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RWA: Comparison of Genetic Algorithms and Simulated Annealing in dynamic traffic

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ABSTRACT

Modern telecommunications are supporting every day a progressive demand for services, which in turn generates greater requirements from the attention capacity in photonic transport networks. This phenomenon forces us to improve the routing systems, to minimize the blocking probability and minimize the use of the network, among other indicators, in order to attend current demand and to have the capacity to attend future demand. This paper compares four studies on routing and wavelength assignment with the aim of supporting the improvement of the already mentioned indicators. A comparison is made between optimizing algorithms and heuristic simulated annealing and genetic algorithms, using comparative indicators such as blocking probability and the use of the network. The results show that the heuristic algorithms are potentially better for a high load dynamic demand (greater than 120 erlangs) that would function much better under stress. GINT proposes genetic algorithms as a solution to the coming future demand of data transport.

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INTRODUCTION

Currently, in the field of fiber optics, the discussion is centered on commutation, which is preferable because of its high response speed to routing. The closeness of the upper layers of OSI to the linkage layer has triggered the reflection of the permanence of the IP layer, but not of the IP address. In any case, the search to establish routes that determine a fast and secure connection should be solved through different algorithms found in the literature or innovative algorithms proposed by researchers, such as those of Dijkstra and Floyd-Warshall among others, however those optimizing algorithms are not efficient with respect to optical demand, which requires good routes rather than optimum routes, due to the need to decrease the probability of blocking the network and improving its use.

The traffic supported by a network can be classified as static and dynamic (Zang, H., J. Jue, 2001). In the optical transport networks the traffic was of the static type because the demand was not sufficient to congest the system; but the static characteristics of traffic have turned toward dynamic traffic, and the RWA (Routing Wavelength Assignment) problem has become important, requiring the selection of a route and a wavelength to establish the connection, under the restriction that there should be no change in wavelength along the chosen route, which is known as CCW (Continuity Constraint Wavelength). This restriction helps to improve the delay on the route of present demand (Chu, X., *et al*., 2003), but the use of the network increases, increasing the probability of blocking the future demand, because the more routes are established, the scarcer the roads become.

In general, this problem has been solved by subdividing it into two parts: The first one solves the route to be followed based on minimizing some pre-established condition (Rodríguez, A., 2011; Guenduez, H., H. Kadir, 2013), while the second part solves the problem of assigning the wavelengths. There are other proposals that solve the problem from an integral perspective, i.e., without subdividing it (Liu, L., *et al*., 2009). The present paper makes a comparison of the two methods from the heuristic standpoint (Rodríguez, A., 2008;Rodríguez, A., 2011).

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1. Description of the RWA problem:

In All Optical Networks (AON) the transmitters are connected with each receiver at all wavelengths, and therefore as many signals are required as there are wavelengths. When many sessions use the same wavelength, these signals cannot be sent simultaneously along the same fiber to avoid collisions within the network, consequently blocking the session. It must be ensured that if a receiver is awaiting data at a given wavelength in a given time interval, only one signal at that wavelength must get to the receiver; if two or more signals arrive under those conditions, we face a phenomenon called contention, which can be avoided by isolating the signals in space and/or in time, i.e., by sending the signal along another road and/or at another time. Temporary isolation is in general what we are trying to avoid, because it causes latency.

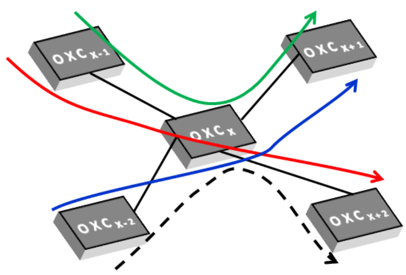

Fig. 1: Example of contention in optical networks.

An optical network is formed by OXC (Optical Cross Connect) or optical commuters linked by optical fibers. Depending on the technology of these commuters, they can commute fibers, wavelengths, wavelength bands, time division multiplexing (TDM). The optical routes are formed by optical links that direct the light beam (data) through the same wavelength according to the wavelength continuity restriction, but this possibility is exhausted when the demand exceeds the number of possible sessions; when this restriction cannot be satisfied, the request is blocked. Routing systems reusing the wavelength, where it is allowed to be changed, have been developed, however the studies do not show significant changes in routing performance (Ramaswami, R., 2006). Fig. 1 shows 5 OXC that are part of a larger system. The established routes with their corresponding wavelengths (colors) are (x-1, x, x+2/Red); (x-1, x, x+1/Green) and (x-2, x, x+1/Light blue); when a service request arrives whose solutions goes through the (x-2, x, x+2) links as shown in blue color, the specified route cannot be assigned the red wavelength because it is being used in the (x,x+2) link, so either another wavelength should be used or a new route should be found. This problem is called contention.

