

# The PBR Approach: Analysis, Performance and Perspective

X. Masip-Bruin, S. Sánchez-López, E. Marín Tordera, J. Solé-Pareta

*Advanced Network Architectures Lab (CRAAX/CCABA), Technical University of Catalonia  
Avda. Víctor Balaguer, s/n, 08800 Vilanova i la Geltrú, Barcelona, Catalunya, Spain  
{xmasip, sergio, eva, pareta}@ac.upc.edu*

## ABSTRACT

Usual RWA (Routing and Wavelength Assignment) algorithms take the lightpath decision based on the network state information existing in those nodes caring about it. Unfortunately, this information might not be accurate enough so that the routing decisions could be incorrectly performed hence driving to a significant connection blocking increment. The Prediction-Based Routing mechanism appears as an appealing and solid contribution challenging the inaccuracy introduced in the RWA problem. A significant topic currently raising many research efforts is the influence of physical impairments on the network performance degradation, in particular on the lightpath selection process. Some parameters should be added to the routing protocol to include information related to physical impairments. Authors in this paper aim at analysing main PBR contributions also presenting main issues related to the introduction of physical parameters in the routing protocol.

**Keywords:** optical routing, prediction-based routing, physical impairments.

## 1. INTRODUCTION

It is widely assumed that optical transport networks (OTN) based on fibre optic communications is and will probably be a relevant part of that Internet portion providing residential users with capabilities to support the huge amount of traffic required by current applications, such as video-conference, video streaming, tele-medicine, tele-education, HDTV, VoIP or VoD.

In such an optical transport networks many points are still devoting research efforts. In particular, issues related to the network architecture (optics and electronics devices, power-law tradeoffs between optical and electronic switching, transport architectures—optical packet switching (OPS), optical flow switching (OFS), optical burst switching (OBS)—, buffering, queuing, etc) as well as those related to the design and development of new protocols (routing, signalling, control plane protocols, etc) are critical in the global network design. This paper deals with routing issues in OTNs and in particular on a mechanism which improves network scalability by means of reducing network signalling overhead.

An OTN consists of switching nodes (Optical Cross-Connect, OXC) interconnected by wavelength-division multiplexed (WDM) fibre-optic links that provide multiple parallel high-capacity communication channels over a common fibre. A wavelength-routed WDM network is a circuit-switched network, in which a lightpath must be established between a source-destination pair prior to data being transmitted. A lightpath is an end-to-end connection between a source-destination node pair, which may span multiple fibre links and use a single or multiple wavelengths. When the OTN includes automatic switching capabilities, it is referred to as an Automatically Switched Optical Network (ASON) [1].

In optical transport networks, the traditional routing concept can be decoupled into both the path selection and the wavelength assignment sub-problems (referred as the Routing and Wavelength Assignment problem, RWA [2]). Assuming source routing as an ASON recommendation [1], the source node calculates the route usually applying Shortest Paths based algorithms and assigns the wavelength/s to the end-to-end connection. Then, the source node starts the signalling process required to set up the connection. Under this constraint, end-to-end routes are computed at the source nodes according to the network state information contained in their network-state databases. This assumption introduces a potential problem often referred to as the routing inaccuracy problem. The routing inaccuracy problem, or the selection of routes based on outdated network state information, may significantly impact global network performance [3]. Many solutions have been proposed in the recent literature addressing such a problem [4-10].

It is also important to recognise that, in optical transport networks, path determination is dependent upon network 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 links in the path between source and destination nodes; known as the wavelength-continuity constraint. Such a constraint may result in higher blocking probabilities at higher loads. Wavelength routed networks with wavelength conversion are known as wavelength-interchangeable (WI) networks. In such networks, several (or all) nodes are equipped with wavelength converters so that a lightpath can be set-up using different wavelengths on different links along the route. However, the cost associated in

providing a wavelength converter at every node is currently considered to be prohibitive. Thus, solutions that attempt to limit the extent of wavelength conversion required within a WI network are sought.

