation is an index used to evaluate the routes, based on the actual state of the network. This function is the performance key of the proposed algorithm. The objective of the algorithm is to minimize the blocking and this fitness function tries to spread the load in the network, i.e. more connection will be stabilized because the routing protocol allow more alternative routes. If the objective

for routing is other, e.g. QoS routing, the fitness function needs to be redesigned.

The function RWS is used for random routes selection to evaluate the fitness function. The RWS function is defined as [15]

$$P_{sel}(r) = \frac{f(\sigma_t^{(r)})}{\sum_r f(\sigma_t^{(r)})}, \quad (5)$$

in which,  $r \in \mathbb{Z}$  and represents the route index mapped into the adjacency matrix of the network. The chosen  $r$  will be the  $\text{MAX}\{P_{sel}(r)\}$ .

*A. Route mutation process*

The mutation process was designed based on the GARA IP routing protocol, but the CSA algorithm is used designed for optical circuit switching. To face this difference the structure of the routing algorithm was designed to improve the RWA problem over optical circuit switching networks. This component of the CSA algorithm is the most important, because it defines the objectives of the route selection process, which is directly related to the performance of the technique.

The gene representation used in the CSA algorithm is a list  $E$  which indicates the links in a route with the nodes (or alleles) to be traversed. The cardinality of the list,  $|E|$ , represents the number of links in a route. Every node is represented by an element of an alphabet. In this way, the genetic operations are not be binary, but simple position permutations. But, the routes need to be valid, i.e. the routes must be free from loops and must have a source and a destination node.

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**Algorithm 2: Route Mutation Process**

