# CSA: A Route Clonal Selection Algorithm for Dynamic WDM Networks

Michael Taynnan Barros, Paulo Ribeiro Lins Junior and Marcelo Sampaio Alencar

*Abstract*— **The minimization of blocking probability is an important problem for the design of next generation high speed networks. This problem is usually approached with an adaptive routing algorithm with traffic grooming, that is costly regarding improvements on network equipment. This paper presents the Clonal Selection Adaptive Routing Algorithm (CSA), a new routing algorithm for use in dynamic optical network. The algorithm uses a fitness function which adapts the route selection cost, minimizing the blocking. Its performance was evaluated considering the blocking probability with three different topologies, for high traffic, compared to the adaptive routing algorithm with traffic grooming. The results present a higher gain for the proposed approach, with no need to improvement on network equipment or conversion capabilities.**

*Keywords*— **Dynamic Optical Networks, Routing, Traffic Grooming.**

## I. INTRODUCTION

The next generation network is characterized by a high number of users and applications. Regarding the Internet users, there are estimates that almost 5,6 billion primary users and 50 billion entities will be active in 2020 [1]. Hence, the next generation of optical networks requires a provision for high quality of service (QoS), directly related with low transmission delay, large bandwidth, high availability and low blocking pro\-ba\-bi\-li\-ty. 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 of a particular wavelength on each link [2].

An unique feature of optical WDM networks is the tight coupling between routing and wavelength selection. Therefore, to establish an optical connection, the network 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 are subject to the following cons\-traints: 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.

Routing in dynamic WDM networks have been studied in the literature. In Mokhtar and Azizoglu [4], 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.* [5] and Dante [6] 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. In [7], the authors present a novel path computation as a part of the traffic grooming technique. RWA algorithms is recently applied to the QoT (Quality of Transmission) problems to create cross-layers approaches, as in [8] and [9].

To minimize the blocking effect on the dynamic optical WDM networks the adaptive routing technique was proposed by Ribeiro [10]. This technique uses two traffic engineering strategies: load balancing, using adaptive routing, and traffic grooming. The obtained results from this work show that integration of adaptive routing algorithm, with traffic grooming for routing and wavelength assignment, improves the system performance with respect to blocking probability and load distribution among the links of the network. However, the use of traffic grooming in the network is associated with the availability of node hardware with this capacity [11].

This paper presents a new 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 clonal selection optimization algorithm, using the mutation phase based on the Genetic Adaptive Routing Algorithm (GARA) [12], applied on IP networks. The main goal of this new algorithm is to achieve a

performance similar or above the performance of the adaptive least used routing algorithm with traffic grooming, without the need to adjust the hardware and no need for wavelength converters. The results obtained by a simulation model show the performance gain of the CSA against the adaptive least used routing algorithm with traffic grooming.

Other approaches, based on adaptation of optimization algorithms, have been presented in the literature. Sinclair [13] 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. A joint routing and dimensioning technique that used GA has been presented in [14], but it does not attack directly the RWA problem.

The remaining of the paper is organized as follow. Section II presents a formulation of routing and wavelength assignment. Section III presents the proposed CSA algorithm. Section IV presents the simulation environment and Section V the analysis of the results. Section VI summarizes the paper.

## II. THE ROUTING AND WAVELENGTH ASSIGNMENT FORMULATION

The physical topology of an optical network corresponds to the cabling installing and the used devices. This structure can be represented by a graph $G = (V,K)$ which has a set $V = (v_1, v_2, ..., v_{|V|})$ of vertices (nodes) and a set $K = (k_1, k_2, ..., k_{|K|})$ of edges (links), in which each edge connects a pair of nodes in $V$.

The graph $G$ has a list of edges $R$, $R$ in $K$, which represents the shortest path between a source node $v_s$ and a destination node $v_d$. In optical networks, $R$ is valid if the wavelength continuity constraint is considered, as approached in the following.