Routing algorithms used in optical networks take into account topology and resource availability aspects to compute the route and assume that every route is characterized by a satisfactory signal quality. On the other hand, the validation of such algorithm is based on experimental scenarios which represent core networks where, in some cases, two nodes are connected through a longest path without estimating the physical impairments (ex. signal quality). Therefore, these assumptions could provide unrealistic result in terms of Quality of Service due to the route does not fulfill the connection requirements. Some publications deal with this problem. In [11] the proposed solution considers a dynamic estimation of the signal quality during the signaling phase of the lightpath set up process. The signaling protocol is extended to collect information about the physical parameters, which will be used for deciding whether the selected route fulfills with the requested requirements. Other publications take into account the physical impairments imposed by the optical layer when solving the RWA problem [12]. In particular, it considers the effects of the related Optical Signal-to-Noise Ratio and its penalties due to linear and no linear propagation which arise when considering dynamic wavelength allocation on optical fibers. Therefore, authors propose a new algorithm which selects the path and the wavelength that present the maximum Optical Signal Noise Ratio.

In this paper authors review the Prediction-based Routing (PBR) also presenting a significant improvement in the basics of the mechanism related to complexity issues. In few words, the PBR is as mechanism that does not only address the *RWA* problem but also the routing inaccuracy problem, achieving a drastic reduction in the signalling overhead. The PBR selects routes not based on the 'old' or inaccurate network state information but based on some kind of 'predicted' information. Since routing information from network state databases is not long required, we may eliminate flooding update messages (except those required for connectivity). Current PBR implementations decide routes based on the "history" of the network based on both the shortest path and the wavelength availability but does not consider physical parameters. In this paper authors propose path length to account for the quality of the signal. Therefore, distance is assumed to be the unique physical parameter also assuming that the network topology database contains information about the distance of every link.

The rest of this paper is organized as follows: section 2 briefly introduces the Prediction-based Routing. In Section 3 authors optimize current PBR's solution by reducing the mechanism complexity. The proposal is evaluated in Section 4 while the final conclusions are presented in section 5.

## 2. THE PREDICTION BASED ROUTING

In this section authors shortly introduce the Prediction-based Routing mechanism pointing out key issues of their performance as well as main advantages of being implemented as a routing mechanism in OTN. The PBR was firstly introduced in [11] in an optical network scenario. Then, the PBR has been extended to be applied to hierarchical networks [12, 13] as well as to IP networks [15].

### 2.1 The PBR basics

The Prediction Based Routing (PBR) mechanism is based on extending the concepts of branch prediction used in the computer architecture area. The PBR mechanism is based on predicting the lightpath, that is path and wavelength between a source destination node pair according to the routing information obtained in previous connections set-up.

Assuming source routing, the method used to register the routing information obtained in previous connections set-up is based on keeping in every source node a history for every wavelength and path (for every lightpath) and destination. This lightpath history includes information about connections previously established in this lightpath. Every lightpath history is stored in history register named Wavelength Register (WR), holding a vector of 0s and 1s reflecting this history. In the source nodes there will be one of such registers for every wavelength on every path (for every lightpath) to every destination node. Every unit of time the WRs are modified by means of shifting the vector one position to the left and setting a new value on the right. Each WR is updated setting a 0 value whenever this lightpath is used on that unit of time. Otherwise, the register of an unused lightpath is updated setting a 1. It must be noticed that the expression "a path is used" means that a connection is established in that path. On the other hand, "a path is unused" when no incoming connection is assigned to this path. The WRs are used to both train and index new defined tables, named Prediction Tables (PT). These PTs have different entries, each keeping information about a different pattern by means of a counter, which is read when accessing the table. One PT is needed in the source nodes for every feasible lightpath between any source-destination node pair. The obtained counter value is compared to a certain threshold value. If the value obtained after reading the PT is lower than the threshold, the prediction is to accept the request through this wavelength on this route. Otherwise, the path is predicted to be unavailable. The counters are two-bit counter, where 0 and 1 stand for the lightpath availability and 2 and 3 stand for the lightpath unavailability.

Based on the PBR mechanism, the proposed algorithm has precomputed the two shortest paths,  $SP_1$  and  $SP_2$ . The decision of which wavelength and path ( $SP_1$  or  $SP_2$ ) are selected is done depending on the value of the counters of the PTs and the availability of the node's output links. The PTs (of each wavelength per path) are checked according to two different policies. The first policy considers that the PTs are checked in a fixed order according to the number assigned to each wavelength. In this case the proposed algorithm is named RWP-f. The RWP-f algorithm selects the first lightpath accomplishing that its two-bit counter is lower than 2 and having output link availability. Under the second policy the wavelengths for each route are ordered according to the number of available fibres on each wavelength. In this case the algorithm is named RWP-o. That is, the RWP-o algorithm selects the lightpath with more available fibres among the lightpaths with their two-bit counter lower than 2 and output link availability. It is important to note that the information about the number of available fibres for every wavelength used to order the PTs is that known by the source node, which certainly might not be accurate since update message have been removed.