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```
if  $|E| > 2$  then
   $M = \text{random}(1, |E|)$ 
  for  $i = 1$  to  $M$  do
     $\lfloor$  MutatedRoute = MutatedRoute +  $E[i]$ 
  if  $\text{len}(\text{neighbors}(M)) > 1$  then
     $\lfloor$   $NM = \text{random}(1, \text{len}(\text{neighbors}(M)))$ 
     $\lfloor$  return MutatedRoute + Dijkstra( $\sigma_t, NM, E[|E|]$ )
  else
    if  $\text{len}(\text{neighbors}(M)) == 1$  then
       $\lfloor$   $NM = 0$ 
       $\lfloor$  return MutatedRoute +
       $\lfloor$  Dijkstra( $\sigma_t, NM, E[|E|]$ )
    else
       $\lfloor$  return  $M$ 
  else
     $\lfloor$  return  $M$ 
return MutatedRoute
```

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As presented in [16], in the mutation process there is an  $M \in E$  that must be randomly selected, in which  $M$  is the allele (node) that must undergo a mutation.  $M$  will be permuted by any node which connects with  $E[\text{pos}(M) - 1]$ . Then, from  $M$

to  $d$  (destination node) the Dijkstra algorithm must be executed to compute the valid routes. At the end of the process the route will be obtained by the sum of the old route to  $M$  and the new route from  $M$  to  $d$ . The restrictions are:  $|E| > 2$  and the number of neighbors must be higher than one. The algorithm 2 shows the pseudo-code for the mutation process.

### B. CSA Calibration

The clonal selection process uses a determined number of clones to chose the more appropriate one with a fitness function. With the increase of this number the evaluated space to chose one solution is bigger and the probability of choosing more appropriated solutions is bigger too. To verify this process this subsection presents the CSA calibration process for the presented performance evaluation in this paper.

In this evaluation, each link has two unidirectional fibers, containing eight wavelengths, creating a bidirectional link. The simulation stops when the maximum number of requests is reached. The number of requests is 100.000 for each load value, ranging from 100 to 200 erlangs, with increments of 2

erlangs. The calibration of the number of clones in the presented clonal selection algorithm is shown in Figures 1 (for a regular mesh topology with 9 nodes) and 2 (for a ring topology with 9 nodes). Analyzing these graphs, the increase in the number of clones decreases the blocking probability. With the increase in the number of clones, the processing complexity increases too.

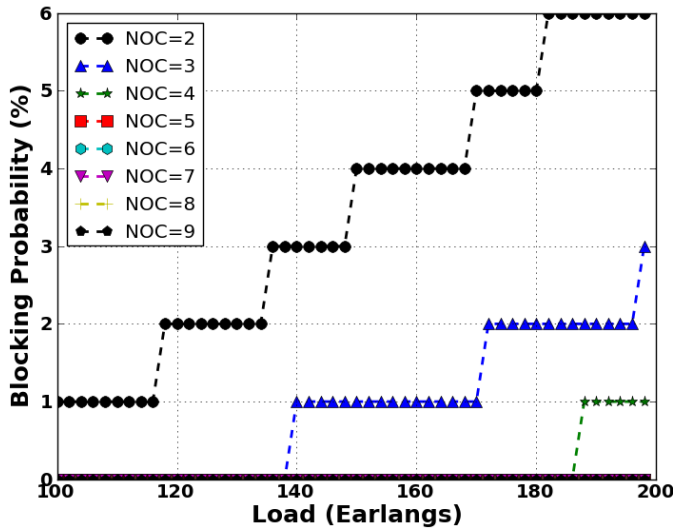


Fig. 1. Results with the variation of the number of clones (noc) with the Clonal Selection (CS) routing using First-Fit (FF) for a regular mesh topology with 9 nodes.

In the regular mesh topology (Fig. 1), the number of clones that zeros the blocking probability is four. In the ring topology (Fig. 2), the number of clones that zeros the blocking probability is two. The objective is to evaluate the effects of traffic grooming approach with the variation of the wavelength selection heuristics in the clonal selection routing. Because of

this the number of clones used in all simulations is two for graphical visualization.

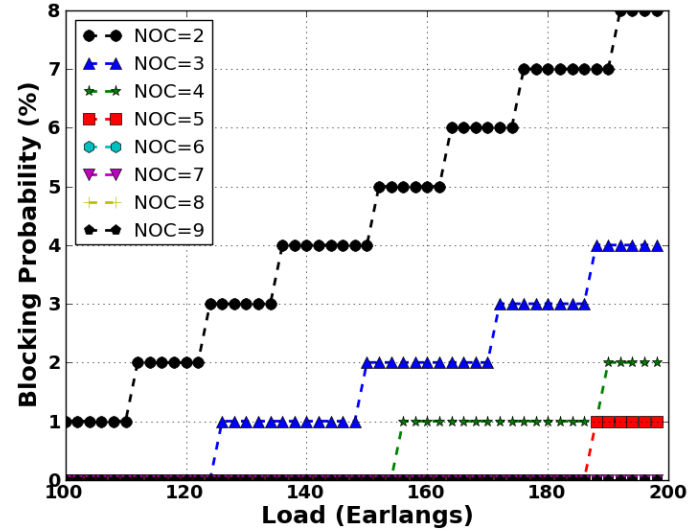


Fig. 2. Results with the variation of the number of clones (noc) with the Clonal Selection (CS) routing using First-Fit (FF) for a ring topology with 9 nodes.

### V. WAVELENGTH ASSIGNMENT HEURISTICS

Four heuristics are considered in the evaluation. They are described in the following:

- **First-Fit (FF)**: In first-fit, the wavelengths are indexed, and a lightpath will be attributed to a wavelength with the lowest index before attempting to select a wavelength with a higher index. By selecting wavelengths in this manner, existing connections will be packed into a smaller number of total wavelengths, leaving a larger number of wavelengths available for longer lightpaths;
- **Random (RD)**: Another approach to choose between different wavelengths is to simply select one of the wavelengths at random. In general, first-fit will outperform random wavelength assignment when full knowledge of the network state is available. However, if the wavelength selection is done in a distributed manner, with only limited or outdated information, then random wavelength assignment may outperform first-fit assignment. The reason for this behavior is that, in a first-fit approach, if multiple connections are attempting to set up a lightpath simultaneously, then it may be more likely that they will choose the same wavelength, leading to one or more connections being blocked.
- **Least-Used (LU)**: The least-used approach attempts to spread the load evenly across all wavelengths by selecting the wavelength which is the least-used throughout the network. This approach requires global knowledge.
- **Most-Used (MU)**: In most-used wavelength assignment, the wavelength which is the most used in the rest of the network is selected. This approach attempts to provide maximum wavelength reuse in the network. This approach requires global knowledge.

## VI. TRAFFIC GROOMING

The minimum granularity of a connection in a wavelength-routed network is the capacity of a wavelength. The transmission rate on a wavelength increases with advances in the transmission technology. However, the requirement of end-users such as Internet service providers (ISPs), universities, and industries are still much lower than the capacity of one wavelength. The bandwidth requirement will increase in the near future, and doubling the current bandwidth would be more than sufficient to handle the projected demand. The current transmission rate on a wavelength is 10 Gbit/s (OC-192). At the time of writing, 40 Gbit/s (OC-768) technology is commercially available, however it is not widely deployed.

The large gap between the user requirement and the capacity of a wavelength has forced the need for wavelength sharing mechanisms that would allow more than one user to share the wavelength channel capacity. Wavelength sharing, similar to sharing a fiber using multiple wavelengths, can be done in several ways. One approach to share a wavelength is to divide its bandwidth into frames containing a certain number of time slots. A time slot on successive frames would then form a channel. Other approaches such as phase modulation and optical code division multiple access (OCDMA) can also be employed to share the capacity on a wavelength.

The traffic merging from different source-destination pairs is called traffic grooming. Nodes that can groom traffic are capable of multiplexing or demultiplexing lower rate traffic onto a wavelength and switch it from one lightpath to another. The traffic grooming can be either static or dynamic. In static traffic grooming the source-destination pairs for each request are predetermined. In dynamic traffic grooming, connection requests from different source-destination pairs are combined depending on the existing lightpaths at the time of the request.

The traffic grooming algorithm used in this work is the one in [17] that aims at optimizing the wavelength utilization. This algorithm searches an established lightpath with sufficient bandwidth. If no active lightpath offer sufficient bandwidth, then a new channel is established. This algorithm can adapt, as a modification, every wavelength assignment heuristic [18] and it is described using the following notation:

- $w$ : wavelength index;
- $SelectedLambda$ : control variable;
- $L$ : number of links in the selected path;
- $P_l$ : vector containing the links of the selected path;
- $\lambda(ij)$ : element of the occupation matrix, indexed by the number of links  $i$  and by the wavelength  $j$ . If  $\lambda(ij) = 1$ , the wavelength  $j$  in the link  $i$  is busy; else, if  $\lambda(ij) = 0$ , in any of the links composing the path, the wavelength  $j$  is free;
- $\lambda_{MAX}$ : maximum number of wavelengths per fiber;
- $B_{ij}$ : available bandwidth in the wavelength  $j$  of the link  $i$ ;

## VII. SIMULATION MODEL

The main objective of the simulation model is to compare the performance of the presented routing algorithm (CSA) with

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### Algorithm 3: Traffic Grooming( $\sigma_t, E, B_{ij}$ )

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```

SelectedLambda = FALSE
while SelectedLambda == FALSE do
    w = WavelengthAssignmentHeuristicFunction()
    if  $B_{i,j} \leq \lambda(P_l, w)$  then
        SelectedLambda = TRUE
    else
        if  $w \leq \lambda_{MAX}$  then
            Continue
        else
            return Blocked
return Wavelength Selected

