The Minimum Coincidence Routing in Optical Networks[1]

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Abstract: In optical networks routing is often decoupled into both the path selection and the wavelength assignment problems. Shortest path based algorithms are usually applied to compute paths. Although the main advantage of such algorithms is that network is not unnecessarily loaded, the main weakness is that routes are selected without taking into account any parameter related to the desired service guarantees. Under this limitation, the wavelength assignment process must assign a wavelength on a path that might not be the optimum according to the incoming traffic requirements in terms of the desired degree of service. This positioning paper aims to address the lightpath selection problem proposing a new concept to select routes based not only on minimizing the number of hops but also on balancing the network load, hence reducing both the network congestion and the blocking probability.

Keywords: Routing and wavelength assignment, routing inaccuracy, prediction-based routing

1. INTRODUCTION

In recent years the introduction of high capacity and reliable transport networks has become necessary in order to cover Internet traffic demands. New Internet applications increasingly request greater capacity and guarantees of traffic delivery in such a way that the traffic transmission model must be modified. An Optical Transport Network (OTN) consists of switching nodes (Optical Cross-Connect, OXC) interconnected by wavelength-division multiplexed (WDM) fibre-optic links that provide multiple huge bandwidth communication channels over the same fibre in parallel. A wavelength routed WDM network is a circuit-switched network, in which a lightpath must be established between a source-destination pair before data can be transferred. A lightpath is an end-to-end connection between a source-destination node pair, which may span multiple fibre links and use a single or multiple wavelengths. When the OTN includes automatic switching capabilities, it is referred to as an Automatically Switched Optical Network (ASON). ASON must include a Control Plane, necessary to provide the network with dynamic provisioning, fast protection, restoration and Traffic Engineering. The IETF proposed Generalized Multi-Protocol Label Switching (GMPLS) as a protocol to implement this Control Plane. This Control Plane includes a centralised or distributed lightpath control mechanism to efficiently set up and tear down lightpaths. In the centralised case, a single central controller having complete global network state information sequentially selects and establishes a lightpath for any incoming request. In the distributed case (see also Figure 1), the different network nodes simultaneously process the incoming connection requests. Lightpaths are selected based

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on either local (the nodes do not have information about the whole network) or global network state information. On one hand, if the routing decision is taken based on local information the probability that the set-up message will be rejected at any intermediate node is very large. On the other hand, using global network state information (e.g., the link-state database that each node constructs in step 1c in Figure 1, based on the received link-state packets in step 1b) reduces the blocking probability, whenever this information represents a current picture of the network state. An update mechanism must be included in the routing protocol to guarantee that the path selection process is performed based on accurate network state information: for example, in step 1a in Figure 1, each node first filters the link-state updates in order to select only those link-state packets needed by the other nodes to construct a link-state database that accurately represent the actual network status. Due to scalability concerns, most lightpath control mechanisms, recently proposed in the literature, use distributed mechanisms based on source-routing: in Figure 1, the source node A calculates the route (step 2a) and assigns the wavelength (step 2b) to the connection AE, before it actually starts the signalling process for setting up the connection. Under this constraint, end-to-end routes are computed at the source nodes depending on the network state information allocated in their network state databases. This assumption introduces a potential problem, in the most recent literature often referred as the routing inaccuracy problem. The routing inaccuracy problem or thus selecting routes based on outdated network state information may significantly impact the global network performance.