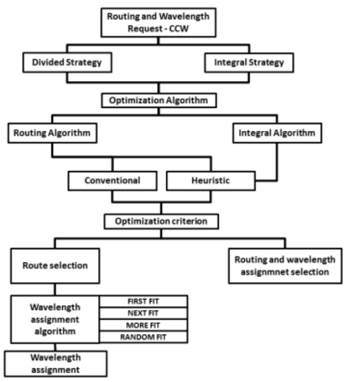

Fig. 2: RWA-CCW solution strategies.

We must define some variables to formulate the problem. We know that in the network there is current traffic and arriving or requested traffic. Traffic can be static or dynamic, depending on the existing relations between the current and arriving traffic. It is dynamic when the average connection time of current traffic is much less than the average time between services request arrivals. This scenario is not optimizable, so heuristic algorithms are used, most of which offer greater solutions that are not necessarily optimum, but this richness provides much support when the contentions problem arises, avoiding a new execution of the algorithmic process. The problem is to establish the routes and the wavelength assignments in the network for various criteria, with minimum probability of blocking the requests, low transport latency along the route, low level of jitter, etc. The problem is known as RWA, Routing Wavelength Assignment (routing and wavelength assignment). Different strategies have been tested to satisfy the demand of an optical network, and optimization criteria and algorithms have been used (Balasis, F., 2013). The optimization criteria have been based on:

- Minimizing the probability of blocking new requests (Liu, L., 2006).
- Minimizing the use of the network's wavelengths (Zang, H., 2000; Ramaswami, R., K. Sivarajam, 1996; Wang, J., 2006).
- Minimizing the use of wavelengths per link (Kuri, J., *et al*., 2003; Saengudomlert, P., 2005).
- Minimizing dispersion on the route (Gurzi, P., 2011).
- Minimizing the ASE (Amplified Spontaneous Emission) (Feres, M., L. Trevelin, 2009)

The optimizations algorithms can be classified into conventional, which are algorithms used in electronic routing or only as an initial population value for heuristic algorithms, such as minimum cost roads, dijkstra; incremental cost roads, bellman fulkerson; minimum delay roads, bellman ford; and Linear Programming (Ozdaglar, E., D. Bertsekas, 2003), and heuristics, which are widely used algorithms in the search for good routes and not necessarily optimum routes, such as Ant (Zeng, P., H. Yu, 2006; Tan, S., 2012), Genetic (Rodríguez, A., F. Saavedra, 2009; Rodríguez, A., 2008), Tabu Search (Assis, K., 2010), and Simulated Annealing (Rodríguez, A., 2011; Guenduez, H., H. Kadir, 2013). The diagram in Fig. 2 shows the processes located in the literature for solving the RWA problem. It is seen that they go from using problem division strategies until it is completely solved, making use of different criteria and algorithms that allow getting a route and a wavelength that allow the information to be transported. It should be stressed that in optical networks the aim is not necessarily to optimize, but what is sought is rather a route that will work without generating a substantial increase of the probability of blocking and without enlarging the network.

2. *Model description:*

In this demand model the nodes N participate in the routing request from the network with a probability pl (for the l-th access node connected with the l-th optical node Xl). This is the routing request probability that will be used as a simulation parameter. The demand Ml of the l-th access node follows a Poisson distribution with an average rate μe .

$$P_{(M_l=m)} = \frac{\mu_e^m}{m!} e^{-\mu_e} \quad (1)$$

With this model we can have a varied range of requests around the whole network and we can vary the load intensity at all the nodes, and the demand can be changed from static to dynamic according to the study that it is desired to make. The comparative work was done under dynamic demand.

3. *Description of the algorithms:*

The selected strategies are to divide the problem into two parts or to use it wholly. Simulated annealing was used in the first case, and genetic Algorithms in the second case, both of them carried out previously by the Grupo de Investigacion de Nuevas Tecnologias (GINT) Industrial Technology Department, Facultad Tecnologica of the Universidad Santiago de Chile.