```

---

the classical Dijkstra algorithm, which is used in the OSPF Internet routing protocol. The protocols will be equipped with traffic grooming and many wavelength assignment heuristics. The performance of CSA is in terms of blocking probability. In the simulations with the OSPF protocol, the improvements of adaptive-alternate routing are used to minimize blocking in the networks [19] and for balanced comparison against the proposal. For all evaluated algorithms the wavelength assignment heuristic was: First Fit, Last Used, Random and Most Used.

A simulator was designed to implement routing and wavelength assignment in an all-optical network, using the Python language. The simulator is called DONS (Dynamic Optical Network Simulator). The software is an event-discrete simulator following the stepwise refinements design methodology. The DONS simulator is capable of statistical and graphical analysis, as those presented in this paper.

In this simulator when a new request arrives, the router uses the routing algorithm to determine the entire path from source to destination. It then attempts to assign a wavelength along this path by propagating a wavelength request to all the routers along the path. If wavelength conversion is available in the network, then a lightpath can be established using different wavelengths on different links. If this request fails, a different wavelength is chosen, the choice can be based on the feedback from the closest node on the shortest path. This process may be repeated till there is at least one wavelength available, and following the wavelength assignment heuristic. If this fails, then the request is blocked, i.e. the lightpath can not be set up.

