An Ant-Based Algorithm for Distributed RWA in Optical Burst Switching

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ABSTRACT
To meet the demanded bandwidth requirements of future optical communication networks, more dynamism, scalability and automatism will need to be provided, which will require, as well, new control plane designs to respond to network changes very rapidly. In this work, we propose the use of an ant colony optimization (ACO) algorithm to support the routing and wavelength assignment in wavelength continuity constraint optical burst-switched networks. The main advantage of the protocol is its distributed nature, which provides higher survivability to network failures or traffic congestion. From the results we see that the new protocol responds effectively to congestion while at the same time providing better performance in comparison to the shortest path routing with random wavelength assignment.
Keywords: optical burst switching (OBS), ant colony optimization (ACO), distributed RWA.

1. INTRODUCTION

With the rising in the late 90's of the Wavelength Division Multiplexing (WDM) technology, the channel capacity of the optical communication networks has been increased by several orders. Nonetheless, these networks have been somehow static and fixed. Whilst the fixed characteristic has to do with the absence of node mobility, the static feature of nowadays networks is more a technological constraint than a physical constraint. Currently, the provisioning of communication channels in Optical Circuit-Switched (OCS) networks is done per connection, which is somewhat inefficient.

Optical Burst Switching (OBS) [1] and Optical Packet Switching (OPS) [2] are such two optical network technologies that offer statistical multiplexing capabilities. Nevertheless, due to the lack of efficient optical buffering techniques and the use of one-way reservation, contentions may occur in the in these two technologies.

Bursts and packets are quite short in comparison to the reserved traffic flows that OCS treats, thus the network becomes more dynamic and flexible, which requires to run agile algorithms in the provisioning process. As well as that, the networks can grow to dozens or maybe hundreds of nodes, hence making necessary efficient distributed algorithms. In this field, the routing and wavelength assignment (RWA) is one of the main issues in optical networks, especially under wavelength continuity constraint.

In this article we deal with a specific autonomous bio-inspired algorithm to cope with the dynamic characteristic of future optical networks, and in particular, for the OBS case. Ant Colony Optimization (ACO) [3] comprises a set of algorithms used for the optimization of several problems. In essence, ACO algorithms try to emulate the biological behaviour of ant colonies on their task of foraging for food.

The use of ant-based algorithms is not new in WDM networks. In particular, in [4] the authors introduce the use of ACO to solve the dynamic RWA in a wavelength-routed network scenario. Regarding the implementation of ACO algorithms in OPS, Pavani and Waldman [5] present an ant-based protocol to support the traffic engineering and restoration processes in OPS networks. However, the implementation is restricted to a scenario with full-wavelength conversion capability. The first and only work about ant-based algorithms in OBS networks is [6], where Shi et al. present a protocol that uses forward and backward control packets. Nevertheless, they only use the algorithm to search for the best paths, not taking into account the wavelength selection, which is done randomly as the authors suppose full wavelength conversion in the network.

In this article we contribute on two main aspects: (1) we apply ant-based algorithm into the RWA process of the OBS network with wavelength continuity constraint; and (2) we extend and adapt the conventional path-scoring methods of ACO algorithms using both switching congestion information and path length.

The remainder of the paper is organized as follows. Section 2 presents our protocol proposal whereas section 3 is devoted to its analysis through simulations. Finally, section 4 summarizes the main conclusions of the paper.

2. ANT COLONY RWA FOR OPTICAL BURST SWITCHING

In this section we introduce the proposed RWA scheme: Ant Colony Routing and Wavelength Assignment (ACRWA). ACRWA is based on the Ant Colony System (ACS) algorithm by Dorigo *et al*. [3]. An advantage of using the proposed architecture is that the routing and wavelength assignment is now totally distributed.

We have chosen to implement the forward ant functionalities into the Burst Control Packet (BCP), and the feedback ants are acknowledgement BCPs (BCP-ACKs). We should note that, these BCP-ACKs are not used to setup the reservations after a positive ACK. The provisioning scheme still uses one-way reservation.

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In ACRWA, the wavelength selection uses the same pheromone tables like in the ant (burst) forwarding. In our case, the algorithm chooses the lambdas and output ports following the same state transition rule from equation 1 (which will be described in detail later), but taking into account that the input port is the node itself. Nonetheless, to emphasize the use of shorter paths, we may change the value of β on the initial wavelength assignment.

