FRA: A new Fuzzy-based Routing Approach for Optical Transport Networks

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***Abstract*—Providing networks with QoS guarantees is one of the key issues to support current and future expected clients' demands. In this scenario, QoS routing is definitely critical as being responsible for defining those optimal routes supporting traffic forwarding throughout the whole network. This paper proposes two new QoS-aware RWA algorithms dealing with the routing inaccuracy problem, aiming at reducing blocking probability while limiting signaling overhead and balancing network load. The proposed algorithms extend the work already published by the authors on prediction based routing by adding a novel fuzzy-based technique featuring a powerful tool for modeling uncertainty. The proposed algorithms are compared with a well-known RWA algorithm and results show the benefit of introducing the fuzzy techniques in the RWA selection.**

***Index Terms*—RWA, routing inaccuracy problem, prediction based routing.**

I. Introduction

Optical Transport Networks (OTN) appear as a solution to support new network requirements motivated by both a significant increment of network users and the current and future Internet applications deployment. Optical networks provide high capacity to cope with the increasing demands of interactive application such video on demand. This great capacity is achieved by means of the wavelength-division multiplexing (WDM) technique, i.e. over the same fibre the information is transmitted by different wavelengths or colors. In Optical Networks the objective of a RWA (Routing and Wavelength Assignment) algorithm is to select the lightpath(route and wavelength) with higher chances to reach the destination while lowering the chances to reduce the connection blocking. On the other hand the objective of QoS routing algorithms is to find the path best suiting the given set of QoS constraints, such as bandwidth, delay, jitter or packet loss. A large number of works can be found in the literature dealing with the RWA problem; that is, proposing algorithms that taking into account the network state information (i.e., topology and resources availability) assign the best lightpath reaching to a connection request, that is the lightpath with lower probability of being blocked.

In a dynamic scenario, where connection requests arrive in some random fashion, lightpaths are continuously set up and torn down along the time. Assuming distributed source routing (an ASON recommendation [1]), the information to be used by the RWA algorithms to select the route and the wavelength might not be completely accurate. In fact, the main disadvantages of distributed source routing are the high signalling overhead produced by the network state information updating process and the inaccuracy of the network state information. Depending on the routing mechanism, the network information about wavelength availability is periodically flooded and then, updated among all the nodes in the network. There are several studies ([2][10]), showing that even with unrealistic (non practical) updating periods (a message per network state change) there is not full guarantees that the network information on the source nodes would be completely accurate. In this scenario source nodes can select lightpaths based on outdated information what may drive to assign lightpaths to routes and/or wavelengths not longer available. The problem of having outdated or inaccurate network state information is known as the Routing Inaccuracy Problem. Different works in the literature propose mechanisms to counteract this negative effect on the path selection process.

In this study, we present two novel RWA routing algorithms addressing the routing inaccuracy problem in optical networks. The main objective of both algorithms is to reduce the effects of the routing inaccuracy problem while minimizing the signaling overhead as long as network load keeps balanced. This is achieved by including two concepts in the path computation: i) prediction issues (PBR mechanism)[2] and ii) a new technique, termed the Fuzzy set. Both algorithms are conceptually inferred from our previous routing algorithm, namely BAPHOR [3].

The basic idea behind predictive and fuzzy mechanisms is that network state information is not obtained from updated messages, but rather is inferred from the behavior of previous connection requests. In this context, signalling overhead is completely eliminated since only topological changes are flooded through the network.

The rest of this paper is organized as follows: Section II presents the related work. Section III shortly describes the basics of the traditional BAPHOR algorithm. Then, the proposed algorithms are introduced in Section IV. The simulation model is presented in Section V and the results shown in Section VI. Finally, Section VII concludes the paper.

II. Related Work

Different works in the literature propose mechanisms to counteract the negative effect of computing routes based on inaccurate network state information. The contributions in [5]-[6] evaluate the impact on the blocking probability because of selecting lightpaths under inaccurate routing information. New Routing and Wavelength Assignment(RWA) algorithms, able to tolerate inaccurate network state information have been proposed in [7]-[11].