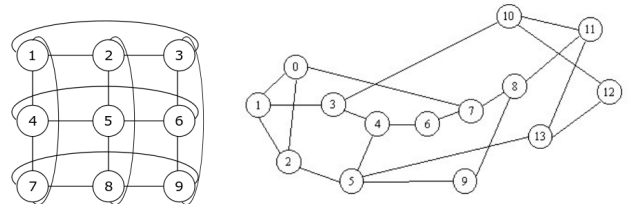


Fig. 3. Mesh torus topology with five nodes (Left). NFS network with 13 nodes (Right).

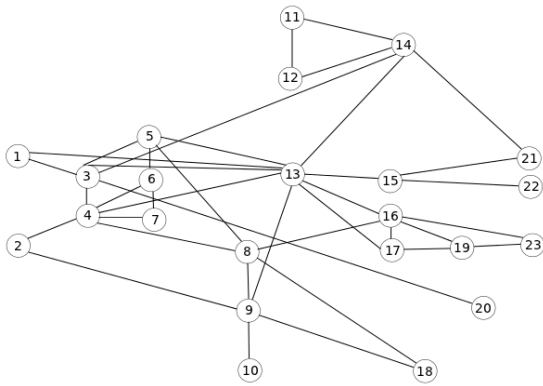


Fig. 4. GEANT network with 23 nodes.

In the experiments one mesh torus topology, shown in left of Fig. 3, the NSF network, shown in right of Fig. 3 and the GEANT network, shown in the Fig. 4 are considered. The independent variables are: Load and Number of wavelength. The load assumes 100 to 2000 erlangs, with increments of 100 erlangs and the number of nodes assumes 5 to 50 with increments of 2 wavelengths. The number of requests is 100.000 for each load value. This configuration enables a heavy and intense traffic analysis with great diversity. In the variation of load the number of wavelength is eight and in the variation of the number of wavelengths the load is 500. Following the Full Factorial Design methodology the total of treatments is 24, obtained by the combination of the two factors, the three topologies and four wavelength assignment heuristics. In the simulation, each link has two unidirectional fibers, containing a number of wavelengths, creating a bidirectional link. The simulation stops when the maximum number of requests is reached. A source-destination pair of each request is randomly determined to account for uniformly distributed traffic in the network. Each wavelength support 10 Gbits/s and a granularity of 1 Gbits/s or multiple. The presented experiments configuration was designed to full stress the network equipments, and observe the routing performance. All the parameters and it values are resumed in the Table II.

TABLE II  
EXPERIMENTS PARAMETERS

Factor	Value
Topologies	NFS, GEANT, Mesh Torus
Routing	Dynamic (Dijkstra), Optimized (CSA)
WA Heuristics	First Fit, Last Used, Random and Most Used
Number of Lambdas	10 to 50, in 5
Independent variables	Load and Number of wavelength
Depended variables	Blocking Probability
Number of Requests	100.000/Load Value
Wavelength Transmission Rate	10 Gbits/s
Granularity	1 Gbits/s or multiple
Load	100 to 2000 erlangs, in 100

## VIII. RESULTS AND DISCUSSION

The results of blocking probability with the load variation are presented in the Figures 5, 6 and 7. For the Mesh torus topology, Figure 5, the performance improvement for blocking with the CSA algorithm is remarkable, with the decrease of blocking compared to a classical approach in almost 60%. This performance gain can be explained by two facts: the fitness function and the number of alternative connections. The fitness function of the CSA algorithm is a interesting process for computing alternatives routes, considering the number of hops and the total of free wavelengths in one single metric. In the other hand, the number of alternative connections is important for computing alternative routes. If the network has a bottleneck is more difficult to the CSA algorithm compute new paths.

The Figure 5 also shows that the variation of wavelengths assignment heuristics do not presents difference, with the variation of the load. This can be explained by the low number of wavelength, in other words, exists a number of wavelengths that the evaluated techniques will present difference. Also, the improvements of traffic grooming performance, regarding blocking, can also be notable as proved in [17]. The same effects that the grooming do with the OSPF routing do with the CSA.