3.1 *Network demand:*

Requests arrive at the boundary nodes (with Poisson behavior, but different probabilistic scenarios could be studied). These requests bring along four parameters that must be satisfied, otherwise the request will be blocked.

$$v_i^S = (r_O, r_D, n_C, t_C) \quad (2)$$

Where:
is the vector that represents the ith request that arrives at the sth boundary node (Edge Router).
is the identification number of the node of origin.
is the identification number of the destination node of the arrival request.
is the number of connections requested for the (rO,rD) pair .
is the time of connections requested for the (rO,rD) pair .

Three matrices have been established: The first linking matrix, C, that will always be setting the available capacity of the links, so it can be used to monitor when a link is not available; the second wavelength matrix, □ □ , which determines the wavelength in use; and the third, the time matrix T, is a matrix that will have the function of keeping count of the connection time of each wavelength in each link, and must be updated dynamically. Its structure is similar to that of matrix □ □ , but its elements will have the value 1 when the wavelengths are available in the given link, and the time will be negative when it is in use, and it will decrease as time goes by, and in this way it can be detected in the aptitude functions FA so as not to use it. The definitions of the matrices are given below (Barpanda, R., 2011; Rodríguez, A., F. Saavedra, 2009; Rodríguez, A., 2008).

$$c=\begin{Bmatrix} c_{ij}/(c_{ij}=0\ \forall\ i=j\ \wedge\ c_{ij}=G\ NEE \\ \wedge\ c_{ij}=g\ \ \forall\ i\neq j\ SEE\ \wedge\ j\in[0,N-1] \\ \wedge\ k\in[0,n_w-1] \end{Bmatrix} \quad (3)$$

G=Very large number g= Instantaneous cost of the link
NEE= There is no link. SEE= There is a link.

$$\lambda=\begin{Bmatrix} \lambda_{ijk}/(\lambda_{ijk}=0\ LOU\ \vee\ NEE)\ \vee \\ (\lambda_{ijk}=k+1\ LOD)\ \forall\ i\in[0,N-1] \\ \wedge\ \ j\in[0,N-1]\wedge\ k\in[0,n_w-1] \end{Bmatrix} \quad (4)$$

nW = Number of wavelengths in the network.

$$T=\begin{Bmatrix} t_{ijk}/(t_{ijk}=-t_c\ LOU\ \ \ t_{ijk}=0\ NEE)\ \vee \\ (t_{ijk}=1\ \ LOD)\ \forall\ i\in[0,N-1] \\ \wedge\ \ j\in[0,N-1]\wedge\ k\in[0,n_w-1] \end{Bmatrix} \quad (5)$$

LOU= Wavelength in the link is being used.
LOD = Wavelength is not being used.

3.2 Simulated Annealing Algorithm:

Let S0 be the two-dimensional matrix of order m x N, where m is the number of rows of the matrix, which indicates the population sample used, in addition to being a simulations variable, while N indicates the number of nodes.

$$S_i=\begin{Bmatrix} s_{xy}/s_{xy}=a\ \wedge\ a\in[0,N-1] \\ \wedge\ \ x\in[0,m-1]\wedge\ \ y\in[0,N-1] \\ \forall\ \ N,m=2k\ \ \wedge k\in Z^+ \end{Bmatrix} \quad (6)$$

Futhermore:

$$s_{0y}=r_O\ \wedge\ s_{xN-1}=r_D\ \ \forall\ \ x,y \quad (7)$$

When a request arrives at node 1, matrix S0 is established; if it arrives at node 2, matrix S1 is established, and so on. When = (1,4,3,128) arrives, we read: 15° service request entering node 1, which requests route from node 1 to node 4 with three 128 ms. connections. Therefore, according to (8), the first column has the origin node and the last column has the destination node. The rest of the elements of the initial population are filled randomly. For example, (Shown Fig. 3), for m = 8 and N = 10, and the request for connection from node 1 to node 4.

Then rotation of the internal layers at different speeds must take place to find the routes. Also, the wavelength assignments were made with First Fit, to be able to compare them under the same conditions in terms of stopping criteria, aptitude functions, and other parameters of the algorithm. They can be seen in detail in (Rodríguez, A., 2011; Guenduez, H., H. Kadir, 2013).