Finally, using the ACRWA scheme, the end-to-end path from the origin OBS node to the destination OBS node is not known a priori, which makes the offset time calculation difficult. We choose to implement an offset-time-emulated approach [7], so that offset can remain constant during the burst delivery. A Fiber Delay Line (FDL) at each input port of the OBS switch is used to compensate the incurred processing delay of the BCP.

In the following subsections, the rules and notation of ACRWA are given.

2.1 Pheromone trails

In our protocol, the pheromone concentrations, which are stored in a pheromone table, $\tau_{i,j,k}$, are computed according to two types of information. The first type is the congestion level, which is a measure of the number of contentions through a specific output port. The higher the number of contentions, the lower the pheromone deposition should be. And the second is the path length. The shorter the path, the greater the pheromone amount through a given output port shall be, hence we favour paths that imply less consumption of optical resources. Regarding the sub indexes of τ: i is the input port, j represents the output port, and k is the wavelength switched.

In comparison to other ant-based algorithms for WDM networks, in our case, the number of free wavelengths is not longer a good measure for the congestion level due to the absence of wavelength converters in our network nodes, i.e. following the wavelength continuity constraint.

In the election of the output port, ACS also provides an extra value, called desirability and represented by η. This value gives heuristic information about the attractiveness or desirability of a certain move, for example, in case where the mean distance (or cost) of paths shall be minimized.

2.2 State transition rule

The state transition rule is used to choose the next hop in the routing of the ant (burst) towards its destination. The aim is to select the best j output link taking into account that the data is going to be switched from the i input link over wavelength k. The chosen transition rule is a pseudo-random-proportional action rule [3] developed to explicitly balance the exploration and exploitation abilities of the algorithm to look for a suitable path.

A forward ant located at a node n, selects the next node j (or output port) using equation 1,

$$j = \begin{cases} \arg\max_{u \in N_n^m(t)} \left\{ \tau_{i,j,k}(t) \eta_{nj}^{\beta}(t) \right\} & \text{if } r \leq r_0 \\ J & \text{if } r > r_0 \end{cases} \tag{1}$$

where $r \sim U(0,1)$ and $r_0 \in [0,1]$ is a user-specified parameter to balance between exploitation (if $r \leq r_0$) and exploration ($r > r_0$). β is another user-specified parameter that controls the potential benefit of choosing the output link j with a desirability value of η_{nj}. N_n^m is a candidate list of nodes (ports) to forward the data with destination node m avoiding loops or output links for which there is no route to reach the destination. This list should be filled using a support common routing protocol (e.g. Dijkstra). $J \in N_n^m(t)$ is a node randomly selected according to an integer empirical distribution using equation 2 probabilities,

$$p_{iJ}^{k}(t) = \frac{\tau_{i,J,k} \eta_{nJ}^{\beta}(t)}{\sum_{u \in N_n^m} \tau_{i,j,k}(t) \eta_{nj}^{\beta}(t)} \tag{2}$$

2.3 Global updating rule

The global updating rule is executed by feedback ants, which carry information about the successfulness of the data delivery. They use the reverse path and on its way back to the data origin update the pheromone trails using equation 3. In contrast to ACS, all feedback ants are allowed to reinforce/weaken pheromone concentrations.

$$\tau_{i,j,k}(t+1) = (1-\rho_1)\tau_{i,j,k}(t) + \rho_1 \gamma_{i,j} \Delta\tau_{i,j,k} \tag{3}$$

ρ_1 is again a user-specified value. If ρ_1 is small, then the pheromone concentrations evaporate slowly, and if it is greater, the previous experience (pheromone) is neglected in favour of more recent experiences. $\gamma_{i,j}$ is a value that depends on the successfulness of the ant (data) reception and if the output link is part of the path, $x^m(t)$, travelled by the ant.

$$\gamma_{ij} = \begin{cases} +1 & \text{if } link(n,j) \in x^m(t) \quad \text{and } success = true \\ -1 & \text{if } link(n,j) \in x^m(t) \quad \text{and } success = false \\ 0 & \text{if } link(n,j) \notin x^m(t) \end{cases} \tag{4}$$

