New heuristic algorithm for dynamic traffic in WDM optical networks

Nuevo algoritmo heurístico para tráfico dinámico en redes ópticas WDM

A. Rodríguez-García[1], L. Ramírez-López[2], and J.C. Travieso-Torres[3]

ABSTRACT

This paper presents the results from the simulation of Snake One, a new heuristic algorithm, and the comparison made between three heuristic algorithms: Genetic Algorithms, Simulated Annealing, and Tabu Search, using blocking probability and network utilization as standard indicators. The simulation exercise was conducted on WDM NSFNET under dynamic traffic conditions. The results show a substantial decrease of blocking. However, this causes a relative network utilization growth. There are also load intervals which lead to performance improvement, decreasing the number of blocked requests.

Keywords: WDM networks, heuristic algorithm, optical cross connect, dynamic traffic, NSFNET.

RESUMEN

En este artículo se presentan los resultados y la comparación de la simulación de un nuevo algoritmo heurístico llamado Serpiente Uno. La comparación se hace con tres algoritmos heurísticos: Algoritmos Genéticos, Simulated Annealing y Búsqueda Tabú, utilizando como indicadores estándar la probabilidad de bloqueo y la utilización de la red. La simulación se realizó sobre la WDM NSFNET en condiciones de tráfico dinámicos. Los resultados muestran una disminución sustancial de la probabilidad de bloqueo. Sin embargo, esto causa un aumento relativo de la utilización de la red. También hay intervalos de carga donde el rendimiento mejora, disminuyendo el número de solicitudes bloqueadas.

Palabras clave: Redes WDM, algoritmos heurísticos, conmutadores ópticos, tráfico dinámico, NSFNET.

Introduction

Since the implementation of data transmission through IPv4, information transport has grown at a substantial rate–mainly due to service generation–increasing data demand. The network was not ready for these services, so it had to evolve to IPv6, and so did the number and quality of services. On the other hand, wireless networks grew to the same or greater extent due to the generation of mobile telephony services, which evolved from 1G to 4G. Meanwhile, transport networks supported the increased load, and routing generated much delay compared to switching, causing transport networks to evolve towards fiber optics. This technology, in turn, evolved into WDM (Wavelength Division Multiplexing) networks. AON (All Optical Network) requires OXC (Optical Cross Connect) commutators. It can commute different wavelengths, where each wavelength develops up to 2.5 Gbps. These networks require establishing lightpaths, which are sets of network links where the data travels along different wavelengths as noted in Zang (2000) and Khan (2005). When networks use different wavelengths along the route, they are called Wavelength Conversion Networks, which have the advantage of making good use of the network, but the disadvantage of increased delay in establishing the connection and higher network implementation cost. Thus, Wavelength Continuity Constraint (WCC) is established. On the other hand, finding a route and its wavelength

with WCC to solve this problem is called RWA (Routing Wavelength Assignment), and the state of the art shows different optimization strategies, algorithms and criteria. In general, the route must be found, and then the wavelength is assigned, generating two algorithmic processes. There are other proposals, such as comprehensive solution strategies, which enable finding the route and the wavelength in the same algorithmic process. Additionally, the demand characteristics of these networks vary from static to dynamic, where the former demand context can be optimized, while in latter the problem becomes very complex. Therefore,

[1] A. Rodríguez García: Electrical Engineer. Universidad Nacional de Ingeniería, Peru. ScD in Engineering, Master in Telecommunications. Full-time Professor, Universidad de Santiago de Chile. E-mail: arturo.rodriguez@usach.cl

[2] L. Ramírez López: Electrical Engineer, Master in Systems Engineering, Universidad Nacional de Colombia. PhD in Biomedical Engineering, Universidade de Mogi das Cruzes, Brasil. Associated Professor in Telecommunications Engineering, School of Engineering, Universidad Militar Nueva Granada. E-mail: leonardo.ramirez@unimilitar.edu.co.