## 2.2 Complexity Issues

The main complexity associated with the PBR mechanism is the fact that for every new connection request several PTs have to be accessed by means of different indexes (all the PTs corresponding to the paths and wavelengths between those source and destination nodes). Note that the size of the PTs depends on the number of bits of the WR, because the index necessary to access each PT is extracted from the corresponding WR. Moreover the WRs have to be updated every unit of time, as it is described bellow. Depending on the PT size the PT access time cannot be negligible and so might significantly affect PBR performance.

## 3. LOWERING PBR's COMPLEXITY

The algorithm enhancement described in this subsection aims at showing that the information required about last and previous units of time so far is not longer needed. This means that WRs are not required so that PTs of only one entry (i.e., only one two-bit counter per route and wavelength) are enough to implement the PBR mechanism. This enhancement will be justified by means of several simulations. Now, the two-bit counter can be interpreted as follows: the value of the counter for a route and wavelength is more or less the number of blocked connections produced the last two times this route and wavelength was selected. A particular wavelength and route will not be selected (i.e., predicted to be blocked) whenever a blocking occurs last two times it was selected (counter $>$ 1). Instead, this route and wavelength will be selected whenever there is one blocking at top in the last two times it was selected (counter $<$ 2).

There is a two-bit counter per route and wavelength in the source nodes for every destination node. Just as an example, if a source node can forward connection requests to 2 different destination nodes through 2 possible routes for every destination,  $SP_1$  and  $SP_2$ , and 4 possible wavelengths, then there are 16 two-bit counters in the source node. These two-bit counters are named as Wavelength-Route Counters, WRC. Summarizing, for every new connection request, only the WRC values and the output link availability are checked according to the number of available fibers per wavelength (for example in RWP-o). The PBR mechanism becomes more scalable with this enhancement since only a two-bit counter is needed in the source nodes for every possible destination, route and wavelength.

## 4. PERFORMANCE EVALUATION

First a preliminary evaluation of the PBR behavior is carried out, analyzing the effect of the number of WRs bits. Both algorithms, RWP-f and the RWP-o, are compared with a well known routing and wavelength assignment algorithm, Shortest-Path combined with Least-Loaded. Simulations have been carried out on the network topology shown in Figure 1 that consists of 9 nodes where 2 of them are source nodes and other 2 destination nodes. Assuming  $k = 2$ , the algorithm calculates the 2 shortest path and link disjoint paths from the source nodes to each destination, see Figure 1. Call arrivals are modeled by a Poisson distribution, the connection holding time is assumed to be exponentially distributed, and each arrival connection requires a full wavelength on each link it traverses. Figure 2 shows the blocking probability produced when varying the number of WRs bits applying the RWP-f and the RWP-o algorithms on the topology of Figure 1 for 2 fibres per link, 6 and 8 wavelengths per fibre and different traffic loads per each source-destination pair.

From the obtained results, the optimal number of bits depends on different parameters such as the traffic load, number of wavelengths ( $\lambda$ s in figures). Note that the number of entries of the PT depends on the number of bits of the corresponding WR; if the number of bits is  $n$  the number of entries of the PT will be  $2^n$ . In general the performance for 0 bits of WR is enough good, being in a lot of cases the best. With this enhancement of the algorithm the PTs are only of one entry (i.e., only one two-bit counter per route and wavelength). On the other hand comparing the results for the two options of ordering the checking of the PTs (remember that the RWP-f checks in a fixed order, and RWP-o checks depending on the wavelength availability from the point of view of the source node), the results are in almost all the cases better for the RWP-o than for the RWP-f algorithm. Due