Consider that $K$ links in $G$ have $W$ wavelengths. The status of the $i$-th link, $1 \leq i \leq K$, at time instant $t$ can be specified by the column vector

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

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

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

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 to select a path $R$, composed of links $(k_s, ..., k_n)$, such that $\sigma_t^{(i)}(j) = 0$ for all $k$ in $R$. Such consideration satisfies the wavelength continuity restriction and $j$ is attributed to $R$, represented as $j_R$.

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 $B_R$ is done by the control plane, as follows

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

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

The minimization of $B_R$ for a given $R$ reflects the performance of the RWA algorithm. Finally, the objective of a RWA algorithm is presented in Table I.

TABLE I
OBJECTIVE OF A RWA ALGORITHM

| | |
|---|---|
| Find: | $R = (k_s, \ldots, k_d)$ |
| Minimizing: | $B_R$ |
| Over: | $G, \sigma_t$ |
| Subject to: | $\sigma_t^{(i)}(j) = 0, \forall k_i \in R$ (The j wavelength must be free in all link of route R) $j_R \neq j_{R'}$ (Two routes must not be assigned the same $j$ on a given link) |

## III. CLONAL SELECTION ADAPTIVE ROUTING ALGORITHM

Clonal selection algorithms (CS) are optimization techniques based on artificial immune systems, inspired by the clonal selection theory of acquired immunity. This theory 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. CS is used in applications in engineering and science, the major foci are pattern recognition problems [15].

Based on the genetic mutation process of the GARA IP routing protocol, this paper presents the Clonal Selection Adaptive Routing Algorithm (CSA), which adapts the IP environment in the two phases involved in RWA (the route selection and wavelength assignment). The approach is a stochastic method which produces adaptive routes, not

necessarily the shortest path, computed in real time. Also, the proposed method should be implemented as a regular routing algorithm, in the control plane.

In optical networks when the blocking probability decreases the number of stabilized connections increases, improving the routing performance of the network in terms of QoS. 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 randomly selects several 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 is presented in Algorithm 1.

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**Algorithm 1:** CSA

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

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The algorithm is the main contribution of this paper, in which the fitness function is introduced, as an application of this specific optimization technique as a solution for the RWA problem. The parts of the algorithm are described in the following.

### A. The Fitness Function and The Roulette Wheel Selection (RWS)

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

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

in which $R$ é is the list of links (route) and $G$ is the graph that represents the network. The computed 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 spreads the load into the network, i.e. more connection will be stabilized, because the routing protocol allows more alternative routes. If the objective for routing is other, e.g. guaranteed QoS routing, the fitness function is redesigned.

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

$$Psel(r) = \frac{f(\sigma_t^{(r)})}{\sum_r f(\sigma_t^{(r)})}, \qquad (5)$$

in which, r ∈ represents the route index mapped into the adjacency matrix of the network. The chosen *r* will be the *MAX{Psel(r)}*

### B. Route Mutation Process

The mutation process was designed based on the GARA IP routing protocol, but the CSA algorithm is designed for optical circuit switching networks. To face this difference, the structure of the routing algorithm was designed to improve the RWA problem.

The gene representation used in the CSA algorithm is a list *R* which shows the links in a route with the nodes (or alleles) to be traversed. The cardinality of the list, |R|, 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 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.

As presented in [16], in the mutation process there is a *M* ∈ *R* that must be randomly selected, in which *M* is the allele (node) that must undergo a mutation, and will be permuted by any node which connects with *E[pos(M)-1]*. Then, from *M* to *d* (destination node) the Djikstra 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: |R| > 2 and the number of neighbors must be higher than one. Algorithm 2 shows the pseudo-code for the mutation process.