[3] J. C. Travieso Torres: Electrical Engineer, Master in Electricity, Instituto Superior Politécnico José Antonio Echeverría, Cuba. ScD in Engineering, Universidad de Santiago de Chile, Chile. Associated Professor, Universidad de Santiago de Chile. E-mail: juancarlos.travieso@usach.cl

different algorithmic processes were established, where heuristic algorithms prevail over conventional ones, basically because the conventional ones only find one route, while the heuristic algorithms are able to find several routes more readily. In addition, the latter only look for good routes, while the conventional ones look for the optimum route. The most extensively reviewed algorithms in the state of the art are Genetic as noted in Rodriguez (2008, 2010), Barpanda (2011), Monoyiois (2011) and Rashedi (2012); Particle Swarm Optimization as noted in Rashedi (2012), Artificial Bee Colony in Rashedi (2012), Ant Colony as noted in Zhan (2011), Simulated Annealing as noted in Barpanda (2011), Assis (2010), Hredzak (2011), Na (2011), Rodriguez (2011) and Sakamoto (2013); and Tabu Search as noted in Charbonneau (2010), Boonyopakorn (2011) and Rodriguez (2014); as well as very innovative combinations in Boonyopakorn (2011) and Rodriguez (2014), using different criteria and optimization methods. The TIGUM and GINT research groups in Colombia and Chile propose this new algorithmic processes called Snake One and Snake Two, which will be tested in dynamic demand contexts with an integral strategy, simulating them in the NSFNET Network (National Science Foundation NETwork) as noted in Rashedi (2012). This paper only presents the results of Snake One algorithm, because Snake Two algorithm will be tested later.

Description of the RWA problem.

The purpose of solving the RWA problem is to seek a lightpath (LP) that is not necessarily the optimum one. In an AON a lightpath is defined by a route and a wavelength (λ), and the route is a succession of links (e) in a network.

We define LP as:

$$LP = (R, \lambda) \qquad (1)$$

$$R = \left\{ e_{0x}, e_{xy}, \ldots, e_{ij}, \ldots, e_{ZD} \right\} \qquad (2)$$

Equation (1) represents the pair consisting of a route *(R)* and the wavelength *(λ)*, where *R* is the route from the origin *(O)* to the destination *(D)* of a set of adjacent links, so that *eij* represents the link from OXC$_i$ to OXC$_j$. Figure 1 represents an optical network with eight nodes numbered 0 to 7, with a link to and from nodes, using three wavelengths represented by dashed *(λ_1)*, solid *(λ_2)* and dotted *(λ_3)* lines. The bold lines indicate that they are in use.

In this way we can see routes that go from node 1 to node 6 through different lightpaths, like {e_{10}, e_{07}, e_{76}, λ_1}, {e_{13}, e_{37}, e_{76}, λ_3}, {e_{12}, e_{25}, e_{54}, e_{46}, λ_2}, and from node 2 to node 3 {e_{25}, e_{54}, e_{43}, λ_1}. Assuming that a request arrives at node 3 with node 5 as its destination, we see that there are three ways to arrive at node 5: through node 2, 4 or 6. Through node 2 only one lightpath can be established with λ_3; from node 4 only with λ_3, and from node 6 with λ_1, λ_2 and λ_3.

Depending on the condition, if we choose a route like {e_{31}, e_{12}, e_{25}} the link e_{31} has λ_1 and λ_2, link e_{12} has λ_1 and λ_3, and link e_{25} only has λ_3. Therefore, there is no way to establish

a lightpath with the same wavelength. So to solve the RWA problem we must establish lightpaths that fulfill the WCC without conversion.
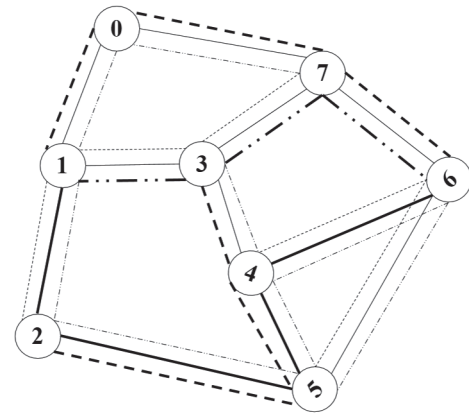

Figure 1. Example of optical network with nodes eight and three wavelengths represented by different dotted lines

State of the art of the RWA.