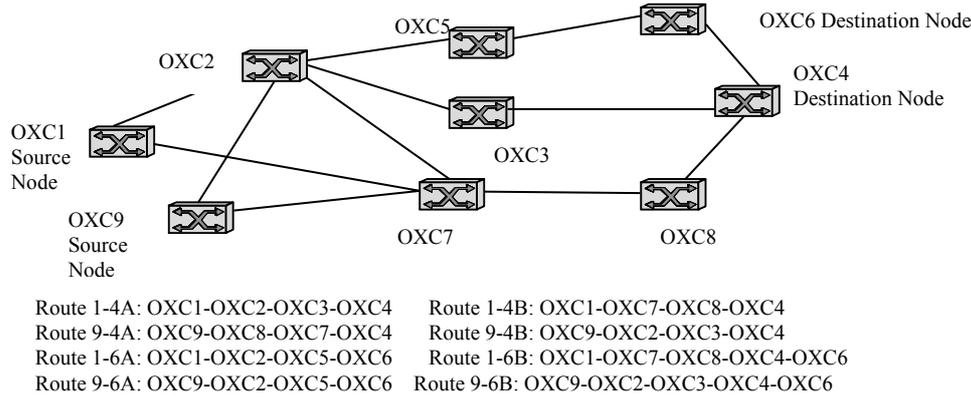


Figure 1. Topology used in simulations

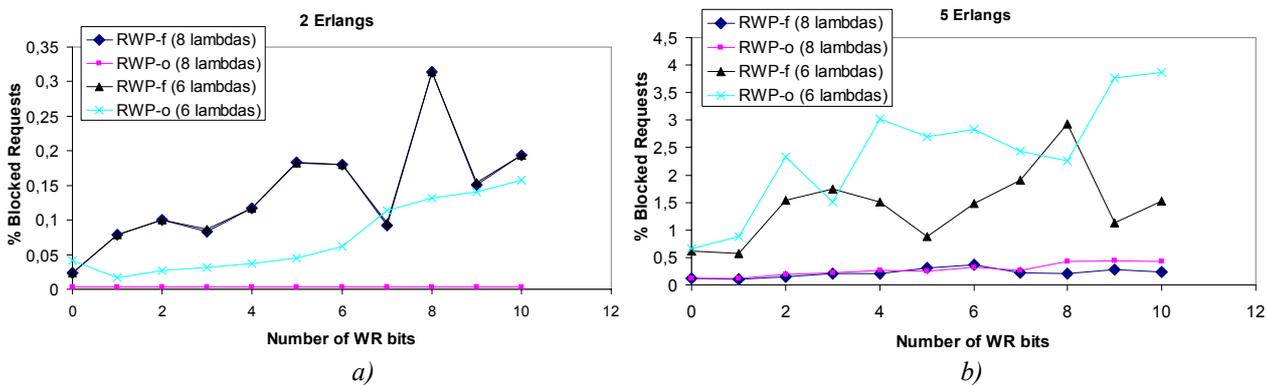


Figure 2. Percentage of blocked connection versus number of WR bits for RWP-f and RWP-o algorithms.

to the two reasons exposed above from now on, only results for the RWP-o algorithm without WRs are presented in the next experiments.

After evaluating the enhancement of the algorithm we now compare the performance of the RWP-o algorithm with the performance of a well-known and commonly used route and wavelength assignment mechanism, Shortest-Path combined with the Least-Loaded. The Least-Loaded algorithm selects the wavelength that has the largest residual capacity (number of free fibres for that wavelength), on the most loaded link along the route. Note that in single-fibre networks the Least-Loaded becomes the First-Fit algorithm. Both heuristic algorithms, First-Fit and Least-Loaded, need network state update messages to know the wavelength availability along the route. On the other hand, the PBR mechanism only utilizes the information about output link availability, local information about wavelength availability along the route and the information contained in the PTs. There are implemented the same two shortest and link-disjoint paths for the Least-Loaded algorithm. All the simulated algorithms check first the  $SP_1$  path. That is,  $SP_1$  has priority to be selected, and  $SP_2$  is the alternative path. A set of simulations have been carried out on the topology of Figure 1, varying the time between the updating (units of time), and the results are presented in Figure 3 (2 fibres, for 2 and 5 Erlangs). For 2 Erlangs and 8 lambdas both algorithms, RWP-o and Least-Loaded, have a blocking percentage practically equal to 0. However for 6 lambdas the RWP-o algorithm has similar performance than the Least-Loaded with updating every 5 units of time. On the other hand for 5 Erlangs the RWP-o algorithm outperforms the Least-Loaded algorithm even on the ideal case with updating every unit of time.

