A New Prediction-Based Routing and Wavelength Assignment Mechanism for Optical Transport Networks[1]

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Abstract. In optical transport networks algorithms dealing with the lightpath selection process select routes and assign wavelengths based on the routing information obtained from the network state databases. Unfortunately, due to some factors, in large dynamic networks this routing information may be non-accurate enough to provide successful routing decisions. In this paper we suggest a new prediction-based routing mechanism where lightpaths are selected based on prediction decisions. Consequently, the routing information is not required at all, so updating this information is neither required. In short, the signaling overhead produced by the updating process is practically removed.

Keywords: Optical routing, routing inaccuracy, prediction-based routing.

1 Introduction

Internet traffic demands are extensively growing in the last years due to the real time applications such as video, multimedia conferences or virtual reality. Optical wavelength-division multiplexing (*WDM*) networks are able to provide great bandwidth to support this growing traffic demands. Unlike traditional IP networks where the routing process only involves a physical path selection, in *WDM* networks the routing process involves both a physical path selection and a wavelength assignment, i.e., the routing and wavelength assignment (*RWA*) problem. The *RWA* problem is often tackled by being divided into two different sub-problems, the routing sub-problem and the wavelength assignment sub-problem. The first approach to the routing sub-problem in a *WDM* network focuses on always selecting the same route between each source-destination node pair, known as static routing. This route is calculated for example in the Fixed-shortest path, by means of the Dijkstra's [1] algorithm or the Bellman-Ford's algorithm. However, since the performance of the fixed-shortest path algorithm is limited, the Fixed-Alternate routing is proposed [2]. According to this, more than one fixed route is calculated for every source-destination node pair. For each new connection request the routing algorithm tries to send the traffic through the

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calculated fixed routes in sequence. This solution substantially reduces the number of connection blocked respect the fixed-shortest path.

The main problem of the static routing is that it does not consider the current network state. Hence, the second approach for the routing sub-problem in *WDM* networks is the dynamic (or adaptive) routing, which selects routes based on the current network state. There are different approaches for this scenario, such as the adaptive shortest-cost-path routing and the Least-Congested Path algorithm, *LCP* [3]. In short, in spite of the fact that *LCP* performs better than Fixed-Alternate routing, it is worth noting that in adaptive routing source nodes require of continuously receiving update messages about the changes in the network state.

The static wavelength assignment sub-problem consists in given a set of established routes for a set of lightpaths, to assign the wavelength to each route. In this paper we focus on Wavelength Selective (*WS*) networks, that is, networks without wavelength conversion capabilities. The main restriction in WS networks is that routes sharing the same link (or links) must have different wavelengths, i.e., the same wavelength must be assigned to the lightpath on all the links in its route.

If connection requests arrive by an incremental or dynamic traffic, heuristic methods are used to assign wavelength to the lightpaths. In this case the number of available wavelength is supposed to be fixed. A large number of different heuristic algorithms have been proposed in the literature as shown in [4], such as Random, First-Fit, Least-Used, Most-Used, Min-Product, Least-Loaded, Max-Sum, Relative Capacity Loss, Protecting Threshold, and Distributed Capacity Loss

Most *RWA* solutions proposed in the recent literature use distributed mechanisms based on source-routing. In this scenario the routing inaccuracy problem (*RIP*) comes up. The *RIP* describes the impact on global network performance because of taking *RWA* decisions according to inaccurate routing information. In highly dynamic networks, inaccuracy is mainly due to the restriction of aggregating routing information in the update messages, the frequency of updating the network state databases and the latency associated with the flooding process. It is worth noting that two factors are negative collateral effects of their inclusion to reduce the signaling overhead produced by the large amount of update messages required to keep accurate routing information. It has been clearly shown [5] that the routing inaccuracy problem, that is, to select a path based on outdated network state information, may significantly impact on global network performance significantly increasing the number of blocked connection requests.

In this paper we propose the prediction-based routing as a mechanism that does not only address the *RWA* problem but also the *RIP*, achieving a drastic reduction in the signalling overhead. In short, the prediction-based routing mechanism selects routes not based on the 'old' or inaccurate network state information but based on some kind of ‘predicted' information. Hence, since routing information from network state databases is not required, we may eliminate the need of flooding update messages (except those required for connectivity).