In the literature there are many innovative solutions for the RWA, but it is achieved distinguish elements that allow understanding the work much better, such as Solution Strategies, Traffic, Optimization Methods and Optimization Criteria.

There are two ways to tackle the RWA problem. One is to divide the problem into a route search and then assigning the wavelength to the route; this solution is the one of the most commonly reviewed ones, because it develops a temporal complexity with less impact, but it requires two algorithmic processes to find the lightpath. On the other hand, there is another way, called comprehensive solution, as noted in Rodriguez (2008), in which the route and the wavelength are obtained through the same algorithmic process, but it has the disadvantage of developing greater temporal complexity. The most widely used indicators are the blocking probability of future demand and network utilization. The aim is to minimize or maximize a criterion such as delay, jitter, etc., which will allow the decrease of blocking probability and of network utilization. Often in WDM the wavelength is increased, which considerably reduces blocking probability, but not necessarily the use of the network. On the other hand, different algorithms that can improve these indicators are tested, but temporal complexity has to be lowered because it is an important factor in increasing blocking probability. On the other hand, network traffic is important to determine if optimization or only finding good routes is possible.

The RWA problem is called SLE (Static Lightpath Establishment) if traffic is static, and DLE (Dynamic Lightpath Establishment) if the traffic is dynamic, as noted in Khan (2005), Rodriguez (2008) and Zang (2001). Traffic is dynamic when the requested average connection time (t_C) is less than the average time between arrivals (t_{LL}) of the request for service, as shown in Figure 2.
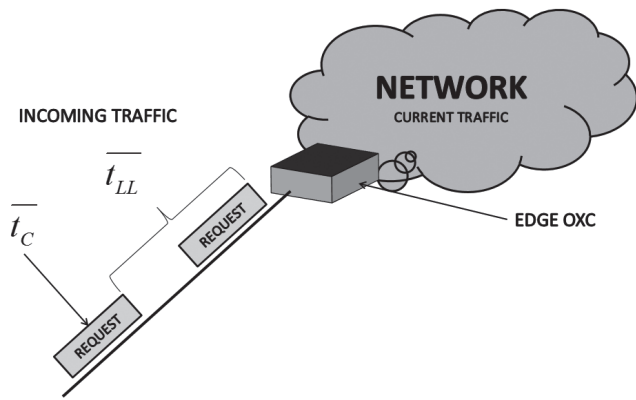
Figure 2. Incoming and current traffic showing the demand for requests and inter-arrival and holding times.

In the currently as well as in the future the traffic is dynamic and new solutions will be tested to improve the efficiency of the optical network. Optimization algorithms can be classified in two categories: routing algorithms and wavelength assignment algorithms. Routing algorithms can, in turn, be classified into conventional and heuristic categories: conventional algorithms are those that optimize the route, and therefore, they are used in SLE contexts, which include Dijkstra, Bellman Ford, Floyd Warshall, among others. On the other hand, heuristic algorithms are used to find only good routes; therefore, they are studied in DLE contexts, such as Genetic, Simulated Annealing, Tabu Search, Ant System, and other algorithms. Furthermore, wavelength assignment algorithms are based on simple methods that enable assigning wavelengths rapidly to the links of the route. The most widely used are First Fit (FF), which assigns the first wavelength that fits; Best Fit (BF), which assigns the wavelength that fits best; Next Fit (NF), which tests the next wavelength after the last one that was assigned; Worst Fit (WF), which tests the wavelength under the criterion of maximum network utilization (it does not improve the use of the network. However, it increases blocking probability); Random Fit (RF), which tests the wavelengths randomly; Least Used (LU), which tests the least used one; and Most Used (MU) which tests the most used one as noted in Zang (2001). Finally, regarding the criteria used for optimizing, we can find research based on minimizing or maximizing some criterion such as ASE noise, total congestion, congestion at a link, jitter, total delay, blocking probability, network utilization, congestion of a specific commutator, and others. In general, the work is based on finding the lightpath to satisfy the demand, in order to guarantee the service of future demand and to fit the maximum network availability as possible.