The observation from the previous results of performance in terms of blocking probability is that the algorithms based on the PBR mechanism deliver in better way the traffic request between the different routes and wavelengths. It is possible to think that this beneficial effect could be because the PBR mechanism assigns the routes and wavelengths in a random manner. To check this possibility in the next set of simulations it is compared how the different algorithms deliver the request between the different routes and wavelengths. The algorithms compared are the RWP based on the PBR mechanism, the Shortest-Path algorithm combined with the First-Fit; and the Shortest-Path combined with a random wavelength assignation. This random wavelength assignation is named First-Fit (Random) because it randomly selects a wavelength among the feasible available wavelengths. The difference with the First-Fit is that the First-Fit algorithm always starts looking for a available wavelength of less index; and the First-Fit (Random) starts looking for a randomly selected index the available

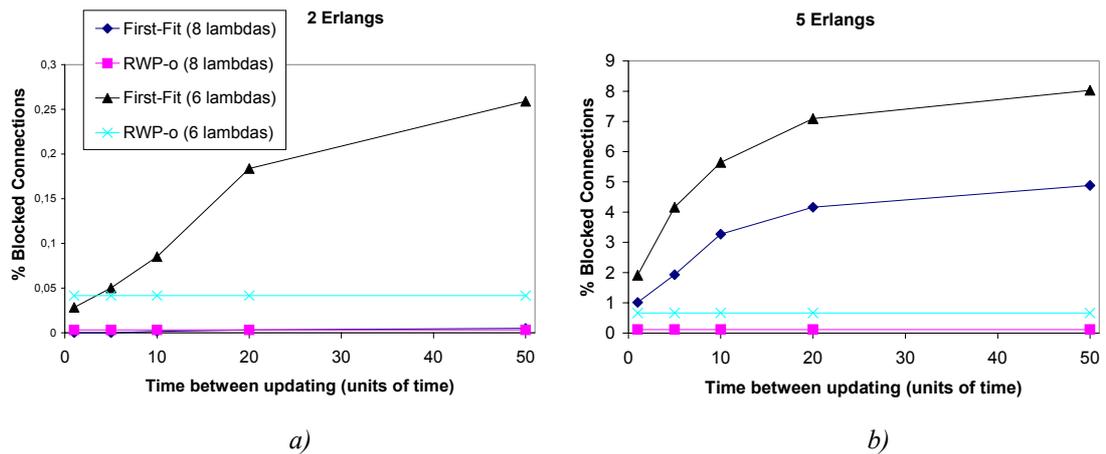


Figure 3. RWP-o versus Least-Loaded.

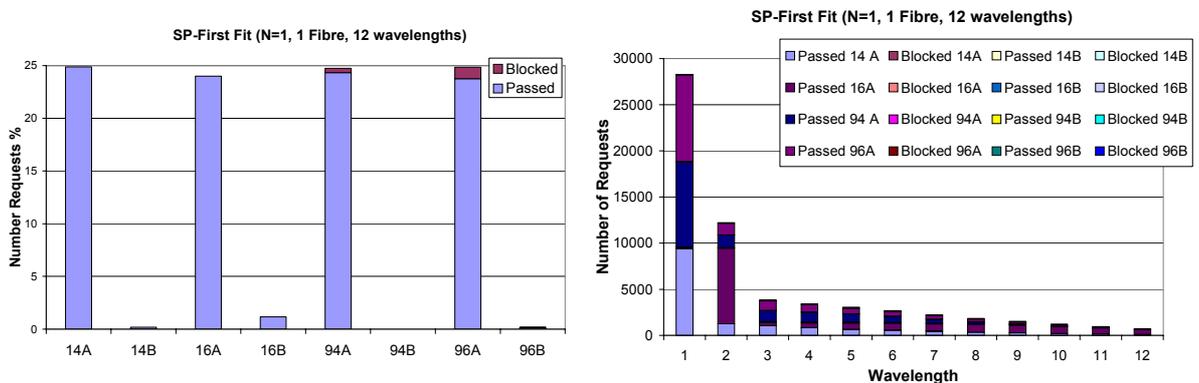


Figure 4. Path and Wavelength Assignment for the SP-First Fit algorithm.

