AN ADAPTIVE ROUTING MECHANISM FOR REDUCING THE ROUTING INACCURACY EFFECTS IN AN ASON

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Abstract: Optical transport networks, based on *wavelength-division multiplexing* (WDM) with automatic switching capabilities (ASON, *Automatic Switching Optical Networks*) appear as a potential solution to cope with the increasingly growth of Internet traffic demands. In spite of the fact that adaptive routing mechanisms based on global information performs better than the ones based on local information, they are only suitable for those networks where frequent network state changes are not expected. Therefore, assuming distributed lightpath control in this optical scenario, maintaining precise global network state information on each node is almost impossible. Many factors, such as non-negligible propagation delay, frequent state updates and hierarchical topology aggregation, can affect the precision of the global network state information. Thus, when the lightpath selection process is performed based on outdated routing information a connection blocking increment is produced. In this paper a new routing mechanism named *BYPASS Based Optical Routing* (BBOR) for reducing the effects of selecting lightpaths under inaccurate network state information are suggested and evaluated by simulation. The BBOR mechanism is based on adding optical capabilities to the *BYPASS Based Routing* (BBR) mechanism already introduced by the authors in an IP/MPLS scenario.

Key words: Adaptive routing, source routing, routing inaccuracy, ASON.

1. INTRODUCTION

In recent years the introduction of high capacity and reliable transport networks is being necessary in order to cover the needs of Internet traffic demands. New incoming Internet applications increasingly request greater capacity and guarantees of traffic delivery in such a way that the traffic transmission model must be modified. In fact the network model is evolving to an *Optical Transport Network* (OTN). An OTN consists of switching nodes (*Optical Cross-Connect*, OXC) interconnected by *wavelength-division multiplexed* (WDM) fiber-optics links, which provide multiple huge bandwidth communication channels over the same fiber in parallel. When this OTN includes automatic switching capabilities, it is named *Automatic Switching Optical Network* (ASON).

Unlike a traditional IP/MPLS scenario where the routing process only looks for the optimal route, in an optical scenario the routing process, named *Routing and Wavelength Assignment* problem (RWA) [1], must find both the physical nodes and links that configure the lightpath (routing subproblem) and the wavelength/s to be used on all the links along the lightpath (wavelength assignment subproblem), in such a way that the network resources are optimized.

On one hand, there are three approaches dealing with the routing subproblem, i.e. *fixed-routing*, *fixed-alternate routing* and *adaptive routing*. The *fixed routing* always selects the same precomputed route for a source-destination pair. In *fixed-alternate routing* a set of fixed precomputed lightpaths exists for a source-destination pair and according to a certain heuristic one of them is selected. In *adaptive routing* the lightpath is dynamically selected, depending on the current network state, according to a particular heuristic, such as the *shortest path* or the *least-congested path* (LCP) [2]. The LCP selects those links with more available wavelengths to configure the lightpath. Notice that approaches based on fixed routes reduce the complexity but unlike adaptive routing may suffer from higher connection blocking. On the other hand, a large number of different heuristics has been proposed for the wavelength assignment subproblem, e.g. random, first-fit, least-used, most-used, min-product, least-loaded, max-sum and relative capacity loss, which can be combined with different routing mechanisms.

In general the RWA is differently addressed depending on the availability of wavelength conversion capabilities. Wavelength routed networks without wavelength conversion are known as *wavelength-selective* (WS) networks. In such a network, a connection can only be established if the same wavelength is available on all the links between the source and the destination (*wavelength-continuity constraint*). This may cause high blocking probability. Wavelength routed networks with wavelength conversion are known as *wavelength-interchangeable* (WI) networks. In such networks, each router is equipped with wavelength converters so that a lightpath can be set up using different wavelengths on different links along the route.

ASON must include a Control Plane, necessary to provide the network with dynamic provisioning, fast protection, restoration and Traffic Engineering. The IETF proposed the *Generalized Multiprotocol Label Switching* (GMPLS) as a protocol to implement this Control Plane. In [3] a different solution to implement the Control Plane is discussed.