The amount of new pheromone deposited by the returning ant is calculated assuming an ant-cycle implementation, where pheromone deposits are subject to exponential decay, that is, the deposit decreases at a rate proportional to a given value. In our case, this value depends on the length of the path followed by the ant,

$$\Delta\tau_{i,j,k} = e^{-\omega\Delta l} \quad (5)$$

where $\Delta l = |x^m(t)| - |x^+(t)|$, being $|x^m(t)|$ the length of the path followed by the returning ant so far, and $|x^+(t)|$ the length of the shortest path to the destination from the current node that processes the feedback ant. Thus, if the route followed to reach the destination is the shortest (or equivalent) and the reception of the ant (data) is correct, $\Delta l = 0$ and $\Delta\tau_{i,j,k} = 1$, depositing the maximum amount of pheromone. ω is the decay constant; the higher its value, the faster the exponential vanishes. Therefore, ω can be used to control the amount of deposition.

2.4 Local updating rule

The main goal of this rule is to diversify the search performed by consecutive ants and probabilistically restrict or favour the use of certain output links during the data switching. The local updating rule is only applied after a successful switching reservation and before forwarding the ant to the next node towards the destination. For the output port where the reservation has been scheduled, the pheromone trail is updated as follows,

$$\tau_{i,j,k}(t+1) = \tau_{i,j,k}(t) + \alpha_1 e^{-\phi\Delta l} \quad (6)$$

and for the rest of the output links of the node entry set N_n^m, the following formula is executed,

$$\tau_{i,j,k}(t+1) = \tau_{i,j,k}(t) - \alpha_2 e^{-\phi\Delta l} \quad (7)$$

Here, α_1 and α_2 are two more user-specified parameters. α_1 and α_2 can have different value, although in the results section we set them the same. Φ is the decay constant and it has the same meaning as ω in equation 5.

3. NUMERICAL RESULTS

The protocol has been evaluated through simulations over two network scenarios. The first one is the fish-like network scenario composed of 8 OBS nodes shown in Fig. 1, which is used to test the operation of ACRWA, and the second scenario is the well-known NSFNET network with 14 nodes and 21 links of Fig. 2, which serves us to evaluate its performance in a more realistic scenario. In all the scenarios, we assume a wavelength capacity of 10 Gbps, a BCP processing time of 10 µs, a switch fabric configuration time of 5 µs, and no wavelength conversion. The numerical results given in this section have been averaged from 30 simulations.

ACRWA parameters ω and Φ are fixed to 0.75 throughout all simulations. The rest of parameters (*r0, ρ1, α1, α2* and *β*) may vary in order to analyze how their values influence the performance of the protocol.

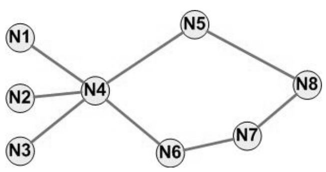


Figure 1. Fish-like network.

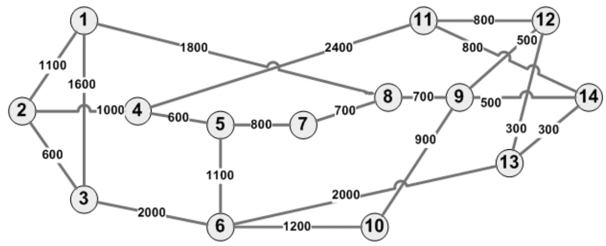


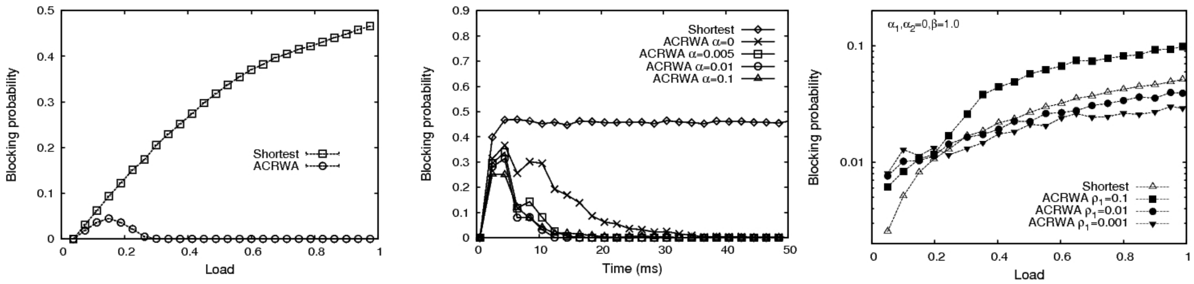
Figure 2. NSFNET network.