wavelengths. The set of simulations have been carried out in the topology of Figure 1 for a configuration of 12 wavelengths (lambdas) per fibre and 1 fibre per link. Remember that for only 1 fibre the Least Loaded becomes the First-Fit. The update of network information for SP-First-Fit and SP-First-Fit(random) is every unit of time. The results of percentage in blocked connections for this configuration are 0,45% for RWP, 1,53% for SP-First-Fit and 2,31% for SP-First-Fit(random). Figure 4a represents the how the connection requests are delivered by the SP-First-Fit among the 2 possible paths for every source destination pair. Figure 4b shows how the connection requests are delivered by SP-First-Fit among the 12 possible wavelengths. We can observe that First-Fit selects preferably wavelengths with fewer indexes and the first shortest path. In Figure 5a and 5b we observe the same results for the SP algorithm combined with a First-Fit (random) wavelength assignment. In this case the requests are delivered proportionally among all the wavelengths. And finally, in Figure 6a and 6b it is showed how the RWP algorithm delivers the connection request among the 2 possible paths and among all the wavelengths respectively. We observe that the algorithm based on the PBR mechanism does not assign the wavelengths randomly; there is a pattern different from the First-Fit and the First-Fit (random) pattern. In addition, the PBR mechanism selects lightly more times the alternative path than the other two algorithms.

### 5. CONCLUSIONS

This paper reviews main issues related to routing lightpaths based on prediction issues. The main contribution of this paper is the reduction on the mechanism complexity achieved by lowering the process required to handle the prediction basics. Simulation results show the advantages of including such improvement in the prediction mechanism. In addition authors also introduce the concept of physical impairments. Under this concept authors include particular wavelengths conditions that must be considered when routing lightpaths.

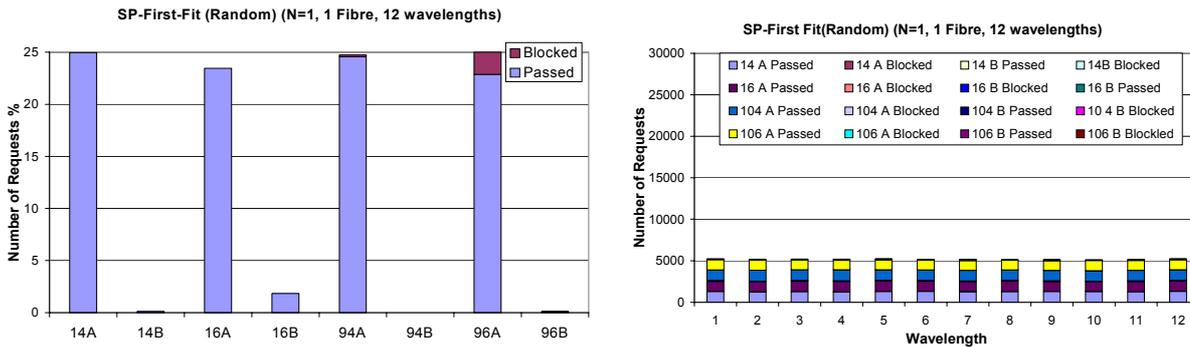


Figure 5. Path and Wavelength Assignment for the SP-First Fit(Random) algorithm.

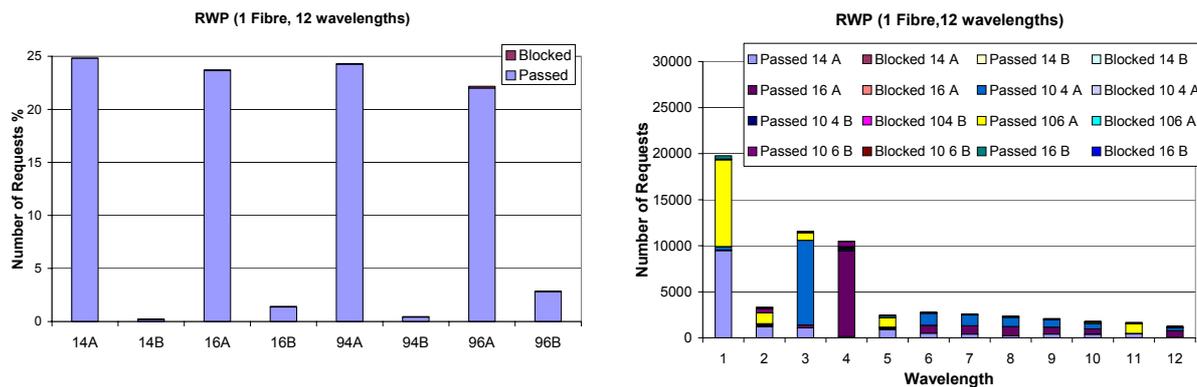


Figure 6. Path and Wavelength Assignment for the RWP algorithm.