Simulation Exercise Context

Optical networks have evolved into what is called,WDM (Wavelength Division Multiplexing) networks, which allow different wavelength traffic on the same fiber, commonly seen in the single-mode low dispersion type, which enables multiplexing without the appearance of nonlinear

phenomena. The most important WDM are NSFNET (National Science Foundation NETwork) as noted in Zang (2001), ARPANET (Advanced Research Project Agency NETwork) as noted in Khan (2005), EON (European Optical Network), UNIT (United Kingdom NETwork), among others. In this research, the NSFNET network is used, simulated without wavelength conversion. Networks with wavelength conversion allow more efficient use of the network's resources than networks without wavelength conversion, but the former have greater delay than the latter. Figure 3 shows the network used in this research (NSFNET), with 14 nodes and 8 wavelengths, without wavelength conversion as noted in Rodriguez (2014).

The parameters used were similar to those presented in Zang (2001), and comparisons were made of the relevant indicators, such as the probability of blocking and using the network, varying the load in the [0,180] interval with increases of 5 erlangs.
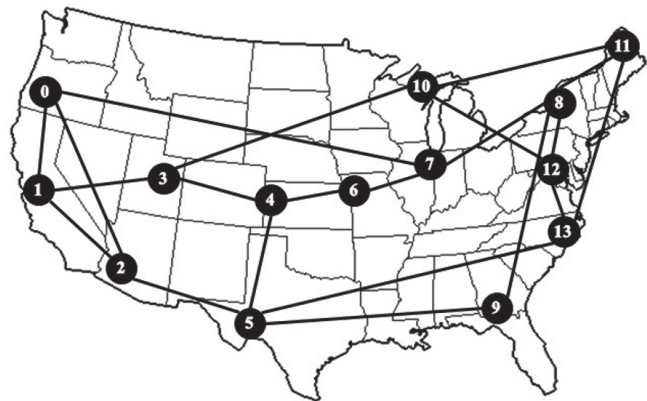

Figure 3. National Science Foundation NETwork (NSFNET) with fourteen nodes and eight wavelengths.

The number of connections made during the simulation exercise in each and every one of the contexts, including Simulated Annealing (SA), Genetic Algorithms (AG), Tabu Search, and Snake-One (SNK1), was 108 connection requests. The non-heuristic algorithm used as reference is the one shown in Zang (2001), which made 104 requests and loads of up to 160 erlangs.

New Snake One Algorithm

This heuristic algorithm simulates the movement of a snake in the cost matrix of the network, with horizontal and vertical movements within a matrix, building the path until it reaches its destination. For this purpose, requests are established to arrive (with Poisson distribution) to the border nodes (Edge OXC), bringing with them three parameters that must be satisfied, otherwise the request must be blocked (Equation (3)):

$$d_i^S = (r_0, r_D, n_C, t_C) \qquad (3)$$

Where d_i^S is the vector that represents the ith request reaching the sth border node, r_O is the identification number

of the start node of the demand input, r_D is the identification number of the destination node of the demand input, n_C is the number of requested connections, and t_C is the requested connection time for the (r_O, r_D) pair. If N is the number of nodes in the network, n_{CX} is the maximum number of connections at each link, and n_W is the number of wavelengths at each link (assumed to be equal in all the network's links).

Five matrices have been established: the links matrix and the cost matrix (E, C, Equation (4) and Equation (5)), the Lambda matrix and the time matrix (λ, T, Equation (6) and Equation (7)), and the Snake matrix (S, Equation (8)). Matrix E will retain the network topology, in this case the NSFNET. However, any network you wish to simulate can be configured. The definitions of the matrices are given below. Two more columns were added in matrix in order to save partial calculations like total cost of the rows and the node's label.

$$E = \begin{cases} e_{ij} / (e_{ij} = 0 \ \forall \ i = j, \wedge e_{ij} = G \wedge i \neq j \ NEE \\ \wedge e_{ij} = 1 \wedge i \neq j \ SEE \wedge G \gg n_C \wedge i,j \in [0, N-1]) \end{cases} \quad (4)$$

$$C = \begin{cases} c_{ijk} / c_{ijk} = n_{CX} * e_{ij} \wedge i,j \in [0, N-1] \\ \wedge k \in [0, n_W - 1] \end{cases} \quad (5)$$