This Control Plane includes a lightpath control mechanism to efficiently set up and tear down lightpaths, which may be either centralized or distributed. In the former case, a single central controller having complete global network state information sequentially selects and establishes a lightpath for any incoming request. In the later case, all incoming connection requests are simultaneously processed at different network nodes, which select the lightpaths based on either local (the nodes have not 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 setup message is rejected in any intermediate node is very large. On the other hand, using global network state information reduces the blocking probability, whenever this information represents a current picture of the network state. Therefore, in order to keep this network state information correctly updated, the routing protocol must include an updating mechanism. In general, this updating mechanism is implemented by a triggering policy based on either a periodical refresh, or a certain threshold value, which define when an updating message must be flooded throughout the network.

In this paper we focus on distributed lightpath control under global information, which is more appropriate and reliable for highly dynamic large networks if the network state information perfectly represents the current network state. However, it must be noticed that in highly dynamic large networks, the number of updating messages generated by any triggering policy, needed to keep the network state information correctly updated, may overflow the network of signaling messages which may cause a non desirable overhead.

The remainder of this document is organized as follows. In Section 2 the problem addressed in this paper and the existent related work are described. Then, Section 3 clearly describes the BBOR mechanism. After that, the BBOR mechanism is evaluated by simulation in Section 4 and finally, Section 5 concludes the paper.

2. PROBLEM DEFINITION

As above mentioned, adaptive distributed routing mechanisms based on global network state information in a dynamic environment, requires a huge number of updating messages to correctly update the network state databases on each node, which implies a non-desirable signaling overhead. In order to overcome this signaling overhead, the number of updating messages are limited by either a periodical refresh or a threshold value. As a result of limiting the number of updating messages, the information contained in the network state databases does not represent the current picture of the network. Indeed, the RWA problem under inaccurate routing information produces an increment in the connection blocking probability.

The effect of having inaccurate routing information in the path selection process has been widely analyzed in an IP scenario and some mechanisms has been proposed in the literature to deal with it. Most recent works can be found in [4-8]. Documents [4-6] try to find the path that maximizes the probability of supporting the incoming traffic requirements and different solutions are proposed to cope with satisfying both traffic with bottleneck requirements (e.g. bandwidth) and traffic with additive requirements (e.g. end-to-end delay bounds). Unlike these proposals [7] presents a mechanism, which is not based on computing the path able to support the traffic requirements with a larger probability. Instead, a new multipath distributed routing scheme named *Ticket Based Probing* (TBP) is implemented.

In [8] authors propose a new routing mechanism named *BYPASS based Routing* (BBR) which instructs some intermediate nodes to reroute the setup message to a precomputed alternative path when there is not resources enough to cope with the incoming request.

Regarding WDM networks, in [9] the effects produced in the blocking probability because of having inaccurate routing information when selecting the lightpaths are shown by simulation. In fact, authors verify over a fixed topology that the blocking ratio increases when routing is done under inaccurate routing information. The routing uncertainty is introduced by adding an updating interval of 10sec. Some other simulations are performed to show the effects on the blocking ratio due to changing the number of fibers on all the links. Finally, authors argue that new RWA algorithms that can tolerate imprecise global network state information must be developed for the dynamic connection management in WDM networks.

In [10] the routing inaccuracy problem is addressed by modifying the lightpath control mechanism, and a new distributed lightpath control based on destination routing is suggested. The mechanism is based on both selecting the physical route and the wavelength on the destination node and adding rerouting capabilities to the intermediate nodes to avoid blocking a connection when the selected wavelength is not really available in any intermediate node along the lightpath. Two are the main weaknesses of this mechanism. Firstly, since the rerouting is performed in real time in the setup process, the wavelength usage deterioration is directly proportional to the number of intermediate nodes which must reroute the traffic. Secondly, the signaling overhead is not reduced, since the RWA decision is based on the global network state information maintained on the destination node which must be perfectly updated.

In this paper, a new adaptive source routing mechanism named *BYPASS Based Optical Routing* (BBOR) based on inaccurate global network state information to compute dynamic explicit lightpaths in an ASON without conversion capabilities is suggested. This mechanism is derived from the BBR mechanism, already developed and evaluated by the authors in an IP/MPLS scenario. Although the BBOR mechanism also introduces a rerouting mechanism, unlike the mechanism suggested in [10] the alternative paths are precomputed at the source node along with the selected lightpath. In this way the connection setup time and the wavelength usage deterioration are both reduced. The work presented on this document modifies the BBR structure to make it capable of addressing the effects of having inaccurate routing information because of applying a certain triggering policy to reduce the signaling overhead in an ASON.

