

Routing and Wavelength Assignment under Inaccurate Routing Information in Networks with Sparse and Limited Wavelength Conversion¹

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Abstract— In large dynamic networks it is extremely difficult to maintain accurate routing information on all network nodes. Different causes can motivate this inaccuracy, such as the state aggregation produced in hierarchical networks, the delay in flooding the network state, and the triggering policy used to determine when this network state information must be updated. This paper focuses on the inaccuracy caused by the triggering policies. Triggering policies are included in the routing protocol to reduce the large number of update messages needed to guarantee accurate network state information on all the network nodes. The *BYPASS Based Optical Routing (BBOR)* has already been proposed by the authors to reduce the effects of having inaccurate routing information in networks operating under the wavelength-continuity constraint. This paper extends the BBOR mechanism to be applied to wavelength convertible networks and evaluates its performance.

Keywords- *Optical networks, routing and wavelength assignment, routing inaccuracy*

I. INTRODUCTION

Optical Transport Networks based on wavelength division multiplexing (WDM) appear as a potential solution to cope with the increasingly growth of Internet traffic demands. In such systems all-optical WDM channels are used to allow the end-to-end users communication. These WDM channels are referred as lightpaths, and must be selected in a proper manner in order to optimize the network resources. It is in this point where the routing becomes an important factor in the global network performance. Unlike traditional IP routing where only a physical route was selected, two processes are required to establish a lightpath in a WDM network, i.e. selecting the physical route and selecting the wavelength that will be used to transport the traffic flow. This problem is known as *Routing and wavelength Assignment* problem (RWA) and different heuristics exists to cope with it [1].

The RWA problem 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 pair (*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 Optical Cross-Connect (OXC) is equipped with wavelength converters so that a lightpath can be set up using different wavelengths on different links along the route.

In order to correctly realize the lightpath establishment, a lightpath control mechanism must exist. This mechanism can be either centralized or distributed. Although centralized control is easier to implement than distributed control it is really not scalable and feasible. Moreover, it must be noticed that when using distributed lightpath control the routing and wavelength decision may be performed under either local or global network state information. It is known that distributed control under global network state information performs better when the routing information perfectly represents the current network state. This is achieved by including an update mechanism in the routing protocol, which generally is implemented by a certain triggering policy. However, in a highly dynamic network the number of update messages needed to correctly update the network state information on each node would produce a non-desirable signaling overhead. In order to reduce this signaling overhead the triggering policies may change the frequency used to decide when an update message must be flooded throughout the network. As a consequence, although applying any triggering policy reduces the signaling overhead, it introduces a certain inaccuracy in the network state information contained in each node. Under this routing inaccuracy, the route and the wavelength selected by the source node could not be available when establishing the lightpath, generating an increment in the connection blocking. So, a trade-off exists between having accurate network state information and the amount of update messages flooded

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throughout the network. Selecting routes under inaccurate network state information is referred as the routing inaccuracy problem.

Although the routing inaccuracy problem has been widely analyzed in an IP scenario, there are not many contributions coping with this problem in optical transport networks. Most recent related work is summarized in the following paragraphs.

In [2] the effects produced in the blocking probability because of having inaccurate routing information when selecting lightpaths are shown by simulation. The authors indeed 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 update interval of 10 seconds. 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, the authors argue that new *Routing and Wavelength Assignment (RWA)* algorithms that can tolerate imprecise global network state information must be developed for dynamic connection management in *WDM* networks.

In [3] 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 wavelength on the destination node, and adding rerouting capabilities to the intermediate nodes to avoid blocking a connection when the selected wavelength is no longer available at set-up time in any intermediate node along the lightpath. There are two main weaknesses of this mechanism. Firstly, since the rerouting is performed in real time in the set-up process, wavelength usage deterioration is directly proportional to the number of intermediate nodes that 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.

