A Proposal of Dynamic RWA Using Ant Colony in Optical Burst Switched Networks

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***Abstract* - One of the main problems in optical networks concerns routing and wavelength assignment for establishing optical circuits. Burst switching is a viable alternative to overcome the problem of idle circuit waste, but it also prevents data to pass to the electrical domain where conversion is necessary, thus making this switching purely optical. A solution to the problem of dynamic RWA in Optical Burst Switching (OBS) networks, called AntOBS, is inspired by ant colony behavior. It is used to decrease the blocking probability during the routes establishment phase. The dynamicity and self-organization are the main features of AntOBS, which through various experiments shows a reduction of the blocking probability of requests from the cross connect electro-optical network.**

Keywords-Optical Networks; Ant Colony; Burst Switching; RWA.

I. Introduction

Many technologies and techniques have emerged to enhance the use of optical fibers, aiming to enjoy its unique qualities such as very low transmission error, high transmission speed and capacity, overall reliability, and much longer distance ranges before the use of repeaters are required.

Some multimedia applications require certain minimum requirements for good functioning and near real-time source to destination delivery. For example, these applications require that some network resources like buffer space, high payload capacity delivery, throughput and minimum transmission delays are guaranteed as part of a Service Level Agreement (SLA) with stated Quality of Service (QoS) parameters and their values at an offered price. There are some features like very low propagation distortion and transmission error rates in optical networks that can meet the needs of these applications better than non-optical networks.

Optical networks provide high transmission rates with very low interference between virtual channels and also immunity from electromagnetic interference [1]. Only where the merging of an optical network cross connects with non-optical networks, interference and higher error rates and lower capacities are still a problem [1, 2]. Other than this, the optimization of Routing and Wavelength Assignment (RWA) can be made as close as possible to their maximum limits. Any failures of these functions can result in wastage and effectively reduce reaching the upper threshold value limits. Given this fact, it is asserted that optical network may provide the ability to handle failures through smart routing algorithms which take into account the current network state to find the best path between the source and destination nodes considering various bottlenecks and restrictions. In doing so, such algorithms must assign the wavelength so that they maximize the use of network resources by minimizing the blocking probability.

The current problems of RWA algorithms in optical networking have the goal of choosing the path between two nodes in the network and set the wavelength to be used in communication. The performance of these algorithms directly compromises the performance of these networks.

In solving the above mentioned RWA problems, it is further asserted that applying the technique of Ant Colony Optimization (ACO) [3] in proposing a new dynamic RWA algorithm for optical burst switching against a defined set of QoS and autonomic self-organization learned knowledge would result in a more satisfactorily solution compared to the performance of the current RWA algorithm.

ACO is a bio-inspired system that is based on ants' social organization and behavior patterns [3]. Ant societies have division of labour, communication between individuals, and an ability to solve complex problems [4]. Ants communicate with each other using *pheromones* [4]. These chemical signals are more developed in ants than in other similar groups. Like other insects, ants perceive smells with their long, thin and mobile antenna. The paired antennae provide information about the direction and intensity of scents. Since most ants live on the ground, they use the soil surface to leave pheromone trails that can be followed by other ants. In species that forage in groups, a forager that finds food marks a trail on the way back to the colony; this trail is followed by other ants, these ants then reinforce the trail when they head back with food to the colony. When the food source is exhausted, no new trails

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are marked by returning ants and the scent slowly dissipates. This behavior helps ants deal with changes in their environment. For instance, when an established path to a food source is blocked by an obstacle, the foragers leave the path to explore new routes. If an ant is successful, it leaves a new trail marking the shortest route on its return. Successful trails are followed by more ants, reinforcing better routes and gradually finding the best path [5]. The colony organization and how the internal ants' communication structure through pheromones is made makes this meta-heuristics functional and appropriate to find the best solution for the problem [6]. The ants come down paths of the "nest" until the "food source" and place the pheromone there. This enables other ants to be induced to paths in which there is the largest amount of pheromone. This induction is probabilistic, what makes a possible variety in the path choice by the ant. This scenario allows the meta-heuristics to converge for the best solutions within a set of viable alternatives.

