The Blocking Probability Comparison for Some Routing and Wavelength Assignment Methods

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Abstract – **Optical networks employing wavelength division multiplexing (WDM) technique are becoming increasingly popular for high bandwidth connections. With the advent of the cross-connect technology, optical connections or lightpaths can be established fully in the optical domain without optical to electronic conversion at intermediate network nodes. Routing and wavelength assignment (RWA) are important issues in such networks. This work focuses on the RWA problem in optical networks with dynamic traffic demands. One of the primary design objectives of wavelength-routed all-optical networks in such situation is to minimize the blocking probability. Two routing algorithms together with four wavelength assignment methods are tested and compared according to the blocking probability performance metric. Simulations are performed on a given optical network topology with 8 network nodes in a case of Poisson traffic arrivals and exponential call holding times.**

Keywords – **Routing and wavelength assignment (RWA), optical network, lightpath, blocking probability**

I. Introduction

Recent advances in wavelength division multiplexing (WDM) and optical switching technique make it possible to consider the deployment of wavelength routing optical networks (WRON) that will provide backbone connectivity over a wide-area distances at very high data rates. A WRON consists of wavelength routers and the fiber links that interconnect them. Wavelength routers are optical switches capable of routing optical signal at a given wavelength from any input port to any output port, making it possible to establish end-to-end lightpaths. A lightpath is direct all-optical connection between two end nodes in physical network topology that is established without any intermediate electro-optic conversion. Such networks are also referred to as all-optical networks *(AON).*

To establish a lightpath in a WDM network, it is necessary to determine the route over which the lightpath should be established and the wavelength to be used on all the links along the route. This problem is known as the *routing and wavelength assignment* (RWA) problem. Routing and wavelength assignment requires that two lightpaths on a given link do not share the same wavelength. In addition, in networks without the wavelength converter in network nodes, lightpaths must satisfy the wavelength continuity constraint, that is, the same wavelength must be used on all the links along the selected route. The RWA algorithm is critically important to increase the efficiency of wavelength routed networks. It is responsible for selecting a suitable route and wavelength among the many possible choices for establishing the lightpath.

Acording to the traffic assumptions, the RWA problem can be classified into two types: the *static* RWA problem and the *dynamic* RWA problem. In the case of static RWA problem, the set of connections is known in advance and the problem is to set up lightpaths for the connections while minimizing network resources such as the number of wavelengths or the number of fibers. Alternatively, one may attempt to set up as many lightpaths as possible for a given number of wavelengths. Dynamic RWA tries to perform routing and wavelength assignment for connections that dynamically arrive to and depart from the network one by one in a random manner. The objective of dynamic RWA problem is typically to minimize the connection blocking probability, that is, the probability that a lightpath cannot be established in the network due to lack of resources (e.g., link capacity or free wavelengths). Blocking is highly undesirable in WRON networks due to the very high data rates carried on a single wavelength channel.

We consider dynamic RWA problem in this paper. Because of the real time nature of the problem, RWA algorithm in a dynamic traffic environment must be very simple. Since combined routing and wavelength assignment is a hard problem, a typical approach to designing efficient algorithms is to decouple the problem into two separate sub-problems: the routing problem and the wavelength assignment problem.We simulated and compared two routing algorithms: fixed routing and fixed-alternate routing, jointly with the four wavelength assignment methods, which will be described in more detail in the next section.

The rest of the paper is organized as follows. In Section II we describe the problem we study. In Section III, the simulation results related to the connection blocking probability for different routing and wavelength assignment methods and traffic scenarious are given. Finally, the section IV concludes the paper.

II. Problem Statement

In this paper, we consider a wavelength-routing network without the wavelength conversion operating in circuit-switched mode under dynamic traffic scenarious. When

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connections are established and released dynamically, RWA algorithms must be used to assign resources dynamically to the connection requests. In case when the network does not have sufficient resources to support a connection, the connection is *blocked*. In networks without the wavelength convertors, a connection may also be blocked if there does not exist any common wavelength on all the links along a path. The routing and wavelength assignment problem for dynamic traffic is called Dynamic Lightpath Establishment (DLE) problem. Given a physical network topology, the DLE problem can be defined as the RWA problem with maximization of accepted connection requests or equivalently with minimization of blocked requests in a given time period.

Our objective is to study the performances for some dynamic RWA algorithms, in terms of their call blocking probabilities. We considered two routing methods: *fixed* routing (FR) and *fixed-alternate* routing (FAR).

In *fixed* routing, for every source-destination *(s,d)* node pair a fixed route (typically the shortest path) is computed offline. When a connection request arrives, a free wavelength is searched along the corresponding route to establish the connection. The request is blocked if there does not exist any free wavelength along this route. This technique addresses the problem by minimizing the amount of resources used to establish a connection.

In *fixed-alternate* routing, for every *(s,d)* node pair, a set of k alternate paths (k>1) is computed off-line. When the connection request arrives, the candidate routes are searched in the sequential order and the first available (if it exists) is choosen for the establishing the lightpath between coresponding node pair. The candidate routes in our simulations are ordered according to the total number of their physical hops (links).