The remainder of this paper is organized as follows. In Section II the main Routing and Wavelength assignment mechanisms concepts are described and the problem

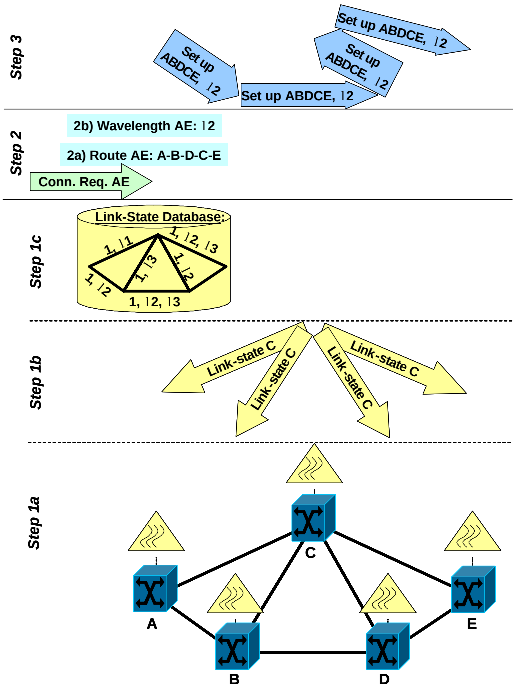

Fig.1. Principle of source-based link-state routing: Step 1a) each node filters link-state updates; Step 1b) flood link-state packets; Step 1c) each node constructs LSDB; Step 2) RWA; Step 3) Signal the set-up of the connection

addressed in this paper is stated. Then, in Section III the proposed solution is described and in Section IV is evaluated. Finally, Section V concludes the paper.

2. THE RWA PROBLEM

Unlike a traditional IP/MPLS scenario where the routing process only looks for the optimal route, in WDM networks the Routing and Wavelength Assignment problem (RWA) [1] must find both the physical nodes and links that configure the lightpath (routing sub-problem: i.e., step 2a in Figure 1), and the wavelengths to be used on all the links along the lightpath (wavelength assignment sub-problem: i.e., step 2b in Figure 1). This has to be done in such a way that the network resources are utilised optimally. Therefore, there are two steps involved in the lightpath establishment process. Firstly the network must select a route for the connection, and secondly reserve a suitable wavelength on each link along the selected route.

2.1 Routing in Optical Networks

Concerning the routing sub-problem (i.e., step 2a in Figure 1), the existing routing algorithms can be classified into two classes: static and dynamic. While static routing considers that a route from a source node to a destination node is selected off-line, in dynamic routing a route from a source node to a destination node is selected dynamically reacting to an incoming connection request, depending on the current network state. Two routing approaches have been proposed for static routing: fixed routing and fixed-alternate routing. Fixed routing, which is the simplest routing approach, is based on always considering the same route for a source-destination node pair. The shortest-path routing fits in this scenario. In this context, any connection between a particular source-destination node pair always uses the same off-line predetermined path. This approach leads to high blocking probabilities since shortest path links may be congested while longer path links would be under-utilised. This drawback can be reduced by fixed-alternate routing. In fixed-alternate routing multiple routes can be used for setting up a connection between any source-destination node pair. When a connection is requested for a source-destination node pair, a free wavelength is searched according to a certain wavelength assignment heuristic on all the off-line pre-computed routes. If an available wavelength is not found, the incoming connection is blocked. Generally speaking, the main drawback of static routing is that routing decisions are taken without considering the current network state. This weakness is addressed by the dynamic routing where routes are dynamically selected based on the current network sate. The Least-Congested Path Routing (LCP) [2][3] selects the least congested route among a set of pre-computed routes, to accommodate the incoming connection. Congestion is measured in terms of available wavelengths so that links with fewer available wavelengths are considered to be more congested. Therefore, the route with more available wavelengths is selected to establish the path. When a connection is requested for a source-destination node pair, a route from this set of pre-computed routes must be selected and then an available wavelength must be assigned to this route according to a certain wavelength assignment heuristic. As a summary we can say that approaches based on fixed routes reduce the complexity, but unlike dynamic routing approaches may suffer from higher connection blocking and thus degrading the global network performance. On the other hand, fixed-alternate routing offers a trade-off between computing overhead and network performance.