3.1 Simulation results in the fish-like network

Our goal here is to specifically validate the protocol operation when three huge traffic flows are transmitted from three different traffic sources (*N1*, *N2* and *N3*) and need to be switched at a node (*N4*) to reach a common destination (*N8*) through two possible routes and a number of wavelengths. To make easier the analysis of the protocol, we limit the case space using only 2 wavelengths. We compare the performance to shortest path routing with random wavelength assignment (hereafter, named S+R). In here, burst length is fixed to 19,000 bytes.

Figure 3 a shows the performance of the protocol against S+R as a function of the offered traffic per wavelength. In this case, we start the simulation with an empty network. Then, we add at 50 ms steps, three new traffics from N1, N2, and N3, each one of 0.025 Erlangs, until we fill the capacity of the two wavelengths. Here the parameters values are: $\alpha_1 = \alpha_2 = 0.01$, $\beta = 0.75$ and $\rho_1 = 0.1$. We can see how in the S+R case, the burst blocking probability increases for the entire load range. On the contrary, in ACRWA, after an initial period of time within ants (BCPs) forage for the best route-lambda, the protocol responds to the congestion at N4 and cancels the contentions even when the traffic load increases. This behaviour is shown in Fig. 3 b where the burst blocking probability is plotted as a function of time (ms) for the same network scenario, but with a fixed offered load per wavelength of 0.9 Er. In this case $\beta = 0.25$ and $\rho_1 = 0.01$, whereas $\alpha_1 = \alpha_2 = \alpha$ vary throughout different simulation runs. In the first stages, ACRWA experiences some blockings as the pheromone tables have just been initialized.

However, after this initial ant foraging phase, blockings are cancelled. We should note also the behaviour between different $\alpha_1 = \alpha_2 = \alpha$ values. Incrementing the value of the alphas implies a bigger increment/decrement of pheromone values using the local updating rule, which remarks/restricts more quickly the paths and wavelengths to avoid burst congestion.



(a) (b) (c)

Figure 3. Simulation results: (a) Burst blocking in fish-like network, (b) Burst blocking in fish-like network varying α_1 and α_2 with ρ_1=0.01 and β=0.25, and (c) Burst blocking in NSFNET with α_1,α_2=0 and β=1.0.

3.2 Simulation results in NSFNET

In this section, we evaluate the performance of ACRWA in a more realistic environment. We use the NSFNET with 8 wavelengths per link and a capacity of 10 Gbps per wavelength. In this trial, the burst threshold is 50,000 bytes, and traffic flows are uniformly distributed between any pair of network nodes. Figure 3c shows the burst blocking probability as a function of the offered load per wavelength. As shown, results greatly depend on the ACRWA parameter setting. Whilst $\alpha_1 = \alpha_2$ are fixed to 0, and β = 1.0, ρ_1 varies between runs. When ρ_1 = 0.1, we get the poorest result, even worse than the S+R case. However, as we decrease ρ_1, we see that the performance is improved up to a 50 – 60% regarding the shortest path protocol at high loads. This is due to the fact that at $\alpha_1 = \alpha_2 = 0$, the local updating rule is not applied, and all the pheromone concentration updates rely on the global updating rule, which in the case of decreasing ρ_1 gives more importance to past knowledge, so that the exploitation of the pheromone deposits is emphasize. Besides, in NSFNET, under a uniform traffic pattern without network failures and without wavelength conversion, the better performance is obtained when the routing tends to use the shortest paths, that is, when ρ_1 is lower, we exploit more the performance of the past experience instead of giving more importance to the exploration capacities of ACRWA.

4. CONCLUSIONS

Future optical networks will be particularly different to the networks known so far, demanding for more dynamism, scalability, robustness and autonomous capacities. In this paper, we have applied successfully an Ant Colony Optimization (ACO) algorithm to improve the performance of the Routing and Wavelength Assignment (RWA) process in an Optical Burst-Switched (OBS) network with wavelength continuity constraint. The algorithm takes into account both, the length of the routes and the congestion in the network to update the values of the pheromone trails. Initial results are quite promising, and outperform in some cases the random wavelength selection with shortest-path routing. Nonetheless, care must be taken on setting the parameters values, as these greatly involve in the network performance.

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