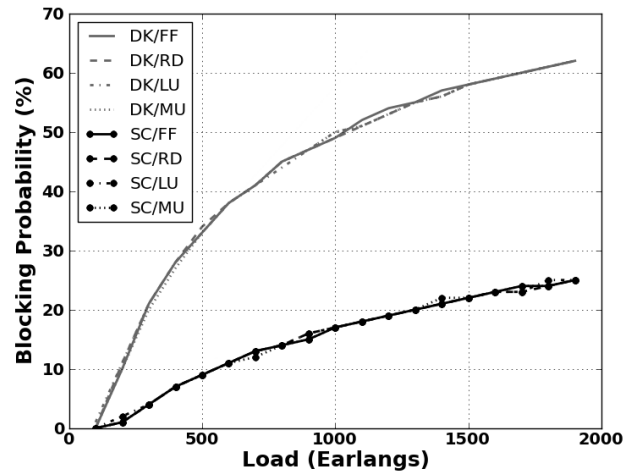


Fig. 5. Blocking probability versus load for the mesh torus topology.

The same results can be observed to the NFS network, Figure 6. The performance of blocking, the wavelength assignment heuristics and the traffic grooming strategy are the same.

For the GEANT topology is achieved a interesting result, Figure 7. The performance of blocking probability with the load variation and traffic grooming approach are the same. But, the variation of the wavelength assignment heuristics, for the CSA algorithm, shows its effect, presenting difference of performance between two groups: (First-Fir,Random) x (Least Used, Most Used). This fact proves that the number of wavelengths interferes in the performance of WA heuristics,

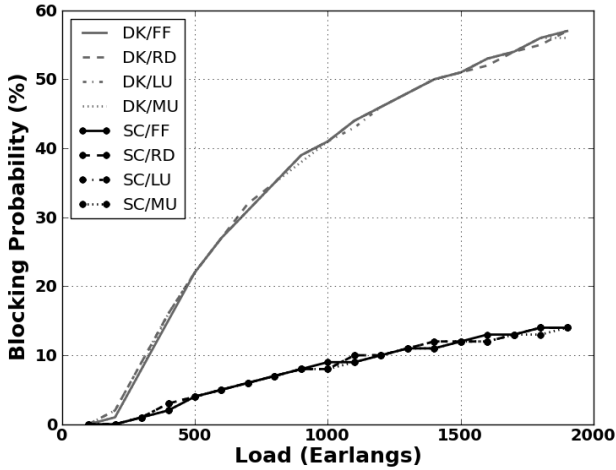


Fig. 6. Blocking probability versus load for the NSF network.

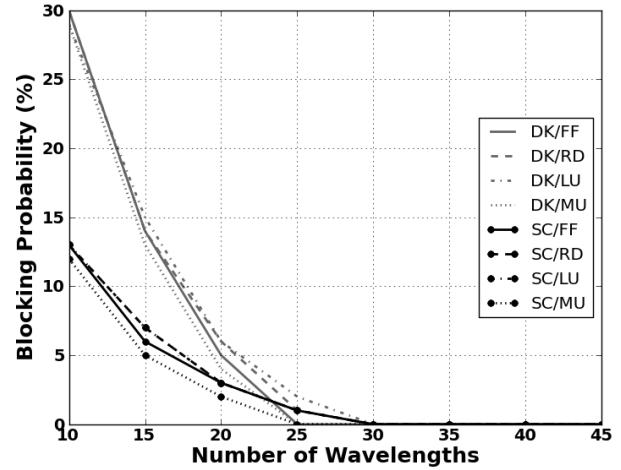


Fig. 8. Blocking probability versus number of wavelengths for the mesh torus topology.

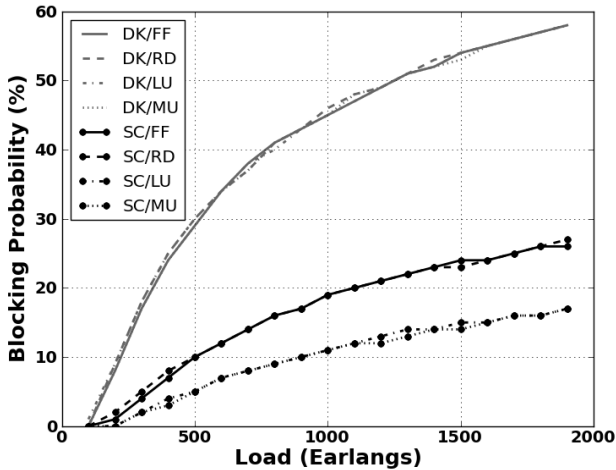


Fig. 7. Blocking probability versus load for the GEANT network.