In [7] Zheng et al assume that distributed routing based on global network state information requires strict guarantees in the routing information accuracy. To reduce the inaccuracy, authors assume that the routing information is updated whenever there is a change. However, even in this non-real scenario the non-negligible propagation delay also yields to outdated information.

Another contribution on this topic can be found in [8] where Darisala et al propose a mechanism whose goal is to control the amount of signalling 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. The effects of the introduced inaccuracy are handled by computing alternative disjoint lightpaths which act as protection lightpaths when resources in the working path are not enough to cope with those required by the incoming connection.

Authors in [9] propose a new distributed signalling scheme named the Intermediate-node Initiated Reservation (IIR) dealing with the outdated information problem. They present a model in which reservations could be initiated by some intermediate nodes. The main concept underlying this lightpath control scheme boils down to allowing the reservation to be initiated by a set of intermediate nodes before the connection request reaches the destination node.

The BYPASS Based Optical Routing (BBOR) proposed by Masip et al aims at reducing the connection blocking probability caused by taking routing decisions under inaccurate network state information in multifibre wavelength switched networks with [11] and without [10] wavelength conversion capabilities. The BBOR mechanism allows several nodes along the selected path to dynamically reroute the setup message in those links where there is no wavelength availability.

More recent proposals dealing with the routing inaccuracy problem can be found in [12]-[13]. In [12] authors propose to allow multiple capacity search and/or wavelength reservation executed simultaneously. If one of the selected wavelengths is unavailable the mechanism allows the lightpath to be set up in a different wavelength from those previously selected. The main drawback of this mechanism is the over reservation. A different approach and similar to the BBOR proposal can be found in [13] where authors also propose crankback rerouting by allowing new retries on alternate paths that circumvent blocked links or nodes. Moreover the RWA algorithm is improved by means of ant colony optimization. In general the above reviewed works dealing with the routing inaccuracy problem, propose both, new routing algorithms and new update policies. Concerning to the update policy, the higher the update frequency is the lower the inaccuracy would be. But it may exist a trade-off between the frequency of updating and the signalling overhead produced by these update messages in the network. Even assuming that in an optical network that the signalling overhead might not be a problem because a fibre or a wavelength may be dedicated to signalling tasks (out-of-fibre/band), it is possible that the information is not completely accurate. It exists a minimum propagation time needed to disseminate and to stabilize this information in the network databases.

On the other hand, it is important to highlight that nowadays' Internet only provides a best effort transmission model, which is definitely not suitable to face with. Real time applications requiring a certain degree of Quality of Service (QoS). The volume of information that source nodes exchange when the QoS parameters are included is larger, impacting negatively on the signalling overhead.

In [2] authors proposed the PBR mechanism for optical networks, which is based on the prediction concepts used in branch prediction. The main objective of the PBR mechanism is to optimize the routing decision not using the network state information coming from updated messages but rather looking at how a lightpath behaves in previous connection requests. The mechanism is based on registering the lightpaths behavior through a two-bit counter, hence removing the need for flooding update messages throughout the whole network, therefore substantially reducing signaling overhead while negatively impacting on the network.

III. The BAPHOR Algorithm

As mentioned in section I, the RWA algorithms proposed in this paper are conceptually based on the BAPHOR algorithm proposed in [3]. This algorithm assigns a weight to each lightpath aiming at minimizing the negative effects of routing under inaccurate network state information while simultaneously balancing the traffic load. The BAPHOR algorithm bases its decision on choosing the ligthpath that minimizes the W(λ_i) weight. W(λ_i) is computed according to Eq.(1).

$$W(\lambda_i) = Hn \times Od \times \left[\frac{1}{Cd}\right] + Counter,\ 1 \leq i \leq n \quad (1)$$

As Eq.(1) shows there are four basic components impacting on how BAPHOR selects the ligthpath: the length of the selected lightpath (Hn), the degree of congestion (Cd), the degree of obstruction (Od), and the two-bit counter, being n the number of lightpaths. The BAPHOR algorithm was initially proposed in [3] for hierarchical optical networks where a two-bit counter was allocated for each hierarchical level. However, the scenario analyzed in this paper is a flat optical network, that is, only one hierarchical level and then there is only a two-bit counter in Eq.(1). A version of the BAPHOR algorithm for IP/MPLS networks can also be found in [4].