## REFERENCES

- [1] ITU-T Rec.G8080/Y.1304, "Architecture for the Automatically Switched Optical Network (ASON)," November 2001
- [2] H.Zang, J.P.Jue, B.Mukherjee, "A Review of Routing and Wavelength Assignment Approaches for Wavelength-Routed Optical WDM Networks," *Optical Networks Magazine*, January 2000.
- [3] J.Zhou, X.Yuan, "A Study of Dynamic Routing and Wavelength Assignment with Imprecise Network State Information," *Proc. ICPP Workshop on Optical Networks*, Canada, August 2002
- [4] X.Masip-Bruin, S.Sánchez-López, J.Solé-Pareta, J.Domingo-Pascual, "Routing and Wavelength Assignment under Inaccurate Routing Information in Networks with Sparse and Limited Wavelength Conversion," *IEEE GLOBECOM 2003*, San Francisco, USA, Dec. 2003
- [5] J.Zheng, H.Mouftah, "Distributed lightpath control based on destination routing in wavelength-routed WDM networks," *Optical Networks Magazine*, July/August 2002, vol.3, n°:4, pp.38-46.
- [6] K.Lu, G.Xiao, I.Chlamtac, "Behavior of Distributed wavelength provisioning in Wavelength-Routed Networks with Partial Wavelength Conversion," in *Proc. of IEEE INFOCOM 2003*
- [7] G.Xiao, K.Lu, I.Chlamtac, "An Evaluation of Distributed Wavelength Provisioning in WDM Optical Networks with Sparse Wavelength Conversion," in *IEEE Journal of Lightwave Technology*, vol. 22, no. 7, July 2004
- [8] K.Lu, G.Xiao, I.Chlamtac, "Analysis of Blocking Probability for Distributed Lightpath establishment in WDM Optical Networks," *IEEE/ACM Transactions on networking*, vol. 13, no. 1, February 2005
- [9] S.Shen, G.Xiao, T.H.Cheng, "Evaluating the impact of the link-state update period on the blocking performance of wavelength-routed networks," in *Proc. of OFC 2004*
- [10] K.Lu, G.Xiao, J.P.Jue, T.Zhang, S.Yuan, I.Chlamtac, "Blocking Analysis of Multifiber Wavelength-Routed Networks," in *Proc. of IEEE GLOBECOM 2004*
- [11] F. Cugini, N. Andriolli, L. Valcarengi, P. Castoldi, "Physical Impairment Aware Signalling for Dynamic Lightpath Set Up.," *ECOC 2005*, September 2005
- [12] R. Cardillo, V. Curri, M. Mellia, "Considering transmission impairments in configuring wavelength routed optical networks," *Optical Communications*, 2006
- [13] E.Marin Tordera X.Masip-Bruin, S.Sánchez-López, J.Solé-Pareta, J.Domingo-Pascual, "A New Prediction-based Routing and Wavelength Assignment Mechanism for Optical Transport Networks," *QoIS'04, Bachelona, Catalunya*, September 2004.
- [14] E.Marin Tordera X.Masip-Bruin, S.Sánchez-López, J.Solé-Pareta, J.Domingo-Pascual, "A Hierarchical Routing Approach for Optical Transport Networks," *Computer Networks Journal, Elsevier*, vol.5, issue 2, pp.251-267, February 2006.
- [15] Eva Marin-Tordera, Xavier Masip-Bruin, Sergio Sánchez-López, Josep Solé-Pareta, "Efficient Routing Algorithms for Hierarchical Optical Transport Networks," *ECOC 2005*, Glasgow, Scotland, September 2005
- [16] E.Marin-Tordera, X.Masip-Bruin, S.Sánchez-López, J.Domingo-Pascual, A.Orda, "The Prediction Approach in QoS Routing," *IEEE ICC 2006*, Istanbul, Turkey, May 2006