Another contribution on this topic can be found in [4] where authors propose a mechanism whose goal is to control the amount of signaling messages flooded throughout the network. Assuming that update messages are sent according to a hold-down timer regardless of frequency of network state changes, authors propose a dynamic distributed bucket-based Shared Path Protection scheme (an extension of the *Shared Path Protection, SPP* scheme). Therefore, the amount of signaling overhead is limited by both fixing a constant hold-down timer which effectively limits the number of update messages flooded throughout the network and using buckets which effectively limits the amount of information stored on the source node, i.e. the amount of information to be flooded by nodes. The effects of the introduced inaccuracy are handled by computing alternative disjoint lightpaths which will act as a protection lightpaths when resources in the working path are not enough to cope with those required by the incoming connection. Authors show by simulation that inaccurate database information strongly impacts on the connection blocking. This increase in the connection blocking may be limited by properly introducing the suitable frequency of update messages. According to the authors, simulation results

obtained when applying the proposed scheme along with a modified version of the *OSPF* protocol, may help network operators to determine that frequency of update messages which better maintains a trade-off between the connection blocking and the signaling overhead.

In [5] we propose a new adaptive source routing mechanism named *BYPASS Based Optical Routing (BBOR)* which is inferred from the *BYPASS Based Routing (BBR)* [6] mechanism, aiming to reduce the routing inaccuracy effects, i.e., blocking probability increment and non-optimal path selection, in a network without conversion capabilities, i.e. a wavelength selective network (WS network).

This paper extends the BBOR mechanism to be applied to networks with conversion capabilities, i.e., wavelength selective or interchangeable networks (WI networks). In these networks lightpaths may be selected without using the same wavelength in all the links along the selected lightpath. As a consequence, the global network efficiency is largely improved. 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 route selection problem 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 , i.e., limited range wavelength conversion, defining the *degree of translation* D as

$$D = \frac{100k}{\Lambda - 1} (\%), \quad (1)$$

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

In this way, if translations of k wavelengths are allowed either side of the input wavelength, 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 [7] that a substantial improvement in the global blocking probability of the network when limited-range wavelength converters with as little as 25% of the full conversion range are introduced.

In this paper we want to analyze the impact on the blocking probability due to applying a routing algorithm inferred from the BBOR mechanism to a network with wavelength conversion capabilities. Existing algorithms inferred from the BBOR mechanism so far take routing decisions based on combining the shortest path selection with a parameter defined in the BBOR mechanism. In this paper we also modify the path selection mechanism regarding existing BBOR algorithms to optimize load balancing.

The remainder of this paper is organized as follows. Section II shortly describes the BBOR mechanism. Then, in Section III the proposed BBOR modification is presented. After that the performance is evaluated by simulation in Section IV. Finally, Section V concludes the paper

II. BBOR REVIEW

The BBOR mechanism [5] is an adaptive source routing mechanism which mainly consists of two components, that is, it introduces a new triggering policy to reduce the signaling overhead and it implements a new routing algorithm which addresses the routing inaccuracy effects produced by this triggering policy. A brief description of both components is now presented.

A. Triggering Policy

The main goal of this new triggering policy is to include the network congestion as a parameter to be considered in the triggering decision. Assuming that the network congestion is measured by the amount of available wavelengths, a network node triggers an update message whenever a fixed number N of wavelengths changes their status. By changing the value of N we can evaluate the impact of the triggering policy on the blocking probability. Fig. 1 shows the reduction obtained in the quantity of update messages when applying the triggering policy defined in the BBOR mechanism as a function of the N value. As expected, the larger the N the lower the number of update messages flooded throughout the network, i.e. the signaling overhead. Note that the case of $N = 1$ corresponds to a policy that forces nodes to trigger update messages whenever a single change occurs in the resource availability of their directly connected links.

B. BYPASS Based Routing Algorithm

When a source node is required to establish a new incoming connection it selects the route and the wavelength and sends a set-up message piggybacking the explicit route along the selected lightpath. However, because of selecting routes and wavelengths under inaccurate routing information, the selected route may have become unavailable at the time of the lightpath set-up, leading to the rejection of the set-up messages. The BBOR mechanism addresses this problem by offering an alternative route to all those intermediate nodes that would reject the set-up message.

In fact, when an intermediate node detects that the explicitly routed output link has insufficient resources, i.e., there is neither any available wavelength (WI networks) nor the same incoming wavelength (WS networks) to accommodate the new incoming connection, it dynamically sends the set-up message along a pre-computed *bypass-path* which bypasses this link. Therefore, the wavelength availability is the critical parameter in deciding when a lightpath must be rerouted.