The length, Hn, is simply the number of hops. The degree of congestion, Cd, is the wavelength availability, that is, the minimum number of available wavelengths of that colour in that route. In our proposal, this availability is only from the point of view of the source node because there is no updating for network state information. Each source node updates each local network database with the availability of all links on the network inferred from the information about the connections it either establishes or tears down. The degree of obstruction in Eq.(1), Od, tries to minimize the impact of such inaccuracy on the lightpath selection process. Od represents the number of links on the lightpath where such a wavelength is defined as potentially obstructed wavelength (POW). Being B (any link is a bundle of B fibres) the total number of a certain wavelength λ_i on a link, R the current number of available λ_i on this link, the wavelength λ_i is defined as POW, namely $\lambda(POW)_i$ on a certain link, when R is below a percentage (pr) of B. When computing the weight in Eq.(1), the counter is used to predict the route and the wavelength availability according to the routing information obtained in previous connection establishments.

By computing W(λ_i) we will know the weight of each wavelength on an end-to-end path (the updated network state information is not used to take routing decisions, so the update process is completely unnecessary). Instead, each source node registers, for each of its possible destinations, previous information about both the wavelength and the route allocated. For every wavelength on every route (lightpath) to every destination a two-bit counter is defined. If the counter value is lower than 2 (0 or 1), the lightpath is predicted to be available. Otherwise (counter value 2 or 3), the lightpath is predicted to be not available. After the lightpath selection, if the connection can be established without blocking, the selected counter is decreased, otherwise it is increased.

The Od/Cd factor stands for a balance between the number of potentially obstructed wavelengths and the real congestion. The length of the path is also included in order to avoid those paths that are either widest but too long or shortest but too narrow.

IV. The proposal

Our goal is to generate a RWA routing algorithm that efficiently deals with the routing inaccuracy problem (hence reducing the blocking probability) while guaranteeing both low signalling and an efficient network load balance. This turns out into two new RWA routing algorithms, Improved BAPHOR (IBAPHOR) and Fuzzy-based Routing Approach (FRA). In the following, we present a detailed description of both algorithms.

A. The IBAPHOR Algorithm

The traditional BAPHOR algorithm is aimed at minimizing the impact of the routing inaccuracy on the blocking probability, as well as minimizing the number of link-state updates and balancing the network load.

We detect two weaknesses on the traditional BAPHOR performance. First, as Eq.(1) shows, in cost function, W(λ), of the BAPHOR, the counter has the main weight; but for routes with equal counter the second term breaks the tie. Therefore, most of time, when the counters are not equal, the second term is useless and does not have any role in making decisions. Second, when the counter of cost functions of two or more lightpaths are equal and also the Od factors of them are zero too, the first W(λ) will be selected without considering the Hn and Cd factors.

In order to improve these weaknesses, we suggest the Improved BAPHOR (IBAPHOR). In the IBAPHOR algorithm all factors (Cd, OD, Counter and Hn) cooperate together to select the best lightpath; to this end we also add an ϵ to the Od for solving the second weakness of the traditional BAPHOR. As we mentioned before, the cost function consists of two terms : $'counter'$ and $'Od.[1/Cd].Hn'$. In the traditional BAPHOR, when the Od be zero the second term will be zero too (without considering the Hn and Cd factors). For this reason, we add the ϵ to the Od for considering Hn and Cd factors in any case (even when the Od is zero) as follow:

$$W(\lambda_i) = Hn \times (Od + \epsilon) \times \left[\frac{1}{Cd}\right] \times [Counter + \epsilon] \quad 1 \leq i \leq n \tag{2}$$

In Eq.(2), we add the ϵ to the counter too, since the counter may be zero in some situations. The main advantage of the IBAPHOR is that it considers all possible factors concurrently (Cd, Od, counter and Hn) when selecting lightpath.