2.2 Wavelength Assignment in Optical Networks

Once a route is selected for a source-destination node pair, a distributed reservation protocol must be used to reserve the proper wavelength on each link along the selected path (see also step 2b in Figure 1). A large number of different heuristics has been proposed in the literature for the wavelength assignment sub-problem, such as Random, First-Fit, Least-Used, Most-Used, Min-Product, Least-Loaded, Max-Sum, Relative Capacity Loss and Protecting Threshold. Each of them can be combined with different routing mechanisms to establish the lightpath.

In general the RWA is addressed differently depending on the availability of wavelength conversion capabilities. Wavelength routed networks without wavelength conversion are known as wavelength-selective (WS) networks (for instance the example in Figure 1). In such a network, a connection can only be established if the same wavelength is available on all the links between the source and destination nodes (wavelength-continuity constraint). This may cause a high blocking probability. Wavelength routed networks with wavelength conversion are known as wavelength-interchangeable (WI) networks. In such a network, each router is equipped with wavelength converters so that a lightpath can be set up using different wavelengths on different links along the route. If a wavelength converter provides the ability to translate any input wavelength to any output wavelength, i.e., full range conversion, and every node of the network includes a wavelength converter, the network is defined as having full wavelength-conversion capabilities. In this case, the network is equivalent to a circuit switched network, where only the routing subproblem must be considered. However, the cost associated to provide a wavelength converter at every node is currently not affordable. Therefore, other solutions based on limiting the global wavelength conversion in a network appear to design a WI network. There are three main issues to be considered. First, the global conversion capability may be reduced by having only a few nodes with conversion capabilities, i.e. sparse conversion, modeled by the conversion density q of the network. Second, converters may be shared among various output ports of a node. Third, the range of wavelength conversion is limited to a fixed value K, defining the translation degree D as

$$D = \frac{100\,K}{\Lambda - 1} (\%) \tag{1}$$

where Λ is the total number of wavelengths on a link.

In this way an input wavelength λ_i may only be translated to wavelengths $\lambda_{\max(i-k,1)}$ through $\lambda_{\min(i+k,\Lambda)}$. It is shown in [3] that a substantial improvement in the global blocking probability can be achieved even when the wavelength conversion range is limited to only 25% of the full conversion range.

Generally speaking, being aware that dynamic routing mechanisms perform better than the static ones, there are two main drawbacks to be considered:

- Traditional dynamic routing algorithms usually select the route maximizing the number of free wavelengths (i.e. free wavelengths distribution) to set up a lightpath, without explicitly considering the length of the routes. This can reasonably be applied to WS networks, since in networks without wavelength conversion capabilities the route with more free wavelengths usually is of shorter length. However, it is shown in [4] that this property is considerably weakened in networks with wavelength conversion capabilities. Therefore, the length of the routes and the wavelength distribution must be jointly considered in the lightpath selection process.

- It is worth noting that despite the fact that dynamic routing mechanisms based on global information perform better than the ones based on local information, they are only suitable for those networks where frequent network state changes are not expected. Therefore, in highly dynamic networks, where this constraint cannot be guaranteed, dynamic routing requires support from the routing protocol to keep updated network state information on the routing tables at the nodes. However, many causes can lead to have outdated routing information. In this case routing decisions might be wrongly performed at the source nodes producing a significant connection blocking increment (routing inaccuracy problem).
- There are many RWA algorithms based on assigning wavelengths through a physical route selected by the shortest-path algorithm. This process is not optimal since the wavelength assignment process is constrained by a hard limitation, i.e, wavelengths can be selected only on a path which has been selected without considering parameters standing for the degree of service required by the client asking for the connection.

The first drawback is, for instance, addressed in [5] where authors propose a weighted least-congestion routing and first-fit wavelength assignment (WLCR-FF) RWA algorithm which substantially reduces the blocking performance obtained by the SP or the LCP algorithms.