Assuming that any link is a bundle of B fibers, the main BBOR performance can be detailed according to the next steps:

1) **Defining wavelengths to be bypassed:** Those wavelengths in a link that potentially might not be available are defined as *Obstruct-Sensitive-Wavelength* (OSW). Being B the

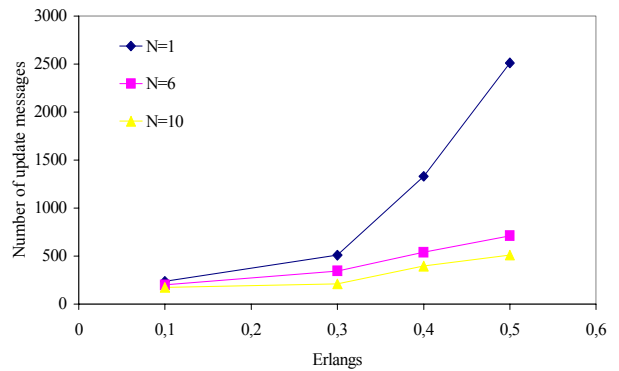


Fig.1 Number of update messages

total number of a certain λ_i on a link, R the current number of available (not assigned to an already established lightpath) λ_i on this link we can say that according to the triggering policy defined by the BBOR mechanism, a wavelength λ_i is defined as *OSW*, namely λ_i^{os} on a certain link, when R is lower or equal than a *threshold percentage* T_p of N , being N the number of changes established in the triggering policy to send an update message.

2) **Selecting the lightpath:** Once the OSW detection has finished, the lightpath is computed. This process consists of two basic steps, selecting the working path and selecting as many *bypass-paths* as wavelengths defined as *OSWs*. On one hand, two algorithms are inferred from the BBOR mechanism, namely *ALG1* and *ALG2*, when including the *OSW* in the path selection process. This is done by adding a new parameter named $OSW_i(L, F)$ where L is the number of links where λ_i has been defined as *OSW* and F is the minimum value of available λ_i along the lightpath. Hence, L represents the degree of obstruction and F the congestion of the path. In fact, according to this parameter, *ALG1* selects those λ_i s in all the links of the shortest paths (minimum number of hops), which minimize L (i.e., less obstructed path) in $OSW_i(L, F)$. If more than one wavelength is compliant with this condition, the algorithm selects the less congested checking the F value in $OSW_i(L, F)$. *ALG2* selects the less congested λ_i s on the shortest paths (i.e., less congested path) according to the F value in $OSW_i(L, F)$. If more than one wavelength is compliant with this condition, the algorithm selects that λ_i which minimizes the L value in $OSW_i(L, F)$. On the other hand, once the working path is selected a *bypass-path* must be computed for those wavelengths defined as *OSW* in this lightpath. 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 (number of hops) *bypass-paths* are selected. Summarizing, in order to explicitly distribute in the set-up message the *bypass-paths*, source nodes must perform both the detection of those wavelengths on a link that potentially cannot be available when establishing the path, and the computation of a *bypass-path* for each one of these wavelengths.

3) **Bypass-paths usage:** Once the working lightpath is computed the set-up message is sent along the selected route. Intermediate nodes can send this set-up message along either

the working path, i.e., the selected wavelength is indeed available, or the *bypass-path*, i.e., the selected wavelength is not really available. Fig. 2 shows the dynamic bypass concept. When node OXC1 receives an incoming request demanding a connection to node OXC4, OXC1 must select a suitable lightpath consisting of the physical route from OXC1 to OXC4 and the wavelength to be used to transport the required traffic. According to the BBOR characteristics we suppose that for example, the selected path is made up of nodes OXC1-OXC2-OXC3-OXC4, and the selected wavelength is λ_1 . Assuming that the selected λ_1 has been defined as an *OSW* in the link OXC2-OXC3, the node OXC1 must also compute a *bypass-path* to bypass this wavelength on this link. A feasible *bypass-path* to bypass this link is that made up of OXC2-OXC5-OXC3. It is important to notice that this *bypass-path* is not permanently reserved instead it is only used when λ_1 is really not available at the path set-up time in that link defined as an *OSW*. Hence, those *bypass-paths* not used in the path set-up time are released.