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**Algorithm 2:** Route Mutation Process

**if** $|R| > 2$ **then**
  M = random(1,$|R|$)
  **for** *i = 1 to M* **do**
    MutatedRoute = MutatedRoute + R[i]
  **if** *len(neighbors(M)) > 1* **then**
    NM = random(1,len(neighbors(M)))
    **return** MutatedRoute + Djikstra($\sigma_t$,NM,$R[|R|]$)
  **else**
    **if** *len(neighbors(M)) == 1* **then**
      NM = 0
      **return** MutatedRoute + Djikstra($\sigma_t$,NM,$R[|R|]$)
    **else**
      **return** M
**else**
  **return** M
**return** MutatedRoute

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## IV. SIMULATION MODEL

The performance of the proposed routing algorithm is compared in terms of blocking probability, expressed as the fraction of the rejected connection requests due to wavelength unavailability divided by the total amount of connection requests at the simulation run. The best performance of the proposed clonal selection algorithm, for a variable the number of clones in all scenarios, is evaluated.

First, in the simulations, the number of clones needs to be defined. This process is called calibration of the CSA. The variation of the number of clones will tell if the effect is destructive or constructive in the blocking performance. The greater the number of clones the higher is the complexity of computing new routing, therefore, a median number needs to be reached.

The main objective of the simulation is to compare the best performance of the presented routing algorithm with the classical Djikstra algorithm, which is used in the OSPF Internet routing protocol. In the simulations with the OSPF protocol the improvements of adaptive routing and traffic grooming are used to minimize blocking in the networks \cite{dis:paulo} and for balanced comparison against the proposal and the impact of the results are bigger. For all evaluated algorithm the First-Fit wavelength assignment heuristic was chosen.

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 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 cannot be set up.
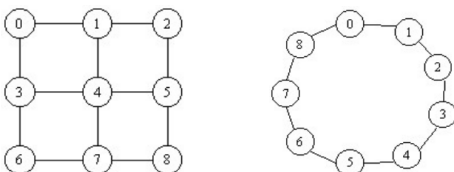


Figure 1. Mesh regular topology with nine nodes (Left). Ring topology with nine nodes (Right).
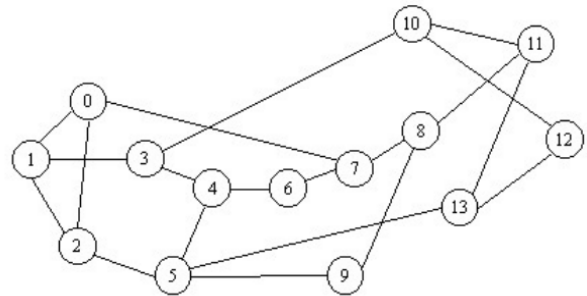


Figure 2. NFS topology with 13 nodes.

In the experiments one regular mesh topology, shown on the left side of Fig. 1, one ring topology, shown on the right side of Fig. 1 and the NSF network, shown in Fig. 6 are considered. Six scenarios are analysed, the scenarios are obtained with the combination of the two factors and the three topologies. In the simulation, 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 two erlangs. This configuration enables a high precision analysis with intense traffic. A source-destination pair of each request is randomly determined to account for uniformly distributed traffic in the network. The presented experiments configuration was designed to full stress the network equipments, and observe the routing performance.

## V. RESULTS AND DISCUSSION

The calibration of the number of clones in the proposed clonal selection algorithm is shown in Figures 3, 4 and 5. From all graphs, an increase in the number of clones decreases the blocking probability, as a destructive effect. As mentioned, with the increase in the number of clones the processing complexity increases too.

For the regular mesh topology (Fig. 6), the number of clones that zeros the blocking probability is four. For the ring topology (Fig. 7), the number of clones that zeros the blocking probability is two. Finally in the NFS topology (Fig. 8), the number of clones that zero the blocking probability is three. The number of clones used is four for a comparison with the adaptive-alternate routing because the minimization of blocking is guaranteed in all scenarios.