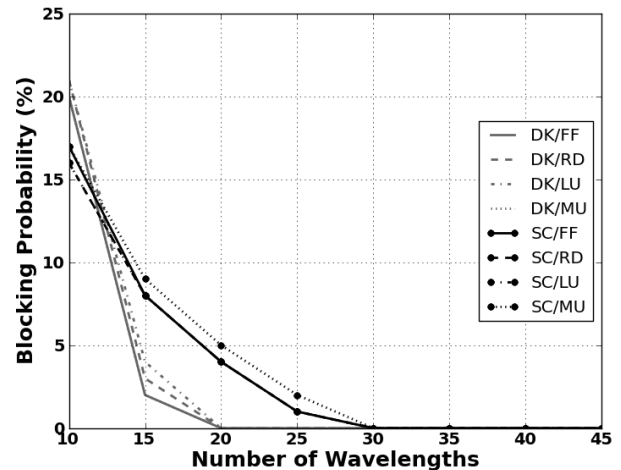


Fig. 9. Blocking probability versus number of wavelengths for the NSF network.

because, the CSA tends to compute alternative path which, in principle, are bigger than compared to the Djiskstra approach.

The Figures 8, 9 and 10 show the results of blocking probability with the variation of the number of wavelengths. In the Figure 8, the same contribution for performance with the CSA algorithm still remains. The only difference, is the difference of performance of the WA heuristics, which the Most Used approach presents the best performance, but nothing striking.

The results of blocking probability versus the number of wavelengths for the NFS network shows different behaviour from the other topologies, Figure 9. There is some performance interchange of the evaluated techniques. This can be explained by the possibilities of alternatives routes. With the increase of the number of nodes, the lower path can be used with no problem, but, if the algorithm still considers alternative routes as the best one, the use of them in a

higher frequency will cause greater blocking. In the NFS, the conventional strategies presents the best performance, as the WA heuristics, which the First-Fit approach present the lowest blocking probability.

For the GEANT network, the results regarding blocking probability versus the number of wavelengths are presented in Figure 10. As the results of the Mesh torus topology, the blocking effect, the WA heuristics and traffic grooming performance are still the same.

## IX. CONCLUSION AND FUTURE WORK

This paper presents an evaluation of the effect of using traffic grooming in the clonal selection route varying of wavelength assignment heuristics. Three topologies were used: Torus mesh, NFS network and GEANT network. The variation of load and number of wavelengths were considered

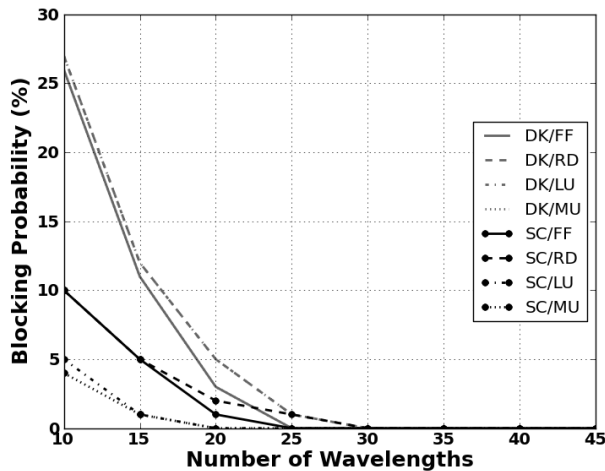


Fig. 10. Blocking probability versus number of wavelengths for the GEANT network.

in different perspectives. Four heuristics were considered (First Fit, Last Used, Random and Most Used) for a highly dense traffic.

The results show that the CSA reduces the blocking probability almost 60% compared to the traditional OSPF protocol. Also, the same effect of the traffic grooming usage is reached, enabling the extension of the CSA to the next generation of all-optical networks. The variation of wavelength assignment heuristics do not differ from regarding the variation of load, but, the variation of wavelengths shows a difference of performance.

The face and operational validity was used to validate the results of the proposed CSA algorithm. This is not the optimum approach but it is sufficient for a simulation model. A mathematical model of the solution is needed for the full validation of the algorithm. The context of optical burst switching networks is proposed as future work, because, this approach is efficient in all-optical networks. Also, other fitness function can be used to solve problems in optical networks, e.g. the QoS routing problem.

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