Ant colony optimization algorithm (ACO) is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. This algorithm is a member of ant colony algorithms family, in swarm intelligence methods, and it constitutes some meta-heuristic optimizations. Initially proposed by Marco Dorigo in 1992 in his PhD thesis [2], the first algorithm was aiming to search for an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food. The original idea has since diversified to solve a wider class of numerical problems, and as a result, several problems have emerged, drawing on various aspects of the behavior of ants as *distributed optimization* [7].

This article is organized as follows: the next section outlines relevant related work; Section 3 describes the main AntOBS features and QoS; Section 4 explains the setup of the simulation and gives the evaluation of the results of from it by comparing and discussing the different approaches of the RWA problem. Section 5 concludes this research study and presents suggestions for future works.

II. AntOBS

In Optical Burst Switching (OBS) networks, data is stored in the network edge node, waiting for the burst to be mounted. With the ready burst, a wavelength (λ) and the path to be covered are assigned to the burst. This problem is called Routing and Wavelength Assignment (RWA) [8, 9, 10]. Then, a burst control packet (BCP) is sent to the target node. BCP uses a channel independent of the data channel (out-of-band), which goes through the path off the plan in a specific wavelength, using a signaling protocol. The main advantage in switching is the data and control plain separation, which enables a good network management and avoids the resources waste because it does not establish a connection. This fact reduces latency and improves network efficiency, i.e., increases the use of network resources, besides using a viable technology.

On the routing problem, routes are calculated according to some heuristics applied to data network. The goal is to find routes that can satisfy the requests that arrive on the network. In WDM networks, each link has multiple wavelengths, and each one of them can carry different data. Therefore, besides setting the route, the wavelength to be used must be set. On the assignment of wavelength problem, one of the available wavelengths must be chosen for a given route.

The behavior of the ACO and the problems of RWA in OBS networks motivated this study to propose the AntOBS. This is an algorithm based on ACO that treats the routing problem and wavelength assignment in OBS networks dynamically. It is also important to mention that in this work, wavelength converters and buffers are not used.

The signaling protocols are responsible for determining how network resources will be allocated and deallocated. In this work the Just-Enough-Time (JET) signaling protocol [8] was chosen due its main feature: delayed reservation, one-way reservation and implicit release. In JET, after the BCP is sent, the burst is sent without confirmation that it has accomplished its task, i.e., reserve network resources along the route of the burst. The BCP contains the information of the burst size and setup time. This enables the reservation is made only during the time of the burst [8].

In the approach proposed in this paper, the ants are characterized by packets that feed the routing tables storing routes pheromone levels that represent the burst success probability in a route, i.e., the higher the level of pheromone, the lower the burst blocking probability. Ants are generated in the nodes and are sent to targets randomly. As the ants follow the path to a particular target, they update the pheromone level in each node.

Two types of ants are proposed: IAnt and MAnt. The first is responsible for creating the routing tables and the second for maintaining up-to-date pheromone levels. The details of each type of behavior are explained in the following sections. The pathway of ants is covered out-of-band. The ants sending frequency is a system parameter.

The wavelength assignment problem is treated by first-fit algorithm and the nodes OBS are not equipped with wavelength conversion capabilities. The choice of wavelength is independent of the choice of the route. In this algorithm, the wavelengths are put in a list of fixed order, determined in advance. In the search for an available wavelength, the first on the list is chosen. If this is already allocated to another request, the second is tested and it continues until you find one available. Global information is not required. The choice of this algorithm was made by the simplicity of it.

A. Main Features

The model used can be defined as a graph G = (V, E), in which V represents the set of network nodes and E represents the set of edges or links in the network. Each link e_{ij} represents a connection between node i and node j.

The IAnt ant is released during the optical networking startup to communicate to other network nodes the node source release. Initially, the node knows only its immediate neighbors, so it is necessary to meet all other nodes in the network so that the protocol can work correctly. This ant works based on the behavior of a broadcast packet. The IAnt has the following structure: identifier code, the source node and the number of hops. This phase is called Initialization Phase.