In [6] and [7], authors address the routing inaccuracy problem. Authors in [6] propose a RWA mechanism named the Bypass Based Optical Routing (BBOR) mechanism aiming to select that path minimizing the chances to be not available because of being selected under inaccurate network sate information. Besides if the selected path is not available (i.e., the selected wavelength is not available in any of the links belonging to the selected path) at the path setup time, the BBOR mechanism also provides a bypass-path where the setup path must be forwarded in order to reach the destination node and so to establish the connection. In [7] authors propose a mechanism named the Prediction-Based Routing (PBR) aiming to select the path based on predicted information instead on link state information. This predicted information provides the node in charge of deciding the path with information about the chances that feasible end-to-end routes can be available. A significant characteristic of the PBR mechanism is that the need of flooding update messages is almost removed (only messages to keep connections alive are sent).

This paper focuses on the third drawback proposing a mechanism, termed the Minimum Coincidence Routing Algorithm (MICORA), to select the physical paths not only based on the shortest path constraint but also on balancing the network load.

3. A NEW PROPOSAL FOR HANDLING THE RWA PROBLEM

Traditional methods to select paths along the network are based on the Shortest Path First (SPF) algorithm. The SPF algorithm selects the k-shortest routes between the source and destination node pair minimizing the number of hops. The paths are ordered in a list according to the number of nodes. In case that the number of nodes is the same for more than one path, the algorithm selects the path placed in the first position in the list. Figure 2 shows an example of optical network where node 1 is the source node and node 13 is the destination node.

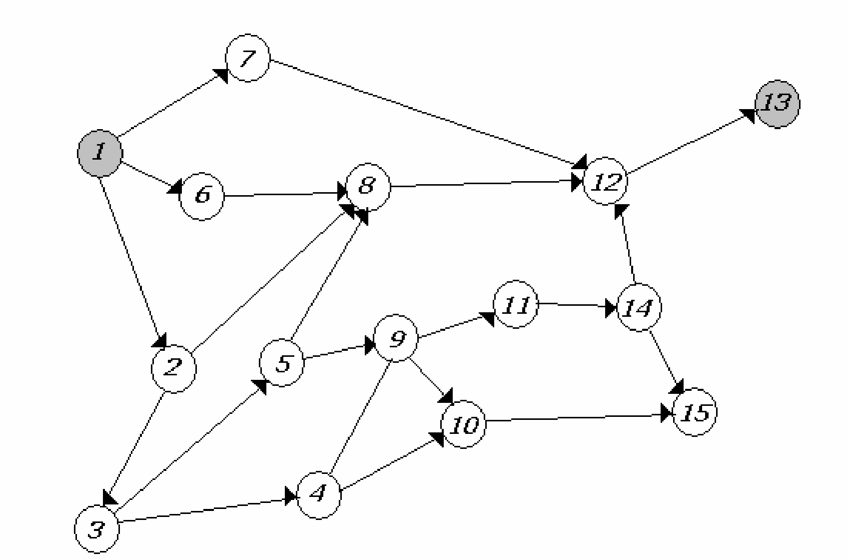

Fig.2. Example of topology

According to the SPF algorithm, when an incoming connection requests a path the algorithm will select the first path in the list whenever this path will be available (i.e. an end to end wavelength is available). Otherwise, the algorithm will select the second route and so on. Notice that we assume an optical network under the wavelength continuity constraint, i.e., the same wavelength must be used on all the links from the source to the destination nodes to transport the required traffic.

If we pay attention on the topology, we can observe that there is a common link, the 12-13 for all the feasible paths between nodes 1 and 13. Besides, some paths will also share another common link (8-12). Therefore, the wavelength assignment algorithm in use should take into account when assigning a wavelength to a route that some links might suffer from a high level of utilization.