SEE = There is a link
NEE = There is no link

$$\lambda = \begin{cases} \lambda_{ijk} / (\lambda_{ijk} = 0 \ LA \ \vee NEE) \vee \\ (\lambda_{ijk} = k+1 \ LD) \forall \ i,j \in [0, N-1] \\ \wedge k \in [0, n_W - 1] \end{cases} \quad (6)$$

$$T = \begin{cases} t_{ijk} / t_{ijk} = -t_C \ LA \wedge i,j \in [0, N-1] \\ \wedge k \in [0, n_W - 1] \end{cases} \quad (7)$$

LA= Lambda activated
LD= Lambda deactivated

$$S = \begin{cases} s_{i0k} = 1 & \forall i \in [0, N-1] \wedge k \in [0, n_W - 1] \\ s_{ijk} / s_{ijk} = c_{ijk} * t_{ijk} & \forall i \in [0, N-1] \wedge j \in [1, N] \wedge k \in [0, n_W - 1] \\ s_{i(N+1)k} = \sum_{j=1}^{N} s_{ijk} & \forall i \in [0, N-1] \wedge j \in [1, N] \wedge k \in [0, n_W - 1] \end{cases} \quad (8)$$

The cost matrix C is constructed from matrix links E and NCX. The λ matrix controls the used and the available wavelengths. The T matrix controls the connection time to each request and its elements are: less than zero, when in use and counting until the connection time runs out; zero, when the connection time runs out; and one when the wavelength on the link is available. The S matrix is where the action of Snake One algorithm takes place. The elements of S are positive when the elements of the

T matrix are one, i.e. they are available. Other cases will be negative, which means that they will not be taken into account for the horizontal and vertical displacements.
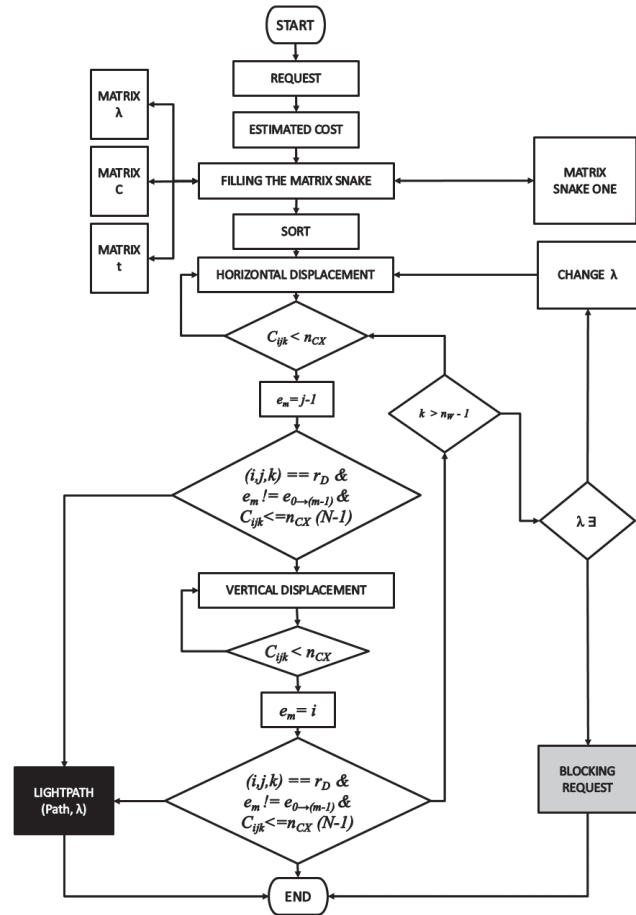

Figure 4. Flowchart showing lightpath obtaining and blocking.

Figure 4 shows the procedures that are carried out to obtain the LP in a single algorithmic process. For example, the seventh request of the demand at node 1 is denoted by $d_7{}^1 = (1,4,1,500)$ in a network of 8 nodes ($N=8$) and 3 wavelengths, i.e., its destination is node 6 and it requests one connection for a time of 500 ms. Then, the Snake matrix is established as a function of the cost matrix, adding two columns: the first one for the labels of the nodes, and the other one for the sum of the cost (Equation(8)), where the required LP will be resolved.