The next phase is the Maintenance Phase. In this, the MAnt ants keep are released by the network nodes. MAnt must maintain and find out new routes to the source node, being launched with a destination chosen randomly. The launching frequency of is a system parameter. The MAnt carries data about the path and the target with the goal of selecting edges with pheromone along its way. When it reaches to the node, this node interprets and renders the MAnt source address as the destination address, i.e., the node will update the routing table in the opposite ant path. Thus, the routing table of the current node is updated to the MAnt source node.

The data conveyed by an Ant MAnt is composed of the following fields: identifier code, source node, target node, stack, Time-To-Live (TTL) and bitmask. The TTL is used to prevent the ant to be on the network indefinitely. The stack is used to store the path covered by the ant. At each hop, the node processes data from the ant and checks if there is a cycle in the path.

The bitmask, in its turn, has the task of bringing the available wavelengths for that route. In this route, each bit represents wavelength availability.

The probability of the ant MAnt, being at node i, choose the node j as next hop path is given by Equation 1.

$$p_{ij}^k = \begin{cases} r \cdot \dfrac{[\tau_{ij}]^\alpha}{[d_{ij}]^\beta}, & \text{se } j \in N_i^k \text{ ;} \\ 0, & \text{se } j \ni N_i^k \text{ .} \end{cases} \qquad (1)$$

In this equation, r is a constant chosen randomly that aims to give diversity to the solution and k is a number of neighbors of node i. N_i^k represents the set of neighbors of node i, and τ_{ij} and d_{ij} represent the pheromone levels and the cost associated to the link e_{ij}. In this study, the cost associated to each link represents the number of collisions that occurred when the node j was chosen. This metric is important because it takes into account the history of collisions in that link. The values of α and β are constant responsible for deciding the importance of the equation terms.

To avoid stagnation in suboptimal solutions, we have proposed a second transition rule for Ant MAnt. So, the Ant MAnt will have two options for transitional rules, in which the Equation 1 is the first one. The second option is a randomly choice, in which the Ant decides the next hop without taking into account the link pheromone level, i.e., all possibilities have the same chance of being chosen. Therefore, before applying the transitional rule, the Ant may decide which rule to use. This first choice is also done statistically, where each rule has the same chance of being chosen.

Equation 2 below illustrates the reinforcement of pheromone [l], i.e., illustrates how the level of pheromone is updated. When an ant reaches the node, it updates the pheromone level. Assume that $\Delta\tau^k$ is a constant and represents the pheromone update. This is one of the system parameters.

$$\tau_{ij} \leftarrow \tau_{ij} + \Delta\tau^k \qquad (2)$$

To update the table, the current node assumes the Ant MAnt source node as target and changes the registry corresponding to it. If the Ant arrives to the current node it implies that there is a route from the current node to the source node of the Ant Mant.

Based on the natural behavior of ants, periodically, the pheromone levels change because the evaporation. This allows the choices to be more diversified and that new solutions are found as shown in Equation 3 [l]. The pheromone level is reduced by ρ percent.

$$\tau_{ij} \leftarrow (1-\rho) \cdot \tau_{ij} \text{ , } \forall (i,j) \in A \qquad (3)$$

where ρ is a constant responsible for the pheromone evaporation level in the links. Along with α and β, 1 equation coefficients, ρ is also a parameter of the AntOBS algorithm presented below.

B. Initialization Phase

Table I below illustrates the structure of a routing table protocol. The nodes have their probabilities of being selected, represented by the column pheromone and, according to the target column, the next hop is chosen. Initially, only the neighbors are known. Ants add and update new rows in the table, thus new routes become available which will be used by control packets and by bursts of data.

TABLE I. PHEROMONE ROUTING TABLE PROTOCOL

Target	Next Hop	Hops Number	Pheromone
N_1	N_1	0	P^i_1
N_2	N_2	0	P^i_2
N_3	N_1	1	P^i_3
...	...	...	...
N_n	N_2	2	P^i_n

After the simulation start, each node i send an ant IAnt through broadcast to its neighbors. This operation creates new registries and values of the nodes routing tables. A node j, intermediate between the source and target Ant nodes, creates a new registry in the routing table. The node j interprets the IAnt source address as the target address and the previous node's address as the next hop, and then initializes the value of the pheromone in the link e_{ji}. Finally, the node updates the value of the field number of hops and the Ant IAnt is forwarded to its neighbors.