B. The FRA algorithm

The IBAPHOR algorithm still faces an unsolved problem, despite the fact that in the IBAPHOR cost function all factors (Cd, Od, counter and Hn) cooperate together to select best lightpath (the percentage of), this cooperation is not fair enough. Since Hn is usually more bigger than the counter and also the Od and also $(1/Cd)$ is below of one, the effects (scales) of these factors on the W(λ) computation are not the same and hence they do not have the same effect on computing the W(λ).

For this reason, we propose a new fuzzy-based algorithm named FRA. Our FRA algorithm solves this problem and makes a fair cooperation between all factors by using a fuzzy set technique. In the FRA algorithm, all factors (Cd, Od, counter and Hn) are mapped on the range [0, 1].

The theory of fuzzy sets was introduced by L. Zadeh in 1965 [14]. After the pioneering work of Zadeh, there has been a great effort to obtain fuzzy analogues of classical theories. Fuzzy set theory is a powerful tool for modeling uncertainty and for processing vague or subjective information in mathematical models. Their main directions of development have been diverse and its applications to the very varied real problems. The notion central to fuzzy systems is that truth values (in fuzzy logic) or membership values (in fuzzy sets) are indicated by a value on the range [0, 1], with "0" and "1" representing absolute Falseness and absolute Truth respectively.

The FRA algorithm considers four fuzzy sets; A, B, C and D. The fuzzy set A for Hn, B for Cd, C for Od and D for the counter. Each set also has a membership function. The membership function of every set maps each value to a value on the range [0, 1]. Then, there are four factors on range of [0,1] for each lightpath. A fair cooperation to compute the cost of lightpaths can be achieved by multiplying these factors together. It means that all four membership values of each lightpath will be multiplied together to compute their related W(λ). Finally, the lightpath with lowest W(λ) will be selected. Next text explains the FRA algorithm practically:

Assume $A = [h_1, h_2, ..., h_n]$ is the fuzzy set of all lightpaths's hop counts. Set A has a membership function, $mA(h_i)$ which can be defined as below:

$$\omega 1 = mA(h_i) = [\frac{h_i}{MaxHop}], \quad 1 \leq i \leq n \tag{3}$$

Where n is the number of lightpaths, and h_i is hop count of i_{th} lightpath.

And $B = [CD_1, CD_2, ..., CD_n]$ is the fuzzy set of all lightpath's CDs with membership function $mB(CD_i)$:

$$\omega 2 = mB(CD_i) = 1 - [\frac{CD_i}{MaxCD}], \quad 1 \leq i \leq n \tag{4}$$

Where n is the number of lightpaths, and CD_i is congestion degree of i_{th} lightpath.

And $C = [OD_1, OD_2, ..., OD_n]$ is the fuzzy set of all lightpath's ODs with membership function $mC(OD_i)$:

$$mC(OD_i) = [\frac{OD_i}{MaxOD}], \quad 1 \leq i \leq n \tag{5}$$

Consider n is the number of lightpaths, and OD_i is obstruction degree of i_{th} lightpath. Let $\alpha = 0$ and $StrongAlphaCut$ (C'_α) of set C be obtained from the following formula:

$$\omega 3 = mC'_\alpha = [OD_i | mC(OD_i) > \alpha], \quad 1 \leq i \leq n \tag{6}$$

Alpha cut is simply a threshold level that converts a fuzzy set into a crisp set. It generates a crisp set that contains the elements that have a membership or grade greater than a certain value. We have already performed $strongalphacut$ in Eq.(6). An $alphacut$ is considered to be a $strongalphacut$ if the inequality of the threshold is strict. For example $x > .25$ is a strong alpha cut while $x >= 68$ is a regular alpha cut.