Taking into consideration this drawback, we propose a new routing algorithm called Minimum Coincidence Routing Algorithm (MICORA). The MICORA tackles the problem of selecting the suitable end-to-end k-paths where the traffic must be forwarded. Then, a wavelength assignment algorithm will assign the wavelength to one of the paths pre-computed by the MICORA. In order to enhance the route selection the MICORA takes into account the concept of minimum coincidence between paths to balance the traffic load, hence reducing the network congestion. This concept is inferred from the Minimum Interference Routing Algorithm (MIRA) already proposed in [8] to enhance the routing in IP/MPLS networks. The MICORA computes the end to end paths considering the routes that have less shared links and minimum number of hops. In order to maintain a trade-off between the number of hops and the number of shared links, the routing algorithm obtains the k-paths with the minimum number of shared links among them. The MICORA looks for the k-paths in three steps as follows:

Firstly, it chooses the shortest path from the list of feasible paths between the source-destination node pair, already pre-computed and ordered by the SPF algorithm. Secondly, it associates a metric to the shortest routes left. This metric is named Minimum Shared Link (MSL) and is computed according to the following expression

$$\mathrm{MSL} = N_H * S_L \tag{2}$$

where N_H is the number of hops of the particular path and S_L is the number of links shared between the particular path and the path previously selected in the first step. The MICORA selects the path with minimum MSL as the second path. Finally, we repeat this process in order to provide an ordered list of k-paths.

We present below an illustrative example to show the MICORA performance. Assume that an incoming connection reaches node 1 demanding a lightpath to node 13 in the network topology shown in Figure 2. The MICORA should compute the k-paths with minimum coincidences. First, according to the description presented above the first step implemented in the MICORA is to select the first route. This is achieved by choosing the shortest one among the set of shortest routes between node 1 and node 13 computed by the SPF algorithm as shown in Figure 3. We assume in this example that the SPF algorithm computes 5 shortest routes and k = 3.

Shortest paths	*Selected paths*
1-7-12-13	**1-7-12-13**
1-2-8-12-13	
1-6-8-12-13	
1-2-8-5-9-11-14-12-13	
1-6-8-5-9-11-14-12-13	

Fig. 3. Route selection: step 1

Second the MICORA computes the MSL parameter with the rest of the paths and chooses the path with a minimum MSL (Figure 4):

Path = 1-7-12-13	*SL*	*MSL*	*Selected paths*
1-2-8-12-13	1	4 * 1 = 4	**1-7-12-13** **1-2-8-12-13**
1-6-8-12-13	1	4 * 1 = 4	
1-2-8-5-9-11-14-12-13	1	8 * 1 = 8	
1-6-8-5-9-11-14-12-13	1	8 * 1 = 8	

Fig. 4. Route selection: step 2

Finally, with this path the process is repeated to choose the next path (Figure 5):

Path = 1-7-12-13/1-2-8-12-13	$SL_{1\text{-}7\text{-}12\text{-}13}$	$SL_{1\text{-}2\text{-}8\text{-}12\text{-}13}$	*MSL*	*Selected paths*
1-6-8-12-13	1	2	4 * 3 = 12	**1-7-12-13**
1-2-8-5-9-11-14-12-13	1	3	4 * 8 = 32	**1-2-8-12-13**
1-6-8-5-9-11-14-12-13	1	1	2 * 8 = 16	**1-6-8-12-13**

Fig. 5. Route selection: step 3

Note that the SL value for the third route is computed by adding the SL values obtained by the two previously computed paths.

Therefore, the set of paths computed by the MICORA is:

1-7-12-13
1-2-8-12-13
1-6-8-12-13

We observe that the algorithm does not choose the longer path, even though that path is the less coincident. This decision is due to the number of shared links is not small enough for selecting that path.

In Section 4 we demonstrate the efficiency of our proposal by comparing the MICORA with the well know SPF algorithm.

4. PERFORMANCE EVALUATION

In this Section the RedIRIS [9] topology (Figure 6) is used to perform the simulations. We assume nodes 1,2,3,8 as source nodes and nodes 11, 15, 16, as destination nodes.