3.3 Genetic algorithms:

Let P0 be the initial population of the genetic algorithm to be used, and nP the number of chromosomes that constitute these initial populations. There will also be “m” genetic algorithms for the “m” nodes that are requesting transport service. Within the genetic algorithms there are various implementations that allow different behaviors of nP (regeneration policies); in this research this value remains constant and it is a simulation parameter. In this way, the three-dimensional matrix P0 of nP x (N+3nW +2) x N elements is defined.

$$P_0=\begin{Bmatrix} p_{abc}/p_{abc}=y\ \wedge\ a\in[0,n_P-1] \\ \wedge\ \ b\in[0,N+3n_W+2]\wedge\ \ c\in[0,m-1] \\ \vee\ \ y\in[0,N-1] \end{Bmatrix} \quad (8)$$

$$P_{0bc}=r_O\ \wedge\ P_{a0c}=r_D\ \ \forall\ \ a,b,c \quad (9)$$

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$$
S_0 = \begin{array}{c} \\ 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \end{array}
\begin{array}{c} \begin{array}{cccccccccc} 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\
\left[\begin{array}{cccccccccc}
1 & 3 & 9 & 3 & 2 & 2 & 5 & 6 & 9 & 4 \\
1 & 4 & 9 & 2 & 6 & 3 & 4 & 4 & 2 & 4 \\
1 & 1 & 1 & 3 & 4 & 5 & 3 & 7 & 1 & 4 \\
1 & 4 & 2 & 7 & 3 & 2 & 4 & 5 & 8 & 4 \\
1 & 5 & 9 & 7 & 5 & 1 & 2 & 1 & 9 & 4 \\
1 & 6 & 8 & 5 & 7 & 4 & 8 & 6 & 1 & 4 \\
1 & 7 & 8 & 2 & 3 & 6 & 9 & 7 & 6 & 4 \\
1 & 3 & 2 & 8 & 5 & 3 & 2 & 4 & 7 & 4
\end{array}\right] \end{array}
$$

Fig. 3: Initial population matrix.

This matrix is filled randomly, the additional columns are for saving the calculations of the aptitude functions referring to each available wavelength. La Fig. 4 shows the 3D matrix of the initial populations that will serve for the genetic process. For example, Fig. 4 shows the initial population of a network with 6 (m = 6) nodes and 8 (nP = 8) chromosomes without intergenerational numerical change, and in Fig.5 each commuter is a gene that constitutes the chromosome, whose information is the route that is sought. For example, in row 4 the chromosome is 2-3-3-2-1-4, where the first and the last genes are the origin and the destination. The rest of the genes are filled randomly in the population matrix. Assuming that the network has two wavelengths (nW = 2), in Fig. 5, we would have one of six genetic algorithms with “a” from 0 to 9, “b” from 0 to 5 and “c” from 0 to 5.

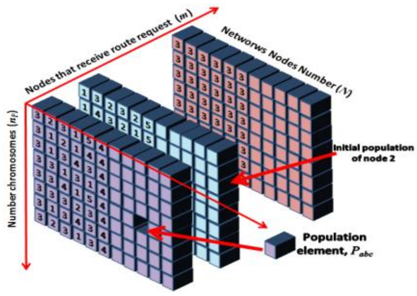

Fig. 4: 3D matrix of the initial population.

If the request that arrives at node 2 is = (2, 4, 3, 128), then the matrix would be:

Then the algorithm is executed to find the routes; as to the stopping criteria, aptitude functions and other parameters of the algorithm, they can be seen in detail in (Barpanda, R., 2011; Rodríguez, A., F. Saavedra, 2009; Rodríguez, A., 2008).

$$
P_{ab1} = \begin{array}{c} \\ 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array}
\begin{array}{c} \begin{array}{ccccccccccc} 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \end{array} \\
\left[\begin{array}{ccccccccccc}
2 & 1 & 2 & 2 & 3 & 4 & & & & & \\
2 & 3 & 1 & 1 & 2 & 4 & & & & & \\
2 & 4 & 3 & 3 & 1 & 4 & & & & & \\
2 & 2 & 4 & 4 & 2 & 4 & & & & & \\
2 & 3 & 3 & 2 & 1 & 4 & & & & & \\
2 & 2 & 4 & 4 & 3 & 4 & & & & & \\
2 & 1 & 5 & 5 & 4 & 4 & & & & & \\
2 & 2 & 3 & 3 & 1 & 4 & & & & & \\
2 & 5 & 2 & 2 & 2 & 4 & & & & & \\
2 & 2 & 3 & 1 & 1 & 4 & & & & &
\end{array}\right] \end{array}
$$

Fig. 5: 2D matrix of the initial population of node 2, belonging to P0.