3. ADAPTATION OF THE BYPASS BASED ROUTING TO ASON: BBOR

The *BYPASS Based Optical Routing* (BBOR) is a new adaptive source routing mechanism based on global network state information that aims to reduce the connection blocking probability due to performing routing and wavelength assignment decisions under inaccurate routing information. Before copying with the BBOR mechanism a brief description of the BBR mechanism from which the BBOR is derived is introduced.

3.1. Review of the BYPASS Based Routing Mechanism

The BBR was introduced by the authors to improve the global network performance in an IP/MPLS scenario when the path selection process is performed under network state inaccuracy due to the use of a certain triggering policy. The main concept is similar to the *deflection routing or alternate link rerouting* [11] and it derives from [12] were the use of protection switching for fast rerouting is analyzed. However important differences exist among them. Unlike the use of protection switching for fast rerouting, in our proposal the working and the alternative (named *bypass-paths*) paths are computed but not set up simultaneously. In *deflection routing* (an approach for adaptive routing with local information), alternate paths are precomputed and sorted in the routing table of each node based on local network state information and can be used depending on the resources availability at any time. Instead, based on global network state information, the BBR mechanism only computes *bypass-paths* for those links that potentially cannot cope with the traffic requirements and the usage of these *bypass-paths* is decided at the path setup time depending on the resources availability.

Two concepts are the most significant in the BBR mechanism: (1) the definition of a new kind of link, named *Obstruct-Sensitive Link* (*OSL*) and (2) how these *OSLs* are used to optimize the path selection process under inaccurate link state information. A link is defined as *OSL* when potentially may not be able to support the traffic requirements in the future. This definition is made in accordance with the triggering policy used to update the network state information. Hence, the details of the triggering policy must be perfectly known. Specifically, BBR instructs the ingress node to compute both the working route and as many *bypass-paths* as links that potentially may not cope with the incoming traffic requirements, i.e. links defined as *OSL*. Assuming that those links that cannot cope with the traffic requirements are only known at the time of path setup, when an intermediate node in the selected route detects a link with available residual bandwidth lower than the requested bandwidth it sends the setup message along the explicit route that bypasses this link. In order to perform this, *bypass-paths* are explicitly sent along with the end-to-end route in the path setup message. In order to minimize the setup message size, *bypass-paths* are removed from the setup message when passing the link that bypass. The details of the mechanism used to explicitly set up the *bypass-paths* can be found in [13].

Once the BBR mechanism has been described, the BBOR mechanism is in detail introduced.

3.2. BBOR Description

As above mentioned, the routing inaccuracy is mainly due to the fact of introducing a triggering policy in order to reduce the signaling overflow produced by the updating messages. Thus, the BBOR mechanism includes two main aspects, namely a triggering policy adapted to the RWA problem to reduce the routing signaling, and a bypass routing algorithm to counteract the effects of the routing inaccuracy produced by this routing signaling reduction.

On one hand, existing triggering policies [4] are based on updating by either a periodical refresh or sending an updating message whenever there is a change in the network state. In the first case, by modifying the refresh time value, the network state accuracy and the number of updating messages can be adjusted. However, this scheme is not valid for large dynamic networks. In the second case, an important signaling overhead is added. In this paper a new triggering policy based on a threshold value which aims to include the network congestion, namely the available network resources in the triggering decision is suggested. In fact, a network node triggers an updating message whenever a fixed number *N* of wavelengths changes their status, i.e. after a fixed number of *N* connections are established or released. By changing the value of *N*, we can evaluate the impact of different degrees of inaccuracy in the connection blocking ratio. On the other hand, the bypass routing algorithm consists of dynamically rerouting the setup messages through an alternative precomputed explicit route (*bypass-path*) when, as a consequence of selecting paths under inaccurate routing information, at any of the intermediate nodes the requested wavelength is found not available

The main BBOR characteristic is that it allows several nodes along the selected path to dynamically reroute the setup message to a different route when, due to the wavelength unavailability produced by computing the selected paths according to inaccurate routing information, this setup message would be rejected in any of these intermediate nodes. Two possible options of rerouting exist, namely, to change the route maintaining the wavelength and to change the wavelength maintaining the route. In a *wavelength continuity constraint* scenario, the first one is chosen. Therefore, when an intermediate node decides to reroute the setup message it sends this message along a different route (*bypass-path*), which bypasses the link that does not fulfill the *wavelength continuity constraint*.