The Snake One algorithm will be applied to the matrix of Figure 5 and a route will be sought. If it is not found, a route will be sought in the next wavelength (FF), and if a route is not found in the available wavelengths, the request is blocked. The time matrix is supposed to determine the total availability, that is, $t_{ijk}=1$.

For the request be, $d_7{}^1 = (1,4,1,500)$, Matrix S is arranged in decreasing order according to the cost column. Looking at column 0 of matrix S (Nodes), we locate the row corresponding to the start node 1 (0,0), as seen in Figure 6. Then we move along horizontally until we locate the first

cost greater than n_C and less than 1000, (value enabling differentiation of a non-existing link) which is located at node 0 (0,1).

$$S_{ij}= \begin{array}{c|ccccccccc} & 0 & 0 & 16 & 1000 & 1000 & 1000 & 1000 & 1000 & 16 & 5032 \\ & 1 & 16 & 0 & 16 & 16 & 1000 & 1000 & 1000 & 1000 & 4048 \\ & 2 & 1000 & 16 & 0 & 1000 & 1000 & 16 & 1000 & 1000 & 5032 \\ & 3 & 1000 & 16 & 1000 & 0 & 16 & 1000 & 1000 & 16 & 4048 \\ & 4 & 1000 & 1000 & 1000 & 16 & 0 & 16 & 16 & 1000 & 4048 \\ & 5 & 1000 & 1000 & 16 & 1000 & 16 & 0 & 16 & 1000 & 4048 \\ & 6 & 1000 & 1000 & 1000 & 1000 & 16 & 16 & 0 & 16 & 4048 \\ & 7 & 16 & 1000 & 1000 & 16 & 1000 & 1000 & 16 & 0 & 4048 \end{array}$$

Figure 5. Snake Matrix of the wavelength of 0, which shows the values for the topology in Figure 1.

Since node 0 is not the destination, we move vertically until we find a cost greater than 0 and less than 1000, which is located at node 7 (5,1). Since node 7 is not the destination, we move horizontally again, locating node 3 (5,4), and then we move vertically locating destination node 4 (2,4), ending the algorithm (Figure 6) because it is the destination proposed in the input request. Therefore, the displacement in matrix S is:

$$(0,0) \rightarrow (0,1) \rightarrow (5,1) \rightarrow (5,4) \rightarrow (2,4)$$

This corresponds to the lightpath 1-0-7-3-4, with wavelength 0, as seen in Figure 7.

Node	0	1	2	3	4	5	6	7	Cost
0	1	2	3	4	5	6	7	8	9
1	16	0	16	16	1000	1000	1000	1000	4048
3	1000	16	1000	0	16	1000	1000	16	4048
4	1000	1000	1000	16	0	16	16	1000	4048
5	1000	1000	16	1000	16	0	16	1000	4048
6	1000	1000	1000	1000	16	16	0	16	4048
7	16	1000	1000	16	1000	1000	16	0	4048
0	0	16	1000	1000	1000	1000	1000	16	5032
2	1000	16	0	1000	1000	16	1000	1000	5032

$S_{ij}=$

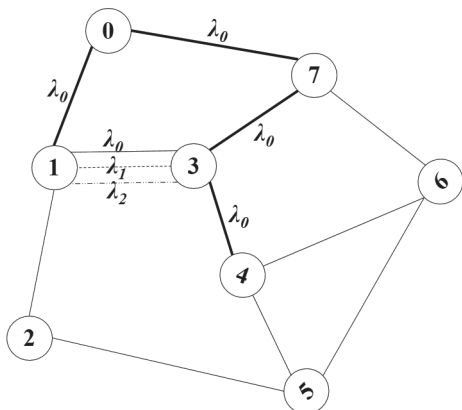**Figure 6.** Vertical displacement for wavelength 0.

Figure 7. Solution for the example network of 3 wavelengths λ_0, λ_1, λ_2.

Comparison of Results

The simulation exercise was carried out under dynamic traffic conditions, and the heuristic algorithms were subjected to a load variation of 0 to 180 erlangs. It should be stressed that the referential work found in Hui *et al.* (2001) only simulated up to 160 erlangs, but this does not undermine the comparison. The performance of the proposed Snake One algorithm is important from the standpoint of the blocking probability.