4. Comparison scenario:

Once the simulation had been made, it was compared with two similar reports under the same simulation conditions.

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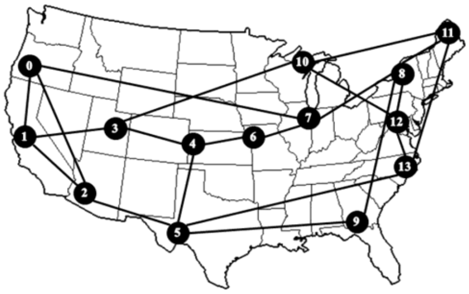

Fig. 6: NSFNET network used with the four methods.

The network used for the test was the NSFNET (National Science Foundation NETwork), which has 16 nodes and 25 fiber optics links (Shown Fig. 6). The parameters used were similar to those presented in [2]. Comparisons were made of probability of blocking and use of the network, varying the load in the [0,180] interval, with 10-erlang increments. The number of connections made during the simulation in both scenarios, simulated annealing (SA) and genetic algorithms (GA), was 108 connection requests.

5. *Results:*

Comparisons were made of the simulated annealing (Rodríguez, A., 2011), genetic algorithms (Rodríguez, A., F. Saavedra, 2009), of Dr. Xiao Wen (2003), and of Dr. Hui Zang (2001)simulations with the blocking probability indicator, which measures the probability of blocking the service requests under a given load, and the network use indicator, which measures network occupation under a given load. Fig. 7 graphs the blocking probability, showing that up to 120 Erlangs the GA has better performance than SA, but above 120 Erlangs the SA is better than GA, but in no case are they better than that of Hui Zang; the excellent performance of the Xiao Wen algorithm is worth noting, but it is because 40 wavelengths are used, compared to eight wavelengths that were used in the other three studies. Fig. 7, graphs the percentage use of the network, comparing the network use with the previously mentioned reports. The SA algorithm improves the network use for loads smaller than 50 Erlangs, but for greater loads the GA algorithm uses fewer network resources. But, under 110 Erlangs the SA and GA algorithms are not better than that of (Zang, H., J. Jue, 2001), but the GA algorithm is better for loads greater than 110 Erlangs. Note that work with SA and GA reaches 180 Erlangs, while the other reports involve simulations with lower load intervals. On the other hand, the performance of the algorithm reported in (Chu, X., *et al*., 2001) involves high network consumption, even with many wavelengths, generating a problem to satisfy future load demand.

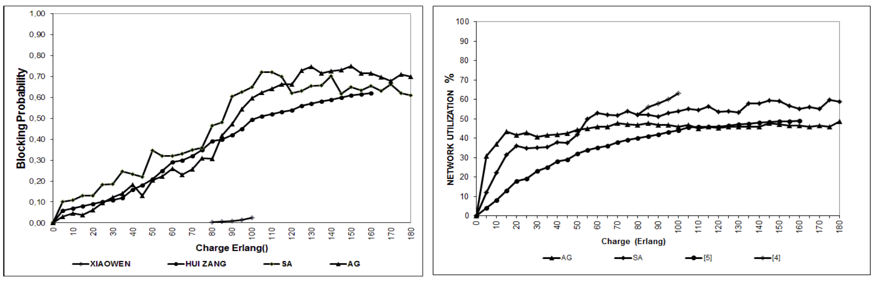

Fig. 7: Comparison of blocking probability and network use in the NSFNET.

6. *Conclusion:*

The work reported in (Chu, X., *et al*., 2001;Zang, H., J. Jue, 2001)[1][2] is always aimed at optimum solutions, while the work based on SA and GA looks for solutions without the need to go over the whole possible universe, thereby saving a large amount of operating time. From the results it can be concluded that heuristic algorithms have great potential for future demand because they function much better at high loads and small dynamic traffic, and the latter should become very important because it allows the use of the network with an optimum sense. This research team agrees that it will be necessary to develop the re-use of wavelengths to be able to remove the restrictions given in CCW and improve the results while better proposals are developed.

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REFERENCES

Chu, X., B. Li, Z. Zhang, 2003. A Dynamic RWA Algorithm in a Wavelength-Routed All-Optical Network with Wavelength Converters, INFOCOM. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies, 3: 1795-1804.

Zang, H., J. Jue, 2001. Dynamic Lightpath Establishment in Wavelength-Routed WDM Networks, IEEE Communications Magazine,. 39: 100-108.