The BBOR mechanism consists of three basic processes: (1) decide which wavelength of which link (bundle of *B* fibers) might be bypassed, (2) include these wavelengths as a parameter to be considered when selecting the lightpath and (3) compute the *bypass-paths*.

Concerning (1) we define the wavelengths that have to be bypassed as *Obstruct-Sensitive-Wavelength (OSW)*. The way to determine when a wavelength l_i is defined as *OSW*, namely $l^{os}{}_i$ on a certain link, depends on the triggering policy used to update the network state information. Being *B* the total number of a certain l_i on a link and *R* the current number of available (not assigned to an already established lightpath) l_i on this link, we can say that acording to the BBOR triggering policy described above, this l_i is defined as l^{os}_i in this link when *R* is lower than a percentage T_p *(threshold percentage)* of *N*. Remind that *N is* the number of changes established in the triggering policy to send an updating message. Hence, the granularity in the *OSW* definition can be modified by changing the T_p value.

Concerning (2), the source node in order to properly perform the RWA problem has to take into account the number of l_i defined as *OSW*. In order to do so, we define a new parameter named OSW_i *(L, F)* where *L* is the number of links where l_i has been defined as *OSW* and *F* is the minimum value of available wavelengths along the lightpath. According to this parameter, two different algorithms can be inferred from the *BBOR* mechanism, *ALG1* and *ALG2*. *ALG1* consists of selecting those l_i*s* in all the links of the shortest path/s (minimum number of hops), which minimize *L* in $OSW_i(L,F)$. If more than one wavelength is compliant with this condition, the algorithm selects de less congested checking the *F* value in $OSW_i(L,F)$. *ALG2* consists of selecting the less congested l_i*s* on the shortest path/s according to the *F* value in $OSW_i(L,F)$. If more than one wavelength is compliant with this condition, the algorithm selects that l_i which minimizes the *L* value in $OSW_i(L,F)$.

Concerning (3), once the lightpath is selected, a *bypass-path* must be computed for those wavelengths defined as *OSW* in this lightpath, in such a way that the *wavelength continuity constraint* is guaranteed. Although other criteria could be used to compute the *bypass-paths* (left for further studies), such as minimizing the number of wavelengths defined as *OSW*, the shortest (minimum number of hops) *bypass-paths* are selected. In order to simplify the *bypass-paths* computation, when a *bypass-path* exists on a link for a particular l^{os}_i, this path will also be used as the first option to bypass any other l^{os}_j on this link. Summarizing, in order to explicitly distribute in the setup message the *bypass-paths*, source nodes must perform both detect those wavelengths on a link that potentially cannot be available when establishing the path, and compute a *bypass-path* for each one of these wavelengths. A brief description of the BBOR mechanism is presented in the box of the next page.

3.3. Example Illustrating how BBOR Works

The topology shown in Figure 1 is used to illustrate how the BBOR works. Considering that every OXC include control functions with signaling capabilities, we assume *B* = 10 fibers per link and 4 wavelengths per fiber. Updating messages are sent according to *N* = 6 and a wavelength l_i is defined as OSW_i according to T_p = 50%, i.e., when the minimum number of available wavelengths on this link is lower or equal than 3. Incoming connection requests arrive between OXC1-OXC4. In Table 1 the network state information existing in OXC1 is shown. It is represented the number of available wavelengths for all the links

BYPASS BASED OPTICAL ROUTING MECHANISM

Input: An incoming connection request between a source-destination pair *(s,d)* with a *wavelength continuity constraint*

***Output*:** An explicit route from *s* to *d* with a common available wavelength on all the links along the path and with enough *bypass-paths* to bypass the routing inaccuracy effects in the *obstruct-sensitive wavelengths*.

Algorithm:
1. Select the shortest paths
2. Mark those wavelengths that are defined as *OSW*
3. Depending on the algorithm to be used, ALG1, ALG2:

ALG1:
- Select that l_i on all the paths minimizing the *L* value in $OSW_i(L,F)$
- If more than one exists the less congested is selected according to the *F* value in $OSW_i(L,F)$.