The remainder of this paper is organized as follows. Section 2 reviews main significant contributions existing in the recent literature about the Routing Inaccuracy Problem. Then, Section 3 proposes the Predictive Routing Algorithm, Section 4 evaluates our proposal and finally, Section 5 concludes the paper.

2 Handling the Routing Inaccuracy Problem

Most of the Dynamic *RWA* algorithms assume that the network state databases (named Traffic Engineering Databases, TEDs when including QoS attributes) contain accurate information of the current network state. Unfortunately, when this information is not perfectly updated routing decisions can be wrongly performed at the source nodes producing a significant connection blocking increment (i.e., the routing inaccuracy problem). Most recent related work is summarized in the following paragraphs.

In [5] 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 [6] 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 [7] 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 [8] authors propose a new adaptive source routing mechanism named BYPASS Based Optical Routing (*BBOR*), aiming to reduce the routing inaccuracy effects, i.e., blocking probability increment and non-optimal path selection, in WS networks. In [9] authors extend the mechanism to be applied to networks with conversion capabilities. The *BBOR* mechanism is based on bypassing those links which cannot forward the setup message because of lacking the selected wavelength. The bypass is achieved by forwarding the setup messages through a previously precomputed alternative path (bypass-path).

3 New Proposal of Prediction-Based Routing

The main idea of the Prediction-based Routing (*PBR*) mechanism is based on extending the concepts of branch prediction used in computer architecture [10]. In this field, there are several methods to predict the direction of the branch instructions. The prediction of branch instructions is not made knowing exactly the state of the processor but knowing the previous branch instructions behavior. The prediction can be either wrong or correct but the goal is to maximize the number of correct predictions. Considering this idea, the *PBR* mechanism is based on predicting the route and wavelength assignment between two nodes according to the routing information obtained in previous connections set-up. Thus, the *PBR* avoids the use of inaccurate network state information obtained from the Traffic Engineering databases, therefore removing the need of frequent updating. It is necessary to mention that a minimal updating is required to ensure connectivity just reporting about link/node availability.

The main objective is to optimize the routing algorithm decision, considering the state 'history' for each path, that is, every source node must keep previous information about both wavelength and route allocated to this path established between itself and a destination node This history is repeated all through the time and is stored in a history register, which will be used as a pattern of behavior, which is used to train a new table, named Prediction Table (*PT*).

It must be noticed that in order to generate the history, every source node must keep not only the last information but also previous information of the wavelength and routes used. With all this information it creates an index which is then used to index the *PT*. This *PT*, has different entries, each keeping information about a different pattern by means of a counter. The prediction is obtained reading the counter value from the table. These counters are updated (increased or decreased) in order to learn [10].

3.1 Wavelength History Registers

Before defining a prediction algorithm it is necessary to introduce the parameter used to decide when the history registers may be modified. We define indeed a cycle as the basic unit of time where the history state is susceptible to be modified.

As it is mentioned above every source node must know the history state information, and for this reason the history state is kept in history registers. There are one of such registers for every wavelength on every path to every destination node. We name these registers as wavelength registers (*WR*).

We propose a method to register the history of the network state in every source node based on assuming that for each cycle, each *WR* is updated with a 0 value when this wavelength on this path is used on that cycle. Otherwise, the register of an unused wavelength on a path is updated with a 1. It must be noticed that the expression "a path is used" means that it has been selected by the prediction algorithm and actually the decision is right since the path is available. On the other hand, "a path is unused" when no incoming connection is assigned to this path.

3.2 Prediction Tables

The prediction tables are the base to be able to predict a wavelength and a path. In the source nodes one prediction table, *PT*, is needed for every feasible circuit between any source-destination node pair. The prediction table for a wavelength on a path is accessed by an index obtained from the corresponding *WR*. For example, a source node sends traffic towards two different destination nodes and every source-destination node pair has two different paths (two shortest-paths). Moreover, if we assume the existence of 6 wavelengths then 24 *PTs* are needed on the source node, one for every path and wavelength. In every source node there is the same number of wavelength registers than of prediction tables.