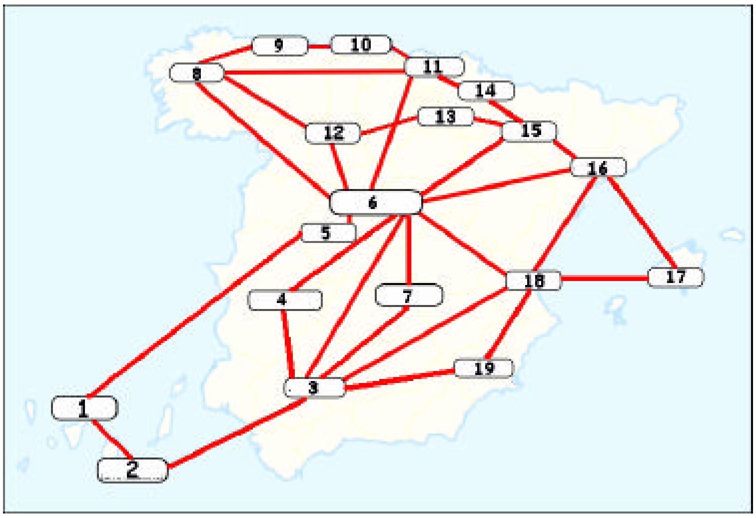

Fig. 6. Spanish National Research Network: RedIRIS

Several simulations have been performed taking into account different values of the traffic characteristics, that is, both the arrival time and the holding time take values to obtain a range of Erlangs between 0,25 and 20 for each incoming traffic. Moreover, we have generated traffic for each source-destination pair with 20000 calls according to a Poisson distribution. Regarding the physical layer, each link consists of 7 unidirectional fibers with 4 wavelengths and there are not wavelength converters in the nodes. Finally, the range of the updating time is [0,20] units of time being the value 0 an ideal case where the available resource/topology database is always updated.

Each routing algorithm simulated in this paper is associated to a well known Wavelength Assignment algorithm, such as First-Fit [1] and Random [1], being the study and analysis of the behavior of these algorithms out of the scope of this paper.

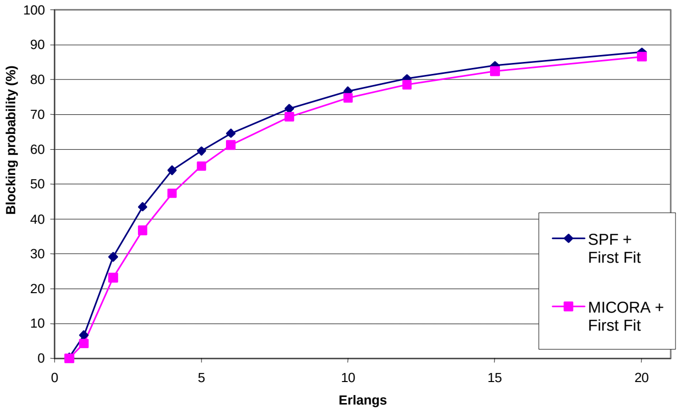

Fig. 7. Blocking probability for T=0 and Wavelength Assignment Algorithm = First-Fit

Figure 7 shows the blocking probability produced by both the MICORA and the SPF algorithms when the WA algorithm in both cases is the First-Fit and the updating time is T=0 (ideal case). We can observe that the blocking generated by the MICORA is always smaller than the SPF blocking. Specifically, if we concentrate our attention between 2 and 6 Erlangs, we observe that the MICORA reduces the blocking around 7% regarding the SPF.

Similar results are obtained when we change the First-Fit for the Random algorithm. In this case, the behavior of the MICORA for all values of traffic load is better than the SPF, as shown in the Figure 8.

When we increase the updating time to 20 units, the results confirm the good performance of the MICORA compared to the SPF, being our proposal the routing algorithm presenting the lowest blocking probability (Figure 9 and Figure 10).