Table 1. Comparison of average values of the heuristic algorithms in this study.

	AG	SA	RF	TS	SNK1
Blocking Probability	0.42	0.45	0.37	0.36	0.32
Network Use (%)	42.17	45.30	36.19	55.17	68.22

Table 1 presents the heuristics and the average values of the blocking probability using a non-heuristic referential (RF) element from the work shown in Zang (2001). The average value of the Snake One algorithm is 0.32, which is the smallest of all. However, observing the use of the network, the algorithm cannot decrease it, and it increases to an average value of 68.22 %, which is the largest of all the heuristics, as seen in Figures 8 and 9.
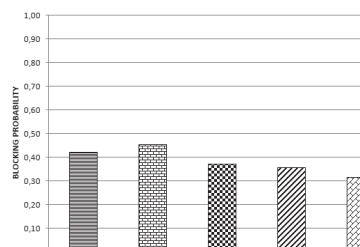

Figure 8. Comparison of the average value blocking probability.

When the performance of the blocking probability in the load distribution is examined (Figure 10), the Snake algorithm achieves better performance of up to 130 erlangs with respect to the reference, and up to 140 erlangs in relation to the other heuristics. However, the network utilization (Figure 11) shows no improvement at any load interval, and it appears as the heuristic with the greatest usage of the network's resources.
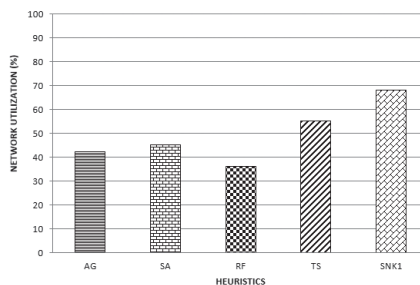

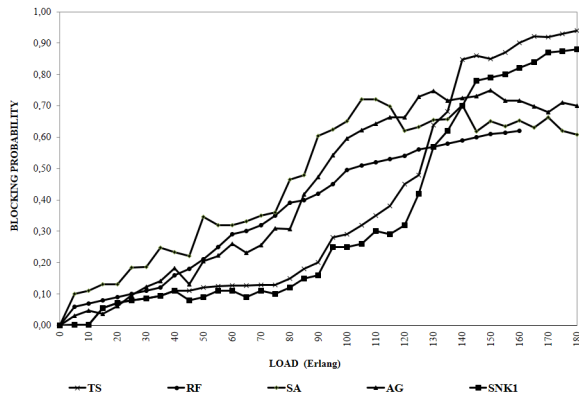**Figure 9.** Comparison of the average value network utilization.

Figure 10. Behavior of the blocking probability in dynamic traffic contexts.
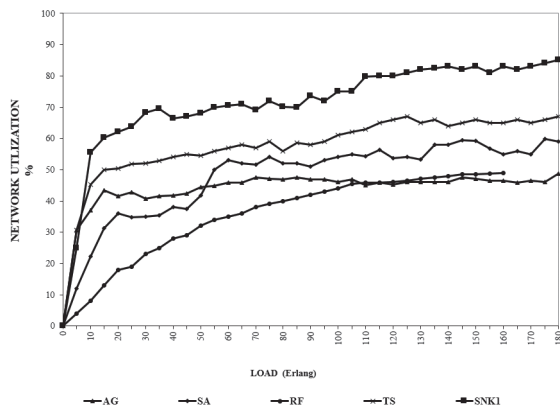

Figure 11. Behavior of the network utilization in dynamic traffic contexts.

Conclusions

The SNK1 algorithm achieves good performance in satisfying the demand, but its performance in network utilization is not acceptable, mainly because its search is made only from the standpoint of the cost matrix, without taking into account the traffic. The next step will be to improve the performance by modifying the algorithm so that it will concentrate the traffic in specific sectors (SNK2). On the other hand, the algorithm responds well up to 130 erlangs, making it recommendable in cases of dynamic high load traffic. Further research on new algorithms and strategies to enhance performance of the indicators is important.

Acknowledgements

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