Fig. 1 below illustrates the IAnts behavior. In Fig. 1 (a), the node 0 launches two ants IAnt, one for each neighbor. Then they create a new entry in the routing table with the node 0 as a target and also save the link of the Ant arrival as outbound link to node 0. When nodes 3 and 4 receive Ant respectively from node 2 and 1, Fig. 1 (b), they will create a new entry in the routing table with the node 0 as a target with the respective node as an output.

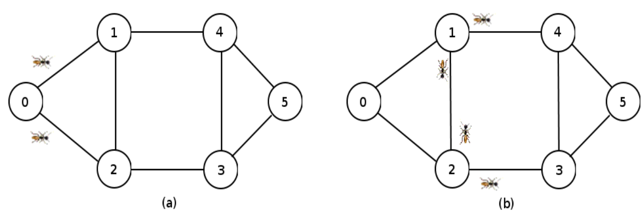

Figure 1. IAnt search and routing behavior

After the end of this phase, all routes have the same probability; therefore, they have the same level of pheromone. Thus, it is necessary that the routes are optimized. This is accomplished through the ants MAnt behavior.

C. Maintenance phase

MAnt ants are responsible for maintaining the routes updated. They circulated through the network updating pheromone levels of links. Periodically, the nodes send the MAnt ants with random targets. The frequency of release of MAnt is a parameter and will be shown later.

When a given node i receives an ant MAnt it can be either the ant target or an intermediate path node to the target. The steps in each of the cases are described in the algorithm below.

Algorithm1 ReceiveMAnt (pkt)

```
if myaddress != pkt.dst address then
    if pkt.T T L == 0 then
        exclude (pkt)
    end if
    add entry route table (pkt)
    update pheromones ()
    next hop ← transition rule ()
    new pkt ← pkt
    new pkt.hops++
    new pkt.T T L −−
    new pkt.dst address ← next hop
    send (new pkt)
else
    update pheromones ()
    exclude (pkt)
end if
```

The MAnt behavior differs from the real ant behavior, because the real ant traverses the path nest-food and goes back using the same path. In the case of ant MAnt, this only makes a one-trip path. This decreases the overhead caused by the use of ant on a network.

In AntOBS, the BCP is only a user of the data generated by the ants, it means, ants create and update the routing tables and the BCP uses the data in these tables.

The process of routes maintenance by the ants happens along the normal use of the network. The main benefit of this use is to ensure that the routes are always in accordance with the current state of the network.

D. Resources saving and Burst sent

The ants start and update the routing tables of the network. However, the BCP uses these routes designed to reserve themselves for the burst sent. The behavior of the BCP is shown below.

On the edge router, the BCP is created. According to the level of pheromone, the next hop is chosen. In this case, the choice is probabilistic, which gives a possibility of diversification in the solution. Soon after, an available wavelength is chosen through First-Fit algorithm [1].

When the BCP leaves the edge node, it acts according to the steps below:

1. Choose the next hop in the routing table taking into account the level of pheromone. This choice is not probabilistic, is based on the highest level of pheromone. Due to the calculation of tuning time, the BCP should not change the number of hops in the path. This could cause a burst blocking;
2. According to the next hop, the possibility of saving the wavelength set in the edge node:
    - If possible:

Set the saving;
Send the BCP;

- If not possible:
    - Return to step 1 to select a second option to the next hop;

E. Example of burst blocking

Based on Figure 1 and Table 1 structure, suppose there is a burst to be sent from node N_0 to node N_4. There are two possible ways. The first possibility is N_0-N_1-N_4 and the second path is N_0-N_2-N_3-N_4.

As described in the previous section, assume that the BCP choose N_1 as the next hop. After that, choose the wavelength λ_1. Then the BCP is sent from the N_0 to N_1.

If N_1 is checked that no wavelength is available for N_4, then the reservation of wavelength λ_1 is not performed and therefore burst blocking will occur.