III. THE BBOR MECHANISM IN A WAVELENGTH CONVERSION SCENARIO

A new algorithm inferred from the BBOR mechanism, named *ALG3* (as an extension of the already proposed *ALG1* and *ALG2*), is suggested in this paper to address the routing inaccuracy problem in a wavelength conversion scenario. *ALG3* incorporates several different aspects in comparison to the *ALG1* and *ALG2*. In fact, although the main concepts are the computation of both the $OSW_i(L,F)$ parameter and the *bypass-paths*, in *ALG3* both aspects are differently handled. There are three main differences between *ALG3* and the other ones:

Firstly, *ALG3* does not select only the shortest paths. Instead, the *K*-shortest paths of all possible disjoint paths between source and destination are computed. Secondly, unlike *ALG1* and *ALG2* where the weight of each link was separately defined by the attributes *L* and *F* of the $OSW_i(L,F)$ parameter, in *ALG3*, the weight associated to each link is represented by the factor L/F . This factor stands for a balance between the number of potentially obstructed links and the real congestion instead of choosing one against the other. Moreover, since longer paths than the shortest ones can be selected, the length *n* of the path (hopcount) is also included in the path decision. Hence, in order to avoid those paths that are either widest (in terms of wavelength availability) but too long or shortest but too narrow, the weight factor of each path is modeled by F_p according to the expression

$$F_p = n \left(\frac{L}{F} \right). \quad (2)$$

Lastly, once the path has been selected, *bypass-paths* are computed. Nevertheless, before computing the *bypass-paths* it is necessary to know whether the output link where a certain λ_i is defined as λ_i^{os} belongs to a node with conversion capabilities. If it does, the bypass concept can be modeled by simply converting the unavoidable wavelength to an available wavelength. If it does not or there are not available wavelengths where limited conversion can be done, *bypass-paths* are computed similarly to *ALG1* and *ALG2*. The box enclosed in Fig. 3 shortly summarizes *ALG3*. An analysis of the cost of the BBOR mechanism can be found in [5].

IV. PERFORMANCE EVALUATION

To evaluate the BBOR mechanism in WI networks a set of simulations have been carried out over the network topology shown in Fig. 4, where the possible source-destination pairs are randomly selected. We suppose a 5-fiber topology, with 10 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. Each arrival connection requires a full wavelength on each link it traverses.

In order to check the benefits obtained when applying *ALG3*, in Fig. 5 we compare the behavior of the *ALG1*, *ALG2*, *ALG3* and *First-Fit* algorithms in an optical network without conversion capabilities by measuring the impact on the blocking probability.

According to [5] all the simulations have been performed considering $N = 6$ (threshold value for triggering update messages) and $T_p = 50\%$ (threshold percentage of N used to define *OSWs*). A light improvement in the blocking probability is obtained with *ALG3* in comparison with *ALG1* and *ALG2*. Actually, although in this scenario no conversion is allowed in the *bypass-path* computation, the weight factor modification implemented in *ALG3* leads to an even further improvement of the blocking probability.

Then, Fig. 6 exhibits the *ALG3* performance when it is applied to a network with sparse and limited wavelength conversion. In our simulations we consider a fixed value of $D = 25\%$ and q in the range of 10%, 25% and 50%. Remind that D represents the *degree of translation*, i.e., it defines the range of wavelength conversion on a node, and q represents the

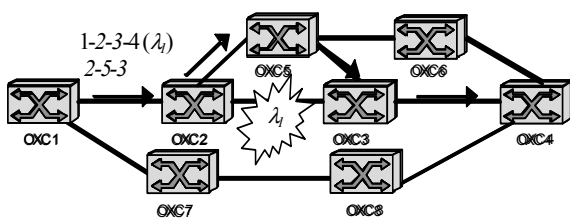


Fig.2 Example showing the dynamic bypass concept

BYPASS BASED OPTICAL ROUTING (ALG3)

1. Select the *K*-shortest paths
2. Mark those wavelengths that are defined as *OSW*
3. Select that λ that minimizes the cost according to

$$F_p = n \left(\frac{L}{F} \right)$$
4. Compute the *bypass-paths* for all wavelengths defined as *OSW*, considering wavelength conversion when it is possible
5. Decide which *bypass-paths* must be used in accordance with real available resources in the path set-up time