ALG2:
- Select the less congested wavelength on each path according to the *F* value in $OSW_i(L,F)$.
- If more than one exists, select that l_i on all the paths minimizing the *L* value in $OSW_i(L,F)$.

4. Compute a *bypass-path* for all wavelengths defined as *OSW*.
5. Decide which *bypass-paths* must be used in accordance with real available resources in the path setup time

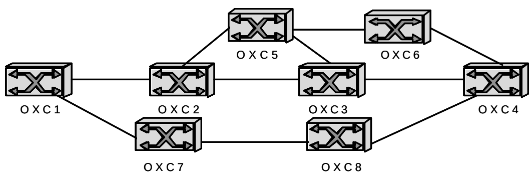

Figure1. Network topology used in the illustrative example

Table 1. Network State in OXC1

Link (OXC)	λ_1 λ_2 λ_3 λ_4	Link (OXC)	λ_1 λ_2 λ_3 λ_4
1-2	6 3 3 6	5-6	0 7 3 3
2-3	2 3 6 0	6-4	1 1 1 1
3-4	6 3 0 2	1-7	6 3 1 6
2-5	6 2 0 1	7-8	0 3 6 1
5-3	6 6 6 6	8-4	6 6 0 6

According with this information, Table 2 shows the routing table existing in OXC1, where all the feasible lightpaths between OXC1 and OXC2 are pointed out. In addition, the minimum number of available wavelengths and the OSW_i *(L,F)* parameter are shown for each lightpath. Finally, Table 3 shows, hop-by-hop, the process of applying the BBOR mechanism. As a result, a different lightpath and a different wavelength are selected to transmit the traffic depending on the algorithm in use. Thus, l_1 along the path made of OXCs 1-2-3-4 and l_2 along the path made of OXCs 1-7-8-4 are selected for the *ALG1* and *ALG2* respectively. In addition, since l_1 is defined as OSW_1 on link OXC2-OXC3 a *bypass-path* through OXCs 2-5-3 is also selected.

Table 2. Routing Table in OXC1

Route (OXC)	λ_1 λ_2 λ_3 λ_4	OSW_i (L,F)
1-2-3-4	2 3 0 0	λ_1(1,2), λ_2(3,3)
1-2-5-3-4	6 2 0 1	λ_2(3,2), λ_4(2,1)
1-2-5-6-4	0 1 0 1	λ_2(3,1), λ_4(3,1)
1-7-8-4	0 3 0 1	λ_2(2,3), λ_4(1,1)

However, when using *ALG2*, *path 2* and l_2 are the RWA result. In this case, l_2 is OSW_2 on links OXC1-OXC7-OXC8. It is not possible to find a proper *bypass-path* to directly bypass these links. In this case, the BBOR cannot be completely applied. Further extensions are currently being done to the BBR mechanism in an IP/MPLS scenario to cope with this problem.

Table 3. Illustrative Example

BBOR steps	*Algorithm 1 (ALG1)*	*Algorithm 2 (ALG2)*
1	path 1: 1-2-3-4 path 2: 1-7-8-4	path 1: 1-2-3-4 path 2: 1-7-8-4
2 (ALG1)	path 1: λ_1(**1**,2) path 2: λ_4(**1**,1)	
2 (ALG2)		path 1: λ_2(3,**3**) path 2: λ_2(2,**3**)
3 (ALG1)	**path 1:** λ_1(1,**2**) path 2: λ_4(1,**1**)	
3 (ALG2)		path 1: λ_2(**3**,3) **path 2**: λ_2(**2**,3)
4	λ_1 is *OSW* on 2-3 *Bypass-path*:2-5-3	λ_2 is *OSW* on 1-7-8 No *bypass-path*

3.4. Setup Time Analysis

In this section the effects of applying the BBOR mechanism over the time needed to establish a lightpath is analyzed. This time is defined as the time taken from the moment an incoming request connection reaches the source node to the moment the lightpath is successfully established. This time depends on:

- T_c = Time taken by the source node to compute a route
- T_{c_b} = Time taken by the source node to compute a *bypass-path* route
- n_s = Number of hops in the shortest path
- n_{OS} Number of wavelengths defined as *Obstruct-Sensitive* in the selected route
- m = Number of wavelengths that really are not available in any intermediate node along the selected route
- n_{bi} = Number of hops in the *bypass-path* i
- T_d = Propagation delay on each link
- T_p = Time taken by an intermediate node to process a connection reuest
- T_r = Time taken by a node to reserve a wavelength