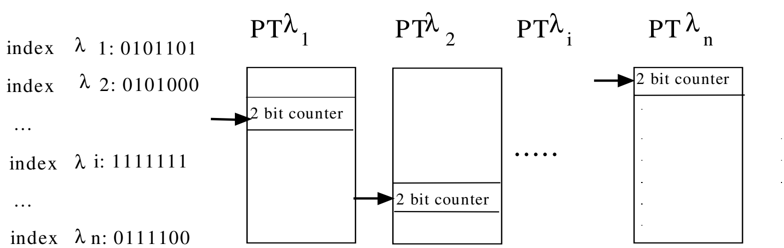
Every entry in the prediction tables has a counter, which is read when accessing the table. This value is compared to a threshold value. If the value from the table is lower, the prediction result is to accept the request through the wavelength on this path. Otherwise, the path is predicted to be not available. The counters are two-bit saturating counter, where 0 and 1 account for the availability and 2 and 3 accounts for path unavailability [10]. The use of two values to account for the availability or the unavailability has been well studied in the area of branch prediction. As it is presented in [10] a two bit counter gives better accuracy than a one bit counter. The use of a one bit counter means that it predicts what happened last time. If last time the traffic request was blocked and the counter has only one bit, the next time that the history is repeated the prediction will be that there will not be availability, or if the traffic was accepted last time the prediction will be that there will be availability. On the other hand if the counter has two bits it is necessary that the traffic request has been blocked (or accepted) two times for the same history to change the direction of the prediction. It is also exposed in [10] that going to counters larger than two bits does not necessarily give better results. This is due to the "inertia" that can be built up with a large counter. In that case more than two changes in the same direction are necessary to change the prediction. Saturating counter means that when counter has a value of 0 and it is decreased its new value is also 0, and when its value is 3 and it is increased its value remains at 3.

As explained above, in the source nodes there is one prediction table, *PT*, for every wavelength on every path and for every destination. The tables have to be updated with the same index used on the prediction. When a new connection request is set up the table of the selected wavelength and path is updated, decreasing the counter. On the other hand, when the connection request has been blocked the counter is increased. The rest of the tables of the unused paths are not updated. Note that when a connection request is set up only the prediction table of the wavelength and path used is updated, but all the wavelength registers corresponding to that destination are updated, of the used with 0 and of the unused wavelengths with 1.

It is worth noting that the updating of prediction tables in the source nodes is done immediately the prediction is done and it is known if the connection request is set up or blocked. For this reason it is not necessary to flood update message through the network to update the network state databases.

3.3 RWA Prediction Algorithm

We define a new *RWA* prediction algorithm, Route and Wavelength Prediction, *RWP*, inferred from the *PBR* mechanism, which utilizes the information contained in the prediction tables to decide about which path and wavelength will be selected. When a new request arrives at the source node demanding a connection to one destination node, all the prediction tables of the corresponding destination are accessed. It must be noticed that one prediction table, *PT*, and one wavelength register, *WR*, exist for every wavelength on every path to every destination. We assume that two shortest paths are computed for every source-destination node pair, SP_1 and SP_2. Prediction tables are accessed by one index per table which is built with the wavelength histories contained in the *WR*. As a consequence of reading the prediction tables, the 2-bit counters are obtained. As an example, Fig. 1 shows the accesses to existing PTs for the shortest path (either SP_1 or SP_2). In Fig. 2 we can see the *RWP* flow chart, supposing W wavlengths in every link. The *RWP* algorithm always starts considering the value of the counter of the *PT* of the first wavelength on the shortest path, for instance SP_1. If the counter is less than 2 (0,1), and this wavelength is free in the node's outgoing link towards SP_1, the prediction algorithm decides to use this wavelength on this path. Otherwise (counter=2, 3 or outgoing link not available) this wavelength is not used. In this last case, the value of the counter of the next PT is examined. Notice that next *PT* corresponds to the second wavelength on SP_1. When the counters of the *PTs* of all the wavelengths of SP_1 have been examined, that is, either the counters always are greater than 2 or all wavelengths on the outgoing link towards SP_1 are not avail-