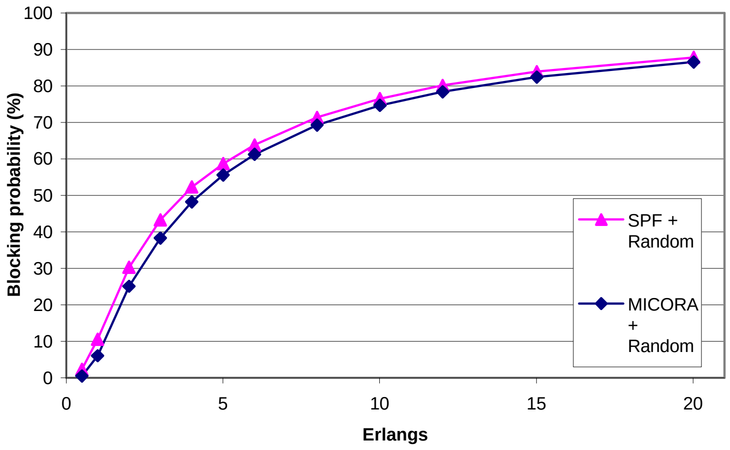

Fig. 8. Blocking probability for T=0 and Wavelength Assignment Algorithm = Random

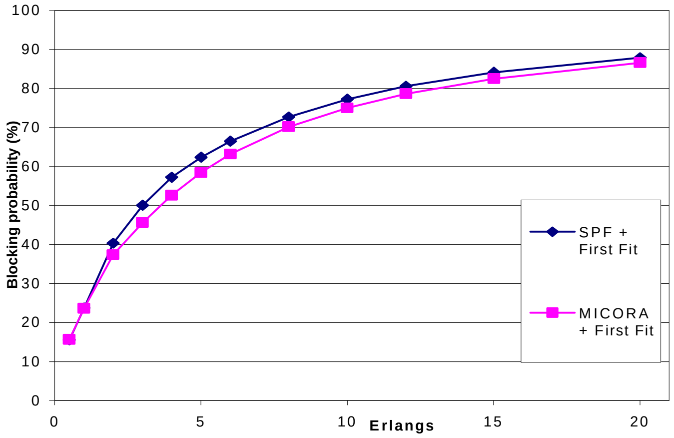

Fig.9 Blocking probability for T=20 and Wavelength Assignment Algorithm = First-Fit

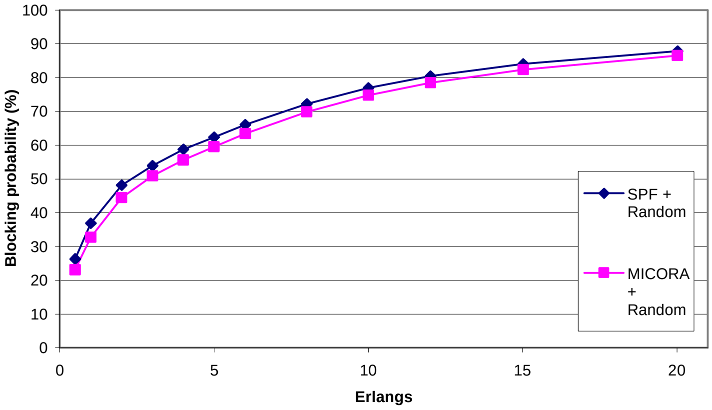

Fig. 10. Blocking probability for T=20 and Wavelength Assignment Algorithm = Random

5. CONCLUSIONS

In this positioning paper authors propose a new routing and wavelength assignment algorithm named Minimum Coincidence Routing (MICORA) to counteract the negative effect of selecting paths based only in the number of hops. Instead the MICORA computes paths aiming to balance the traffic load therefore reducing the network congestion and enhancing the global network performance. The results obtained in the simulations carried out so far presented in this paper, show that the MICORA depicts a promising behaviour in terms of the network blocking probability when compared with the shortest path algorithm. This paper is in fact an ongoing work that is currently being extended. There are many open issues where more efforts must be devoted to solidify the proposal, such as to analyze the impact of the k value on the network performance, to analyze the computational cost of the proposed algorithm, to evaluate the proposal on different network scenarios (including hierarchical networks) and to implement different wavelength assignment mechanisms along with the MICORA.

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