The setup message sent by the source node takes a time T_d to reach the destination node. This time depends on the number of wavelengths defined as *OSW*. Thus, we definer T_s as the total time needed to establish the connection that takes a two-way delay to establish a lightpath. Different cases can be analyzed depending on the number of *OSW*:

1) There is not any wavelength defined as *OSW*.

$$T_s = T_c + 2 \text{ X } n_s \text{ X } T_d + (2 \text{ X } n_s + 1) \text{ X } T_p + (n_s + 1) \text{ X } T_r$$

2) There are n_{OS} wavelengths defined as *OSW* but no one is really used

$$T_s = T_c + T_{c\_b} \text{ X } n_{OS} + 2 \text{ X } n_s \text{ X } T_d + (2 \text{ X } n_s + 1) \text{ X } T_p + (n_s + 1) \text{ X } T_r$$

3) There are n_{OS} wavelengts defined as *OSW* and m are used, where

$$m \subset n_{OS}$$
$$m \leq n_{OS}$$

Now the time T_s can be represented as:

$$T_s = T_c + T_{c\_b} \text{ X } n_{OS} + 2 \text{ X } \left[(n_s - m) + \sum_{i=1}^{m} n_{bi} \right] \text{X } T_d + \\ + \left[2 \text{ X } \left[(n_s - m) + \sum_{i=1}^{m} n_{bi} \right] + 1 \right] \text{X } T_p + \quad + \left(n_s - m + 1 + \sum_{i=1}^{m} n_{bi} \right) \text{X } T_r$$

Instead of the fact that the BBOR mechanism requires an increment in the time needed to set up a lightpath with regard to another mechanism that does not compute *bypass-paths*, this time does not substantially affects the wavelength usage. This claim is next clarified by applying the above described equations to the network topology of Figure 1. Considering the *ALG1* in use, λ_1 on the OXC1-OXC2-OXC3-OXC4 stands for the selected lightpath. This wavelength is defined as *OSW* in the link OXC2-OXC3. Three different cases are analyzed. Firstly, we compute the time needed to establish the lightpath when no BBOR mechanism is applied. Therefore, $n_S = 3$, and the T_S is

$$T_s = T_c + 2 \text{ X } n_s \text{ X } T_d + (2 \text{ X } n_s + 1) \text{ X } T_p + (n_s + 1) \text{ X } T_r = \\ = T_c + 6T_d + 7T_p + 4T_r$$

Secondly, we compute the time needed to establish the lightpath, when applying the BBOR mechanism the *bypass-path* computed to bypass the link OXC2-OXC3 is not really used when the setup message reaches OXC2.Therefore, $n_{OS} = 1$, $n_S = 3$ and T_S is

$$T_s = T_c + T_{c\_b} \text{ X } 1 + 2 \text{ X } 3 \text{ X } T_d + (2 \text{ X } 3 + 1) \text{ X } T_p + (3 + 1) \text{ X } T_r = \\ = T_c + T_{c\_b} + 6T_d + 7T_p + 4T_r$$

Lastly, we represent the time needed to establish the lightpath when the *bypass-path* computed to bypass the link OXC2-OXC3 is used. In fact, the final end-to-end lightpath is made of OXC1-OXC2-OXC5-OXC3-OXC4. Therefore, $n_{OS} = 1$, $n_S = 3$, $m = 1$, $n_{bi} = 2$ and T_S is

$$T_s = T_c + T_{c\_b} \text{ X} 1 + 2 \text{ X } \left[(3 - 1) + \sum_{i=1}^{1} 2 \right] \text{X } T_d + \left[2 \text{ X } \left[(3-1) + \sum_{i=1}^{1} 2 \right] + 1 \right] \text{X } T_p + \\ + \left(3 - 1 + 1 + \sum_{i=1}^{1} 1 \right) \text{X } T_r = T_c + T_{c\_b} + 8T_d + 9T_p + 5T_r$$

We can see that the time increment due to applying the BBOR mechanism when no *bypass-paths* are used is just due to the time needed to computed these *bypass-paths*. Moreover, as the time increment does not affect the time in which a certain wavelength is reserved but not used (since is computed before sending the setup message) does not produce network inefficiency. As far as comparing the first and the last situation, the increment generated in the path setup time can be represented as

$$\Delta T_s = T_{c\_b} + 2T_d + 2T_p + T_r$$

We can observe that only the time needed to propagate, process and reserve a wavelength affects to the time in which a wavelength is reserved but not used. However this increment is very low and is negligible.