2 bit counter:	Prediction
00	Not blocked
01	Not blocked
10	Blocked
11	Blocked

Fig. 1. Example of Prediction Table access and values of the 2-bit counters

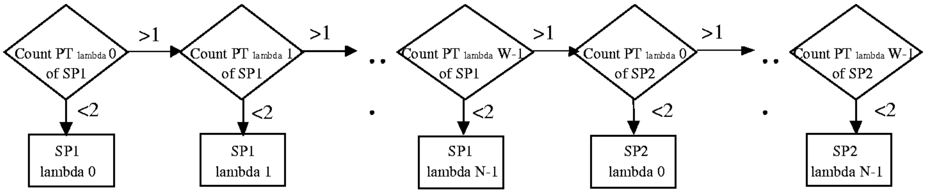


Fig. 2. *RWP* flow chart

able, the prediction algorithm checks the PTs of the next path, SP_2, and so on. When the prediction algorithm, after checking all *PTs*, decides that all the feasible wavelengths on the two paths are blocked, then it tries to forward the connection request through the first available wavelength on the outgoing link towards one of the two shortest path either SP_1 or SP_2. The information about of the outgoing links of the source node is always known by the source node.

Wavelength registers (*WR*) are updated depending on which wavelength is used and whether the request is blocked or not. Also the prediction table, *PT*, of the used wavelength and path is updated by either increasing (means connection blocked) or decreasing (means connection not blocked) the counter of the corresponding entry in the *PT*.

It is worth noting that counters of every wavelength on all the feasible paths between a source-destination node pair can be read, so allowing the prediction to be made, before a new connection request reaches the source node. It is a very significant factor which significantly reduces the cost involved with the *PBR* mechanism. In fact, even though several tables must be accessed to make the prediction, these accesses can be done offline. For every possible new request, the decision of which path to use is already done.

4 Performance Evaluation

We have developed a tool to check the Prediction-Based Routing performance. Simulations are obtained by applying the PBR to a topology test composed by 15 nodes and 27 links, with 2 source nodes and 2 destination nodes. All these nodes are connected by one fiber-links and the number of lambdas is a variable in the range of 2 and 5. Connection arrivals are modeled by a Poisson distribution and each arrival connection requires a full wavelength on each link it traverses. Each *WR* keeps information about the last 5 cycles, 5 bits, so there are 32 entries of 2 bits in each *PT*. In order to show the capacity overhead in terms of bits because of applying the PBR we propose as an example the following: we assume that 2 shortest paths, SP1 and SP2, are computed with 5 lambdas each, therefore will be 20 *PTs* in every source node. Such a scenario represents a total capacity of 1280 bits, which can perfectly be considered as negligible.

The initial goal is to verify that the RWP can know the network behavior, in terms of routing and wavelength assignment, using the prediction tables. We compare the performance of both the *RWP* and First-Fit algorithm. When applying the First-Fit algorithm we vary the updating frequency and the number of available wavelengths on every fiber. As a nomenclature, we define a cycle as the basic unit of time. Fig. 3