Regarding the comparison analyses with the proposed CSA algorithm and the adaptive-alternate routing with traffic grooming, the results show a gain on performance for the presented approach. For the regular mesh topology (Fig. 6) an increase in the load increases the blocking for both techniques. But the difference among them is the slope of the curve. With the adaptive-alternative approach the curve slope increases more
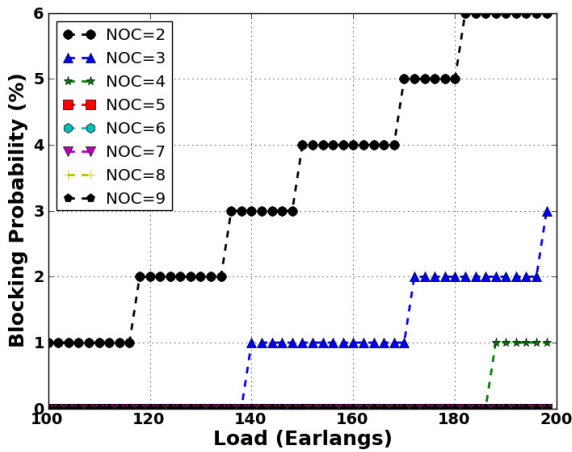
Figure 3. Results obtained as the number of clones (NOC) varies with the Clonal Selection (CS) routing using First-Fit (FF) for the regular mesh topology.
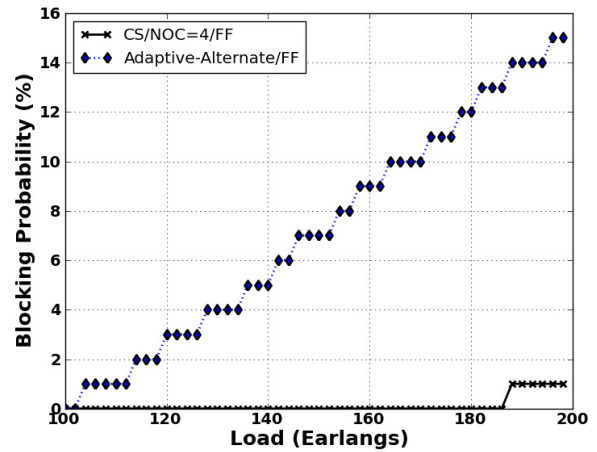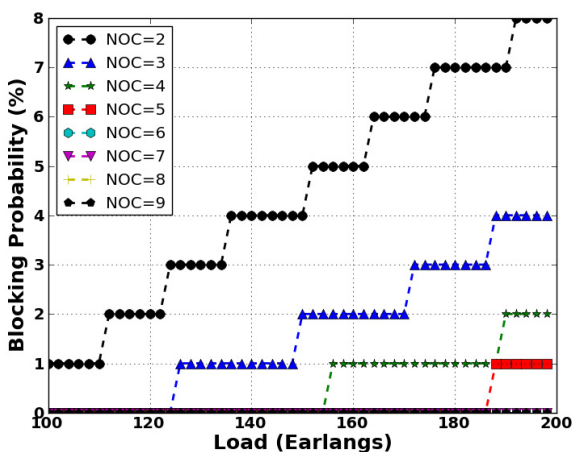


Figure 4. Results for the variation of the number of clones (NOC) with the Clonal Selection (CS) routing using First-Fit (FF) for the ring topology.
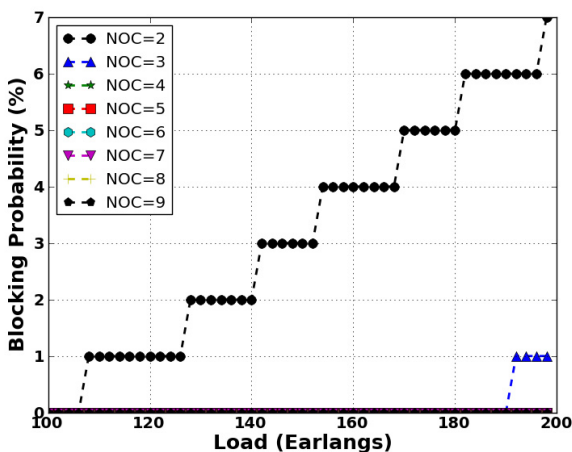


Figure 5. Results for the variation of the number of clones (NOC) with the Clonal Selection (CS) routing using First-Fit (FF) for the NFS topology.