Also $D = [Counter_1, Counter_2, ..., Counter_n]$ is the fuzzy set of all lightpath's $Counters$ with membership function $mD(Counter_i)$:

$$\omega 4 = mD(Counter_i) = [\frac{Counter_i + \epsilon}{MaxCounter + \epsilon}], \quad 1 \leq i \leq n \tag{7}$$

Where n is the number of lightpaths, and OD_i is the obstruction degree of i_{th} lightpath. Also we add the ϵ to the counter, to deal with the cases where the Counter is equal to zero.

The FRA algorithm computes W(λ) for each lightpath based on Eq.(8). Finally, the lightpath with minimum amount of W(λ) will be selected.

$$W(\lambda_i) = \begin{cases} \omega 1 \times \omega 2 \times \omega 3 \times \omega 4, & OD_i > \alpha \\ & 1 \leq i \leq n \\ \omega 1 \times \omega 2 \times \epsilon \times \omega 4, & OD_i \leq \alpha \end{cases} \quad (8)$$

The ϵ is a very low float number; n is the number of lightpaths and the α is our threshold for computing strong-alpha-cut of set C. We use the strong-alpha-cut technique to prevent the W(λ) of lightpaths with $OD = 0$ not be equal to zero.

V. Simulation Model

The algorithms proposed in this paper have been evaluated by means of simulation over the topology shown in Fig. 1. The links have the same available bandwidth, that is 3 fibres on each link with M available wavelengths. Simulations are run using VC++. We simulate all algorithms with three different amount of wavelengths (M=10, 13 and 16). All the connection requests have an average holding and arrival times of 10 units of time. We simulate a total number of 27999 connection requests: 8 of the nodes of the network act as source and destination nodes creating 56 source destination pairs of nodes with 1 Erlang between each source destination pair of nodes (56 Erlangs in total in the network).

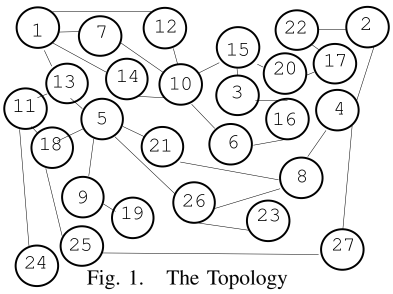

Fig. 1. The Topology

We compare our proposals that do not need network state update messages versus the Shortest-Path Least Loaded (SP-LL) algorithm [15]. SP-LL algorithm selects the shortest available path and the least loaded wavelength, that is the wavelength available in more fibres of the links of path, according to the global network state information stored (and updated) on the nodes.

It is worth noticing that our proposed algorithms, IBAPHOR and FRA do not need updating of network state information (neither BAPHOR). This information is inferred from the behavior of previous connection requests and the corresponding two-bit counter updating.

We simulate SP-LL when the updating process is produced every 1, 2, 5, 10, 15 and 20 units of time. Updating every 1 unit of time means 10 floodings of updated information during the holding time of the connection request, which it is not affordable from the point of view of signaling overhead.

VI. Simulation Result

Figures. 2, 3 and 4 show the obtained FRA and IBAPHOR blocking numbers compared to that obtained by the SP-LL and the BAPHOR for 10, 13 and 16 wavelengths and with various updating periods only for SP-LL. The IBAPHOR and FRA algorithms successfully improve the traditional BAPHOR algorithm in all states. The FRA algorithm is better than the IBAPHOR in all cases.