Fig.3 *ALG3* description

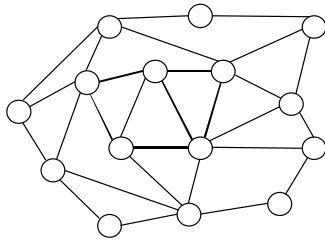


Fig.4 Topology used in simulations

conversion density, i.e. it defines the amount of nodes with conversion capabilities on the network. A main aspect to be solved is which nodes should have conversion capabilities. We address this aspect by locating the wavelength converters in those nodes that support more traffic. These nodes are found after running *ALG3* considering there is no wavelength conversion availability in the network. *ALG3* and the *Shortest Path (SP)* algorithms are compared, combining the *D* and *q* values. We can see that going on the same trend, *ALG3* also decreases the blocking probability when incrementing the number of conversion capable nodes in the network. Moreover, we can see that when using *ALG3*, increasing the converters density *q* more than 25% does not imply a significant blocking probability reduction.

Finally, carefully observing Fig. 5 and Fig. 6 we notice that *ALG3* in a non wavelength conversion scenario presents a similar behavior than that obtained for the *SP* algorithm in a

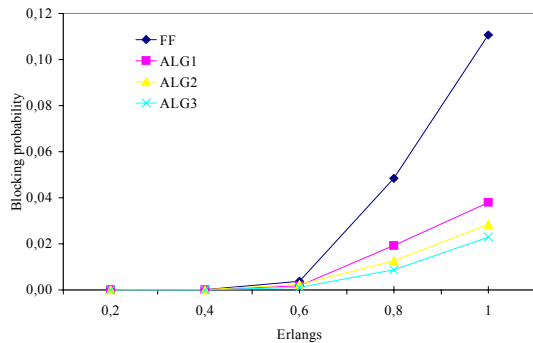


Fig.5 Blocking probability in wavelength-selective networks

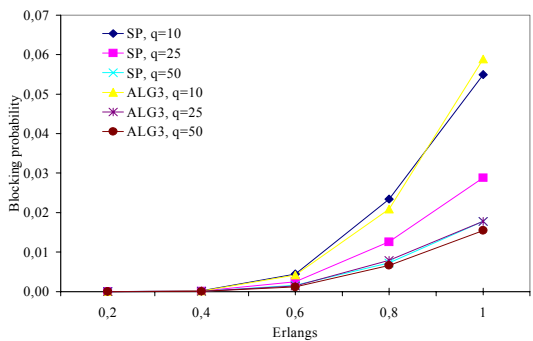


Fig. 6 Blocking probability in wavelength-interchangeable networks with $D=25\%$

wavelength convertible scenario for $q = 10\%$ and $D = 25\%$. In this way, by applying the *ALG3* a cost reduction can be achieved while maintaining the same blocking probability. Hence, we can argue that *ALG3* can be used as an alternative solution (software solution) to reduce the blocking probability in a WS network to that based on adding wavelength conversion capabilities (hardware solution). Therefore, taking into account the current high prices for wavelength converters at network elements, *ALG3* is presented as a good solution to reduce the blocking probability while tempering the signaling overhead produced by the update messages.

V. CONCLUSIONS

This paper describes and evaluates a new routing algorithm, named *ALG3*, inferred from the *BYPASS Based Optical Routing* mechanism (BBOR), already introduced in [5], in order to reduce the routing inaccuracy effects in optical networks with limited and sparse wavelength conversion. Basically *ALG3* modifies the BBOR structure in two main aspects. On one hand a new weight factor is associated to each link to optimize the lightpath selection. On the other hand, the *bypass-paths* computation has been modified so that it includes the wavelength conversion capability as a bypass option on those nodes where wavelength conversion are available.

Initial results show that *ALG3* improves *ALG1* and *ALG2*, substantially reducing the blocking probability ratio when applying to networks without conversion capabilities, i.e. *wavelength-selective* (WS) networks. Then, *ALG3* is applied to *wavelength-interchangeable* (WI) networks assuming a fixed *degree of conversion* and keeping the *converters density* as a variable parameter. Two conclusions can be drawn after analyzing the simulation results. Firstly, WS networks always present a higher blocking probability than WI networks. Secondly, it is shown that in any case *ALG3* exhibits a better behavior when compared to the shortest path algorithm.

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