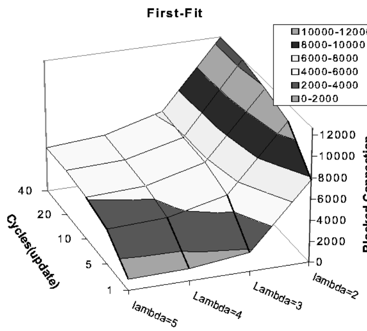


Fig. 3. Blocked Connection Requests for the First-Fit Algorithm

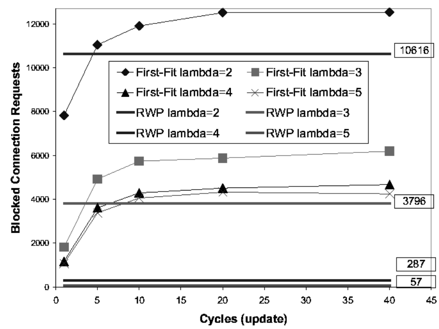


Fig. 4. First-Fit versus *RWP* Algorithm

shows the blocking obtained by the First-Fit algorithm, assuming a total number of 62000 connection requests, when varying the update interval from 1,5,10, 20 and 40 cycles. The Y-axis in Fig.3 depicts the number of blocked requests, consisting in both those requests rejected at any intermediate node and those requests blocked because of lacking resource enough in the path selection process. Fig. 3 also shows the effects of varying the number of available wavelengths. We can see that a minimum number of blocked requests (1054, that is a 1.7%) is obtained when N=1 (update messages every cycle) and the number of lambdas is 5. Fig. 4 shows a comparison between RWP and First-Fit algorithm for several lambda values. Analyzing the results, we demonstrate that from lambda=4 the RWP behaves better than the First-Fit. Therefore, for lambda=4 the result for RWP is of 287 blocked requests and for First-Fit is of 1066, and for lambda=5 the results are 56 blocked requests for RWP and 1054 for First-Fit.

There are two origins of blocked requests. The first is produced when there is no available path for a connection request. The second occurs when the algorithm fails in the route assignment, so that the set-up connection is blocked in an intermediate node.

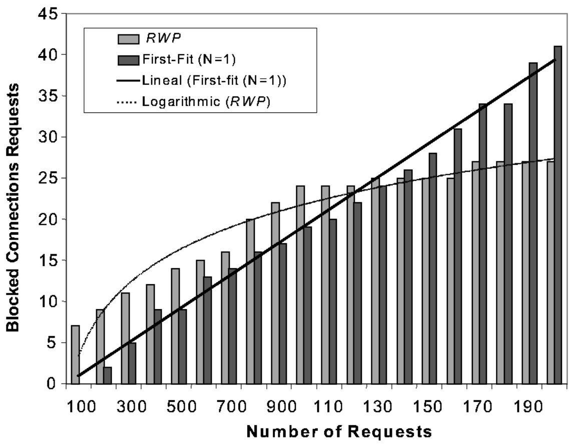


Fig. 5. Evolution of Blocked Connections Requests for the First-Fit and *RWP*.

The *RWP* achieves a number of blocked requests less than the First-Fit (e.g. for lambda=4) due to the fact that the First-Fit fails more in the route assignment. even when the update messages reaches the source node every cycle (N=1). This case occurs when two connections are requested at two nodes at the same time, one node assigns route before the other. Thus, the second node assigns route utilizing network information out of date. This case does not happen in the *RWP* because it has more capability of learn which route is the best for each request. In Fig. 5 we present the evolution of blocked requests (for lambda=4) every 100 new request since the total number of request is 0 to 2000, for both the First-Fit and *RWP*. Initially the prediction algorithm fails more (7 and 0 blocked requests for the first 100 requests for the *RWP* and First-Fit algorithm respectively), then when the number of requests is 1400 the number of blocked requests is equal for both algorithms, and for 2000 requests the results are 27 and 41 for *RWP* and First-Fit respectively. We can conclude that the prediction algorithm learns about its fails and the slope of rising decreases (logarithmic approximation), but the First-Fit algorithm has a constant rising in the number of blocked requests (lineal approximation).

It is worth noting that we have compared the *RWP* with the First-Fit algorithm assuming N=1. However, it is well known that the signaling overhead involved by this updating frequency is non-affordable. Hence, when simulations take into account more realistic values, for instance N=40, *RWP* is still much better than the First-Fit algorithm.

5 Conclusions

In this paper authors propose the Prediction-Based Routing (*PBR*) mechanism to tackle the *RWA* problem in *WDM* networks. The main skill of *PBR* is to provide source nodes with the capability of taking routing decisions without using the traditional routing information, that is the network state information contained in their Traffic Engineering databases (TEDs). Two immediate benefits may be inferred from the PBR mechanism. The former, the *PBR* removes the update messages required to update the TEDs (only connectivity messages are required), so significantly reducing the signaling overhead. The latter, in highly dynamic networks the *PBR* can efficiently change the routing decisions after a training period. Simulation results show that the *PBR* mechanism behaves better than the First-Fit algorithm even when an update frequency of 1 cycle is set for the First-Fit.

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