III. Related Work

Many research proposals apply computational intelligence techniques to solve the routing problem in networks. Among these techniques there are: genetic algorithms (GA) [11], ant colonies optimization (ACO) [3, 4, 12], particle swarms optimization (PSO) [13].

Techniques using ACO to solve problems in optical networks, including OBS networks, have been proposed in the literature, but there are some deficiencies which in some cases may compromise the network operation. Some studies are discussed below.

In [12], ACO was used to solve the problems of RWA and recovery dynamically. In this work, the source node sends the BCP to the target with the goal of reserving resources for the next coming burst. Initially, as the levels of pheromone (routing tables) has not been started, each hop path is chosen randomly. When the target node receives the BCP, it means, when the reserves for the burst are effective, the target node responds to the source one with a message that travels the opposite way, updating the pheromone levels of intermediate. Thus, all other control packets take into account the level of pheromone for choosing a path to the recipient.

To achieve this stage, two types of control packets are used: BCP-REQ and BCP-ACK. The first packet type BCP-REQ reserves resources along the path from source to destination. The second packet type BCP-ACK returns from target destination to the source updating pheromone levels of intermediate switches. BCP-ACK travels the same path as BCP-REQ, changing only its way.

This solution results in unnecessary overheads and, according to the simulations made in the study, in some cases the problem is not solved satisfactorily. For example, when the network goes down or it does not send bursts successfully, even for a moment, this kind of problem leads to a situation in which the levels of pheromone does not represent the current network state. In this solution, the routing tables are well set only if there is traffic in the network, since the control packet plays the role of setting. It is necessary, therefore to have, the existence of bursts in order to have a smooth optical network operation and configuration. If the routing tables are not close to the ideal setup, many bursts may be lost.

This problem does not happen in the purpose of this study. There is no connection with the ants, the burst and the control packet, that is, the routing tables do not depend on the existence of bursts to be setup. The ants are responsible for configuring routes and are independent of the data plan and control package.

In [14], a solution to the problems of routing and wavelength assignment in WDM optical dynamic networks using ACO is presented. In this work, the ants act separately from the control packet and feed two types of routing tables: one table stores the complete routes in the border and another table stores the routing data in core nodes that have the pheromone levels.

The approach proposed in this article differs from the previous work in some aspects. The first one is that the AntOBS uses a single routing table. Another difference is that the AntOBS stores and considers the number of collisions on the node to update of pheromone, to ensure routing table is updated according to real data from the network operation.

IV. Simulations and Results

This section presents the results obtained in simulations to test the performance of routing AntOBS algorithm, comparing to the algorithm called Pure OBS, a routing algorithm in OBS networks that is not based on Ant Colony and uses the shortest path strategy. This algorithm is based on Dijkstra's algorithm [15]. The simulations were made using the Ubuntu operating system and the Network Simulator 2 (NS-2). The NS-2 is a discrete event based simulator, widely used in research on computer networks. The process of generating traffic is stochastic and follows the Pareto distribution. The algorithm parameters were set according to Table II below and were chosen taking into account the simulations made during the work.

TABLE II. ALGORITHM PARAMETERS USED TO TEST ANTOBS' ROUTING PERFORMANCE

Parameter	Value
α (Importance of pheromone level)	0.5
β (Importance of number of collisions)	0.5
ρ (Evaporation level)	0.4
Δ (Increase pheromone update)	0.6
Mant Ant Creation frequency	0.6 s

During the simulations two topologies were used. Fig. 2 shows the topology of a small test network with six nodes, called topology 1. Fig. 3 shows a topology similar to the network NSFNET with fourteen nodes.

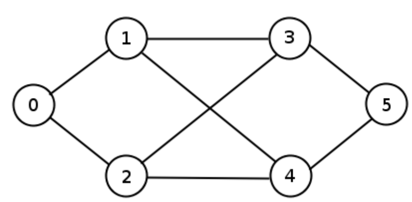

Figure 2. Simulation network topology of test 1

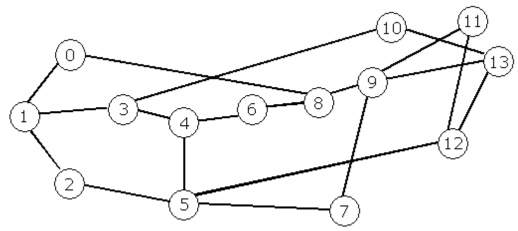

Figure 3. Simulation network topology of test 2

A. Topology of test 1

In the first tests, the network represented by Fig. 2 is used, where two scenarios were used. The first scenario has 6 available wavelengths on each link and the second has 10 available wavelengths on each link. The amounts of wavelength in each scenario were determined taking consideration the simulations done.