4. PERFORMANCE EVALUATION

In this section the simulation scenario where the BBOR mechanism has been evaluated is described along with the parameters used to test the goodness of our proposal and the results obtained from the simulations carried out within this scenario.

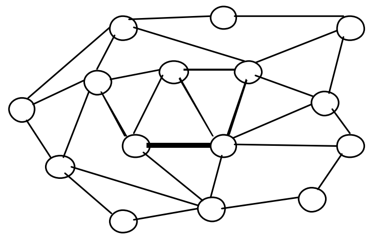

Figure 2. Topology used in simulations

The topology model used in the simulations is shown in Figure 2 where the possible source-destination pairs are randomly selected. We suppose a 5-fiber topology, with 16 wavelengths on all the fibers on all the bi-directional links. Connection arrivals are modeled by a Poisson distribution and the connection holding time is assumed to be exponentially distributed. Assuming adaptive routing, routes are computed after applying the shortest path algorithm. Three routing algorithms are evaluated by simulation, that is, First-Fit, *ALG1* and *ALG2*. In the next figures the effects produced in the network performance by applying the BBOR mechanism are shown, i.e., the reduction of the number of updating messages when the triggering policy defined in the BBOR mechanism is applied and the blocking probability reduction obtained when applying the BBOR mechanism. Both effects are analyzed as a function of both *N* (number of changes established in the triggering policy to send an updating message) and T_p (threshold percentage of N which defines when a wavelength is defined as *OSW*) values.

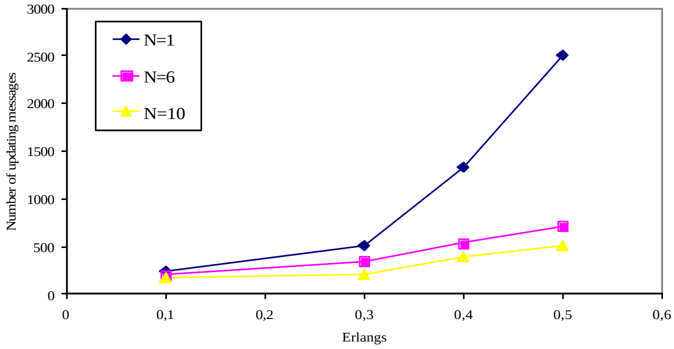

Figure 3. Number of updating messages

Figure 3 shows the reduction obtained in the amount of updating messages supplied to the network when increasing the values of *N*. Note that the case of *N* = 1, corresponds to a policy that triggers updating messages whenever a change occurs. In Figure 4 we show the effects produced in the number of wavelengths defined as *OSW* as a function of the T_p value. The number of defined *OSWs* grows with the T_p value, since the minimum number of available wavelengths on a certain link used to define when a wavelength is an *OSW* on this link is also directly proportional to the T_p value.

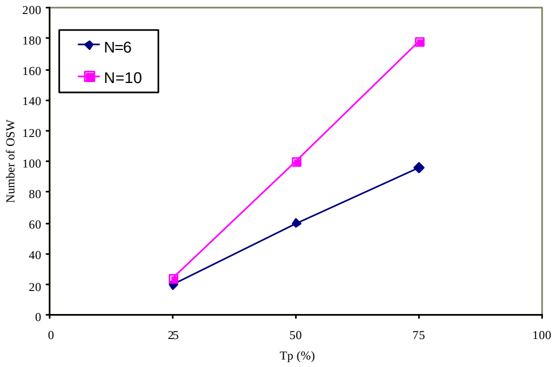

Figure 4. Number of *OSW* as a function of the threshold percentage T_p *value*

According to the results obtained in Figure 4 the blocking probability is evaluated considering a value of T_p = 50%. In Figure 5 we compare the blocking probability obtained by the BBOR algorithms and the shortest path algorithm combined with the First-Fit approach, considering a value of N = 6. We can see that in the worst case a blocking probability reduction of 6.08% is obtained when applying a BBOR mechanism.