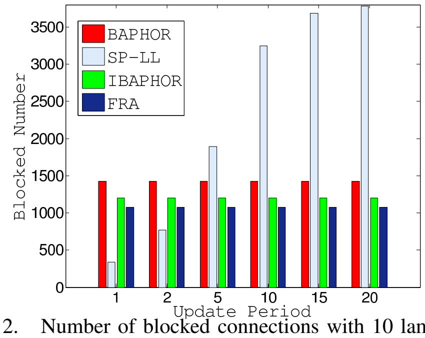

Fig. 2. Number of blocked connections with 10 lambdas

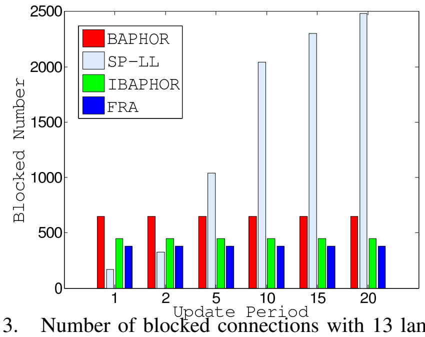

Fig. 3. Number of blocked connections with 13 lambdas

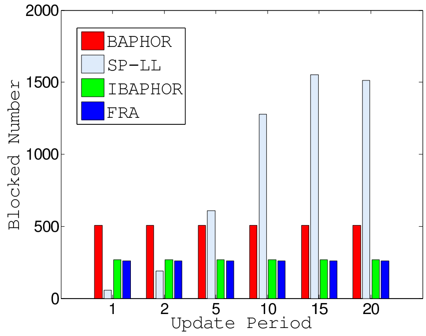

Fig. 4. Number of blocked connections with 16 lambdas

However, when comparing with SP-LL the FRA algorithm improves SP-LL from updating every 5 units of time (5,10,15 and 20), even more, all the algorithm based on prediction concepts (BAPHOR, IBAPHOR and FRA) improve SP-LL from updating every 5 units of time. The predictive algorithms only have worse results than SP-LL for updating periods of 1 and 2. Keeping in mind that updating periods of each 1 (2) unit(s) of time mean flooding the updated information 10 (5) times during the holding time, we can conclude that this is unaffordable from the point of view of the signaling overhead and moreover from the point of view of the delay in transmitting the network information among all the networks in the network.

In figure 5 we compare the algorithms from another perspective. Short updating periods will indeed increase the amount of updated information to be flooded throughout the network. Therefore, updating in short periods of time, i.e 1 and 2 units of time, is unaffordable from the point of view of both the overhead and delay. Also updating in long periods of time, i.e 15 and 20, is unaffordable from the point of view of the network state information accuracy. Therefore, we assume, for testing purposes an intermediate value of 5 as the best scenario for performance evaluation of the algorithms. As figure. 5 shows, the fuzzy-based algorithm (FRA) is the best algorithm for all lambdas. Also the SP-LL is a poor algorithm in updating 5 units of time.

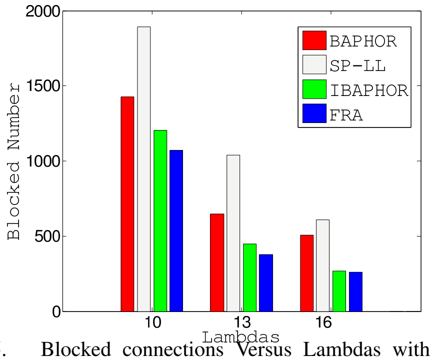

Fig. 5. Blocked connections Versus Lambdas with update period of 5

For all these reasons and considering the updating cost, the FRA algorithm is actually sufficient for computing paths in optical networks since it achieves excellent results on blocking probability without increasing the updating cost.

VII. Conclusion

This paper presents two novel RWA routing algorithms dealing with the routing inaccuracy problem in optical networks. Both algorithms are based on the prediction based routing strategy already proposed by the authors, whose main contribution focuses on completely removing the need for flooding updating messages hence substantially reducing the signaling overhead. Conceptually speaking, the main contribution of this paper is the introduction of fuzzy techniques in the RWA decision. The proposed algorithms succeed on reducing the expected blocking probability increment, produced when routing paths in a source routing scheme (based on global network state information) without flooding any update message (except those to advertise topology changes). Obtained results show that the blocking probability is substantially reduced in realistic scenarios when applying the proposed routing algorithms.

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