Fig. 4 shows the graph of the probability of blocking performance behavior of new AntOBS versus Pure OBS algorithms as a function of load on the network using six wavelengths, with. Not surprisingly, with low loads, the blocking probability rate is substantially lower than in high loads. Due to the reduced number of wavelengths, with high loads the network enables a high burst probability of blocking.

It is also possible to realize in the graph that the probability of blocking of the algorithm AntOBS is smaller than to the Pure OBS algorithm, a routing algorithm in OBS networks that uses the shortest path strategy. The probability of blocking is shorter, mainly from 18 Erlangs on. The congestion generated by the load increasing on the network is the main cause of this difference. Although with this increased workload, the dynamicity of the AntOBS ensures that the best routes will be chosen taking into account the current network status, preventing the block bursts.

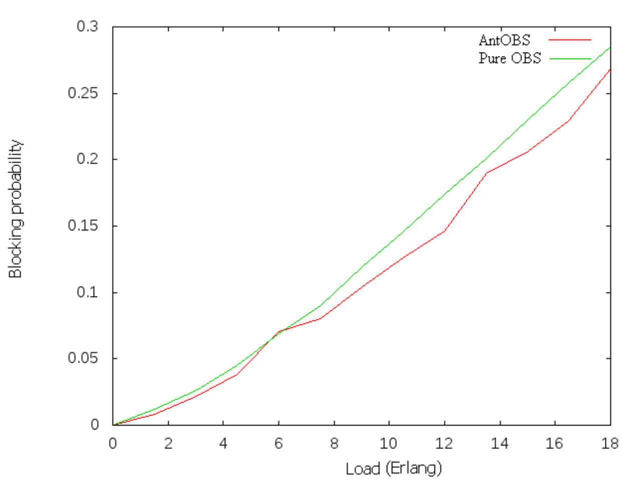

Figure 4. Blocking burst probability performance behavior of new AntOBS versus pure OBS algorithms in topology 1 test with 6 wavelengths.

Fig. 5 shows the graph of the blocking probability as a function of load of the optical Network using topology 1 (see Fig. 2), in which 10 wavelengths are available. The increase in the number of wavelengths obviously decreases the blocking probability in both cases, but the AntOBS continues with the fall of it in both scenarios.

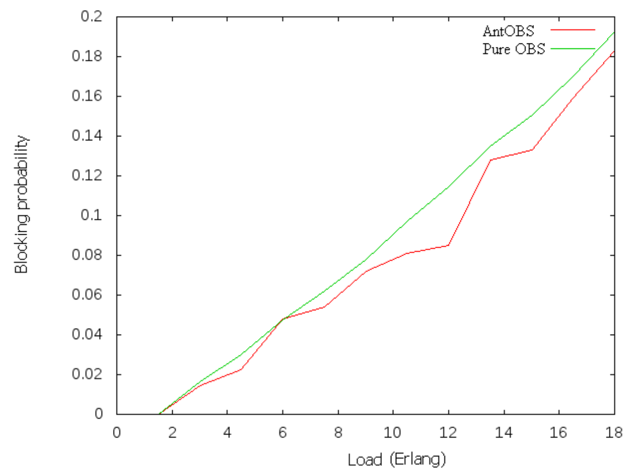

Figure 5. Blocking burst probability performance behavior of new AntOBS versus pure OBS algorithms in topology 1 test with 10 wavelengths.

B. Topology of test 2

Two scenarios have been defined for the second topology again: with 8 and 12 wavelengths, respectively.

Fig. 6 shows the comparison between the AntOBS and Pure OBS algorithms, illustrating the blocking graph as a function of the network load with 8 wavelengths available.