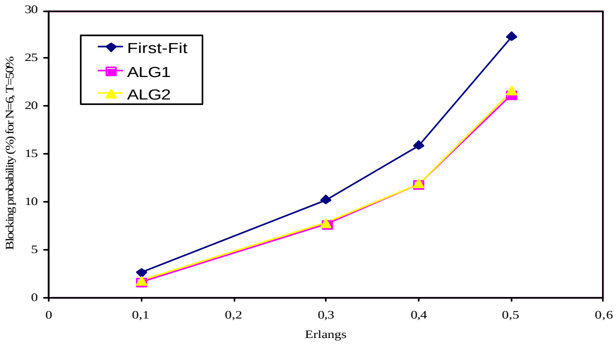

Figure 5. Blocking probability for N = 6 and T_p = 50%

Analogously, the blocking probability for N = 10 is shown in Figure 6. In this case, the blocking probability reduction achieved by the BBOR algorithms in front of the First-Fit approach reached 16.12%.

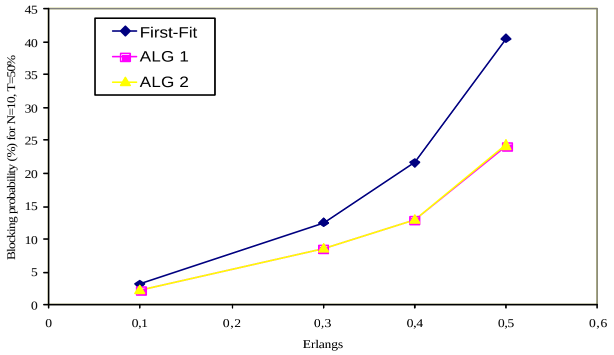

Figure 6. Blocking probability for N = 10 and T_p = 50%

Analyzing a fixed value (27.32%) of blocking probability for the First-Fit approach we can see that unlike Fig.5 where N = 6 and a reduction of 6.08% is obtained, in Fig.6 where N = 10, the obtained reduction is about 11%. Therefore, according to the obtained simulation results, the BBOR mechanism obtains the largest blocking probability reduction, when the N

value increases, that is, when the number of updating messages has been reduced as well. Therefore, the BBOR mechanism reduces both the signaling overhead and the effects produced because of having inaccurate routing information.

5. CONCLUSIONS

An important problem exists when the information contained in the network state databases does not perfectly represent a current picture of the network. Many factors, such as non-negligible propagation delay, frequent state updates and hierarchical topology aggregation, can affect the precision of the global network state information. An immediate effect produced by this routing inaccuracy is a connection blocking increment. One possible way to address this problem is to use wavelength converters. In fact, when the *wavelength continuity constraint* is avoided the connection blocking is reduced. Another option is to increase the number of fibers on each link so that more possible wavelengths exist. Both solutions could be referred as "hardware solutions" and both imply a non-desirable economic cost. Another line of solutions can be named "software solutions", and they are based on modifying the routing algorithms so that the routing inaccuracy can be added as a parameter in the lightpath selection process.

In this paper, a new adaptive source routing mechanism based on global network state information for reducing the routing inaccuracy effects in an *Automatic Switching Optical Network (ASON)* is suggested. This mechanism is named *BYPASS Based Optical Routing (BBOR)* and it is derived from an earlier work developed by the authors in an IP/MPLS scenario. The BBOR mechanism includes two main aspects, namely a triggering policy adapted to the RWA problem to reduce the routing signaling needed to correctly update the network state databases on each node, and a bypass routing algorithm to counteract the effects of the routing inaccuracy produced by this routing signaling reduction. It is analytically shown that the BBOR mechanism has a negligible impact in the wavelength usage deterioration.

In order to perfectly analyze the enhancement introduced when the BBOR mechanism is used a wavelength-selective network, i.e. without wavelength conversion, is considered. Results obtained by simulation show a blocking probability reduction when the algorithms inferred from the BBOR mechanism are applied in comparison with other routing heuristic which do not consider the routing inaccuracy problem. The obtained blocking probability reduction increases depending on the inaccuracy existent in the network state information. In fact, simulation results show that is under conditions of low updating (updating messages are sent when 10 changes occur in the network state), when the BBOR mechanism exhibits the largest reduction in the blocking probability in comparison with the First-Fit approach.

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