Figure 6. CSA algorithm compared to the Adaptive-Alternate routing with traffic grooming for the regular mesh topology

compared with the CSA algorithm. Even with the technique to find more free wavelengths with the adaptive-alternate routing the performance is lower than the CSA algorithm. This occurs because the CSA algorithm dynamics allocates the best path with the fitness function, designed to evaluate the network condition and then allocate a route.

The same results are found for other topologies (Figures 7 and 8). Specifically for the ring topology, the utilization of other routes severely decreases the blocking. The results shows an algorithm that minimizes the blocking in dynamic WDM networks. The best contribution is an algorithm which presents an alternative solution for the RWA problem with higher performance against the adaptive-alternate routing with traffic grooming which needs hardware with expensive technologies. With the utilization of the proposed approach, this cost with new equipment is not needed, because the algorithm only modifies the logic layer of the network.
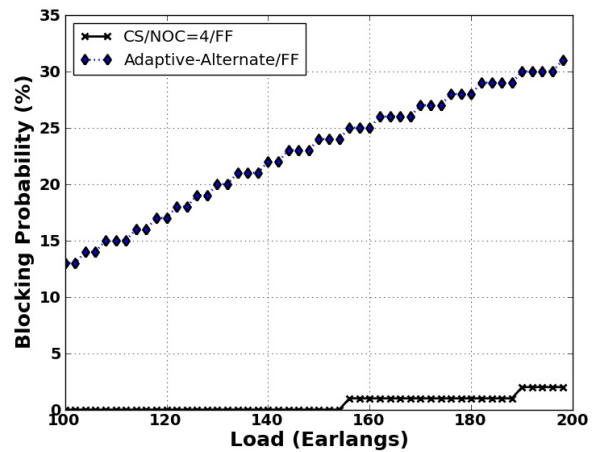


Figure 7. CSA algorithm compared to the Adaptive-Alternate routing with traffic grooming for the ring topology..
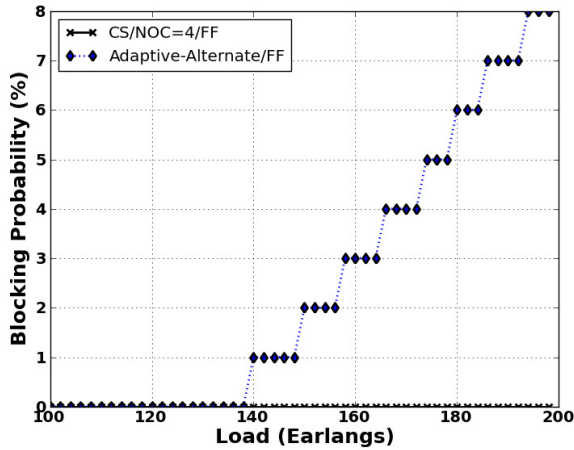
Figure 8. CSA algorithm compared to the Adaptive-Alternate routing with traffic grooming for the NFS topology.
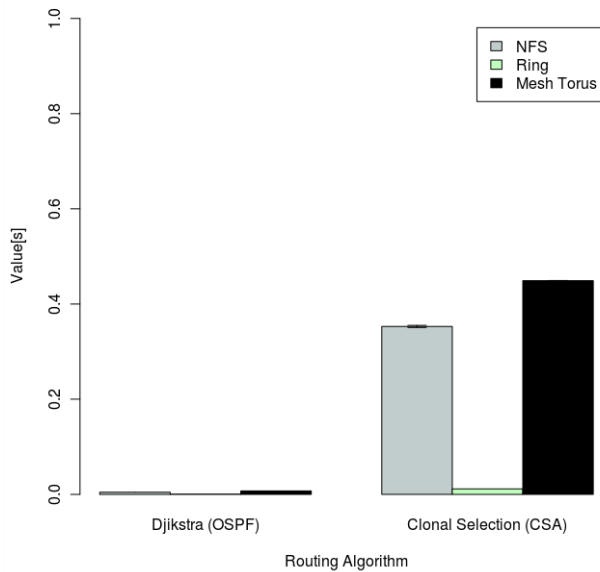


Figure 9. Results for processing time.