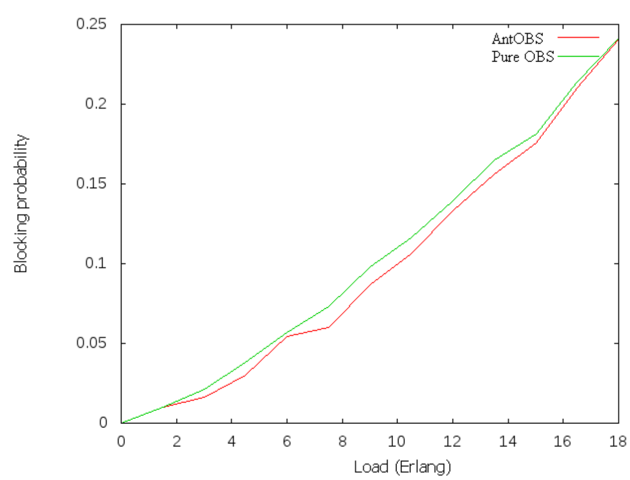

Figure 6. Blocking burst probability performance behavior of new AntOBS versus pure OBS algorithms in topology 2 test with 8 wavelengths.

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The graph behavior shows again a performance improvement of AntOBS over Pure OBS, allowing a decrease in the probability of blocking, in the same scenario of 18 Erlangs load.

Fig. 7 compares the algorithms AntOBS and Pure OBS, using a topology similar to the network NSFNET with 12 wavelengths. In this scenario, once again the AntOBS had the blocking probability less than the Pure OBS.

It is possible to notice that in simulations in this topology, when in high loads, the behavior of algorithms is very close. However, despite having similar performances it is possible to see that in almost all scenarios the AntOBS had better performance, and the efficiency of AntOBS in relation to the Pure OBS could be proved, since any blocking on optical networks can lead to loss of high amounts of data, mainly in OBS networks which work in bursts.

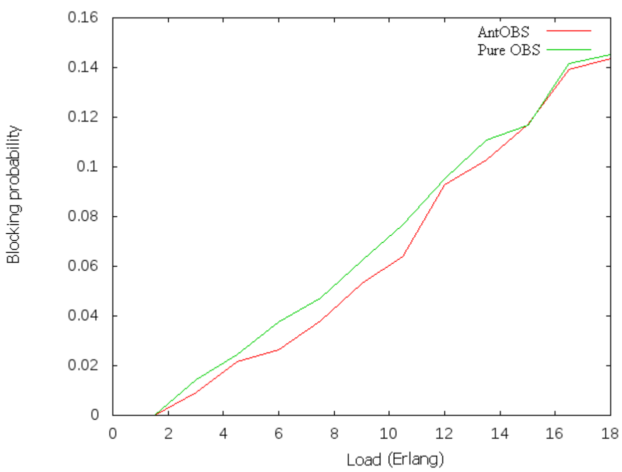

Figure 7. Blocking burst probability performance behavior of new AntOBS versus pure OBS algorithms in topology 2 with 12 wavelengths.

Comparing the results of the topology simulations, topology 2 (see Fig. 3) results showed a minor difference between the performances of two algorithms. This is caused by the greater number of nodes of topology 2, which requires a greater number of updates of routing tables, i.e., it decreases the AntOBS performance.

V. Conclusion and Future Works

This work proposed an algorithm, called AntOBS, aimed in decreasing the blocking probability in OBS networks, taking into account that traffic in this type of network is done in bursts and that blocking can lead to loss of an excessive amount of data. This solution is based on adaptive behavior of an Ant Colony.

One important solution presented concerns the possibility of AntOBS to treat the problem of Adaptive RWA, through changes in the routing tables provided by ants, a route can be changed in case of a link failure.

In terms of signaling, the cost of AntObs Algorithm was small. During the simulations no ant or BCP were lost.

For a future work, another type of Ant can be inserted into the network to do new tasks in the optical network, for example, to check the link status periodically. Other signaling protocols can be tested such as JIT, which explores the immediate saving; in order to compare to the results of this work which used the JET.

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