Barpanda, R., A. Turuk, B. Sahoo, B. Majhi, 2011. Genetic Algorithm techniques to solve Routing, Wavelength Assignment problem in Wavelength Division Multiplexing all-optical networks, Communication Systems, Networks (COMSNETS), 2011 Third International Conference on, 1-8.

Zang, H., L. Sahasrabuddhe, J. Jue, S. Ramamurthy, B. Mukherjee, 1999. Connection management for wavelength-routed WDM networks, Global Telecommunications Conference. GLOBECOM, 99(2): 1428-1432.

Rodríguez, A., F. Saavedra, 2009. Enrutamiento y asignación de longitudes de onda en redes WDM: Solución simultánea basada en algoritmos genéticos, IEEE InterconUNSA, Arequipa-Perú.

Rodríguez, A., F. Saavedra, L. Ramírez, 2008. Solución Simultánea Del Enrutamiento Y Asignación De Longitud De Onda en redes WDM Con Algoritmos Genéticos". IEEE COLCOM, Bogota, Colombia.

Rodríguez, A., F. Saavedra, L. Ramírez, 2011. Simulated Annealing una Propuesta de Solución al Problema RWA en Redes Fotónicas". IEEE InterconUNI, Lima-Perú.

Guenduez, H., H. Kadir, 2013. A Well-Arranged Simulated Annealing Approach for the Location-Routing Problem with Time Windows, System Sciences (HICSS), 46th Hawaii International Conference on, 1144-1153.

Liu, L., Q. Xue, J. Zhang, F. Wang, J. Wu, J. Tong Lin, L. Bin, 2006. Investigation of Uniform Models for Analysing Network Blocking Probability in ASON, Communications, Networking in China, ChinaCom '06. First International Conference on, 1-4.

Zang, H., J. Jue, B. Mukherjee, 2000. A review of routing, wavelength assignment approaches for wavelength-routed optical WDM networks, Optical Network Magazine, 1: 47-60.

Kuri, J., N. Puech, M. Gagnaire, E. Dotaro, R. Douville, 2003. Routing, wavelength assignement of scheduled lightpath demands, IEEE Journal On Selected Areas in Communications, 21: 1231-1240.

Ozdaglar, E., D. Bertsekas, 2003. Routing, wavelength assignment in optical networks, IEEE/ACM Transactions on Networking, 11: 259-272.

Saengudomlert, P., E. Modiano, R. Gallager, 2005. Dynamic wavelength assignment for WDM all-optic tree networks, IEEE/ACM Transactions on, 13: 895-905.

Ramaswami, R., K. Sivarajam, 1996. Design of logical topologies for wavelength-routed optical networks, IEEE Journal On Selected Areas In Communications, 14: 840-851

Ramaswami, R., 2006. Optical networking technologies: What worked, what didn´t, IEEE Communications Magazine, 44: 132-139.

Zeng, P., H. Yu, 2006. An ant-based routing algorithm to achieve the lifetime bound for target tracking sensor networks, Communications, 2006. ICC '06. IEEE International Conference on, 8: 3444-3449.

Wang, J., X. Qi, B. Chen, 2006. Wavelength assignement for multicast in all optical WDM networks with splitting constraints" Networking IEEE/ACM Transactions on, 14: 169-182.

Tan, S., 2012. Ant-based Physical Attack, Amplifier Spontaneous Emission-aware routing, Communication Technology (ICCT), IEEE 14th International Conference on, 650- 653.

Feres, M., L. Trevelin, 2009. RWA algorithm aware of PMD, ASE for all-optical networks, Transparent Optical Networks. ICTON '09. 11th International Conference on, 1- 4.

Gurzi, P., K. Steenhaut, A. Nowe, 2011. Minimum cost flow based R&WA algorithm for dispersion, OSNR limited all-optical networks, Optical Network Design, Modeling (ONDM), 15th International Conference on, 1-6.

Balasis, F., X. Wang, S. Xu, Y. Tanaka, 2013. A dynamic physical impairment-aware routing, wavelength assignment scheme for 10/40/100 Gbps mixed line rate wavelength switched optical networks, Advanced Communication Technology (ICACT), 2013 15th International Conference on, 116- 121.

Assis, K., D. Ferreira, W. Giozza, 2010. Hybrid Algorithms for Routing, Assignment Wavelengths in Optical Networks, Latin America Transactions, 8: 214- 220.