Figure 9, presents the processing time for both evaluated routing algorithms in this paper. It's possible to visualize that the proposed approach increases the complexity of computing new routes. This complexity can decrease with reduction techniques applied in the CSA or low level implementations of the approach, because, the CSA requires mathematical libraries for the RWS function and it increases a lot the time complexity.

## VI. CONCLUSION AND FUTURE WORK

This paper presented the Clonal Selection Adaptive Routing Algorithm (CSA). This approach selects new routes based on the clonal selection algorithms as an optimization approach. The performance of the proposed method, regarding the blocking probability, was analysed. It was compared with the Djikstra algorithm found in the OSPF routing protocol, with an adaptive-alternate routing and traffic grooming technique. The simulations were performed using the DONS simulator with three different heavily loaded scenarios. The calibration of the CSA shows that the minimization of the blocking probability for all scenarios is done with four clones in the mutation process. The main contribution of the proposal is the use of a robust routing algorithm with no need to improve the router hardware, as the traffic grooming approach, and no need for wavelength converters.

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 study of performance with other wavelength assignment heuristics is needed. Also, a fitness function is needed to be developed for other problems, e.g. for guaranteed QoS routing problem. Some of those aspects of the research will be dealt with in the future..

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**Michael Taynnan de Albuquerque Olivera Barros -** Born in Campina Grande - PB, 1990. Graduated in Telematic, the Federal Institute of Science and Technology Education of Paraíba (IFPB) Campina Grande Campus. Actually, he is a graduate student in Computer Science at Federal University of Campina Grande and is a researcher at Iecom (Institute of Advanced Studies in Communications). Interest in Optical Networks, Wireless Networks, Digital Signal Processing and Analysis and Classification of Traffic on the Internet.

**Paulo Ribeiro Lins Junior –** He received his Electrical Engineering degree and Master in Science in Electrical Engineering degree at Federal University of Campina Grande in 2006 and 2008, respectively. Actually, He is D.Sc. candidate at the same institution and Professor at Escola Técnica Redentorista. His interest include: communications networks performance, optical WDM networks, RWA algorithms, traffic engineering techniques applied to WDM networks, coherent modulation for WDM systems, physical layer restrictions in optical communications systems.

**Marcelo Sampaio de Alencar -** was born in Serrita, Brazil in 1957. He received his Bachelor Degree in Electrical Engineering, from Universidade Federal de Pernambuco (UFPE), Brazil, 1980, his Master Degree in Electrical Engineering, from Universidade Federal da Paraiba (UFPB), Brazil, 1988 and his Ph.D. from University of Waterloo, Department of Electrical and Computer Engineering, Canada, 1993. Marcelo S. Alencar has more than 30 years of engineering experience, and 21 years as an IEEE Member, currently as Senior Member. For 18 years he worked for the Department of Electrical Engineering, Federal University of Paraiba, where he was Full Professor and supervised 56 graduate and several undergraduate students. Since 2003, he is Chair Professor at the Department of Electrical Engineering, Federal University of Campina Grande, Brazil. He is founder and President of the Institute for Advanced Studies in Communications (Iecom). His biography is included in the following publications: Who's Who in the World and Who's Who in Science and Engineering, by Marquis Who's Who, New Providence, USA. He published over 250 engineering and scientific papers and 14 books. He is member of the SBrT-Brasport Editorial Board. He has been involved as a volunteer with several IEEE and SBrT activities, including being a member of the Advisory or Technical Program Committee in several events. He served as member of the IEEE Communications Society Sister Society Board and as Liaison to Latin America Societies. He also served on the Board of Directors of IEEE's Sister Society SBrT. He is a Registered Professional Engineer. He is a columnist for the traditional Brazilian newspaper Jornal do Commercio, since April, 2000, and is currently Vice-President External Relations of SBrT. He is member of the IEICE, Japan, SBMO, SBPC and SBEB, Brazil.