Let us discuss the considered wavelength assignment methods, according to the manner in which the wavelength list is ordered. For a given candidate path, the wavelengths are used in the order in which they appear in the list to find a free wavelength for the connection request. To evaluate the blocking probability of the considered routing algorithms, we used next four wavelength assignment techniques:

- *Random* (RN) - using random strategy, a set of available wavelengths that can be used to establish the connection is determined. After that, one wavelength is randomly selected with uniform probability distribution from this set.
- *First-fit* (FF) - in the first-fit scheme, all the wavelengths are numbered. The lowest numbered wavelength that can be used to establish a connection is used for the connection.
- *Most-used* (MU) - in this scheme, all the available wavelengths that can be used to establish a connection are considered. The wavelength that has been used the most in a network is selected for a lightpath. Usage can be defined either as the number of links in the network in which a wavelength is currently used or as the number of active connections using a wavelength.
- *Least used* (LU) – in this method wavelengths are tried in the order of increasing usage in a network.

III. Simulation results

The routing and wavelength assignment methods described in the previous section were applied to the 8 node optical WDM network topology, given in Fig. 1. We assumed that the network is single fiber, which means that each physical link has only one optical fiber for each direction. Also, we assumed that each fiber has the same available number of wavelengths W.

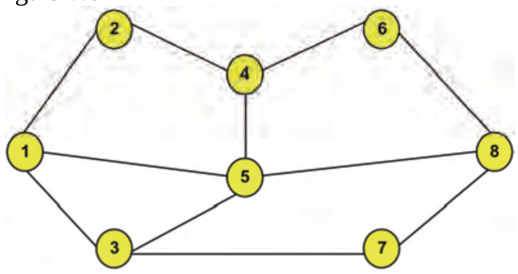


Fig. 1. The considered optical WDM network topology.

A sequence of lightpath requests arrives over time and each lightpath has a random holding time. These lightpaths need to be set up dynamically by choosing a route across the network connecting the source and destination node and assigning a free wavelength along the path. At a given time, only one lightpath can use a specific wavelength in a fiber. The existing lightpaths cannot be re-routed to accommodate the new lightpath requests until they are released. We consider a dynamic traffic model, in which the connection requests arrive according to Poisson distribution with mean arrival rate of λ requests per unit time. The connections have exponential holding time with mean $\bar{t} = 1/\mu$ time units. Thus, the total network load is equal $\rho = \lambda/\mu$ and is measured in Erlangs. The total number of connections simulated in the network during each simulation run is assumed to be 10000. The source-destination *(s,d)* nodes for each connection are chosen (with equal probability) from uniform distribution. In all performed simulations, we assumed that the mean connection holding time is $\bar{t} = 1$ time unit and we only varied the mean arrival rate λ as the number of connection requests per time unit.

Firstly, we will analyze the simulation results for the blocking probabilities in a case of fixed routing (FR) algorithm with different considered wavelength assignment methods applied. Fig. 2 illustrates the relative number of blocked requests per 10000 requests totally generated during the simulations in given network, in a case when network load is $\rho = 60\text{Erl}$ for different number of available wavelengths per fiber links. It can be seen that when the number of wavelengths is small (W<8), the performance of the four wavelength assignment schemes are nearly identical, indicating that the blocking probability is determined mainly by the limited resources and not by the wavelength assignment scheme implemented. However, as the number of wavelengths increase (W>8), the blocking probability values decrease significantly. In such situation, it can also be seen that MU method outperforms the other considered schemes, but also that the FF method gives the similar results as the MU method. The LU method gives the worst performances in terms of call blocking probability.

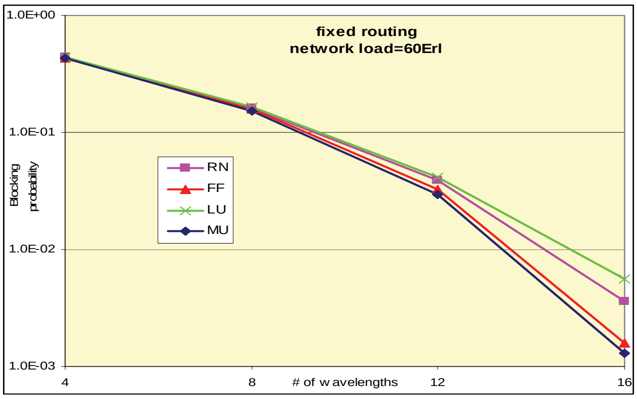


Fig. 2 The blocking probability for different wavelength assignment methods as a function of wavelength number -FR

Let us now consider the performances of fixed-alternate routing (FAR) algorithm. In Fig. 3 the simulation results for blocking probabilities are presented in optical network (Fig.1) for the case of network load value of $\rho = 60\mathrm{Erl}$ and W=12 wavelengths, obtained by applying different wavelength assignment methods and considered routing algorithms with various number of alternate routes, beginning from *k*=1 (case of FR) to maximally *k*=5 (in a case of FAR).

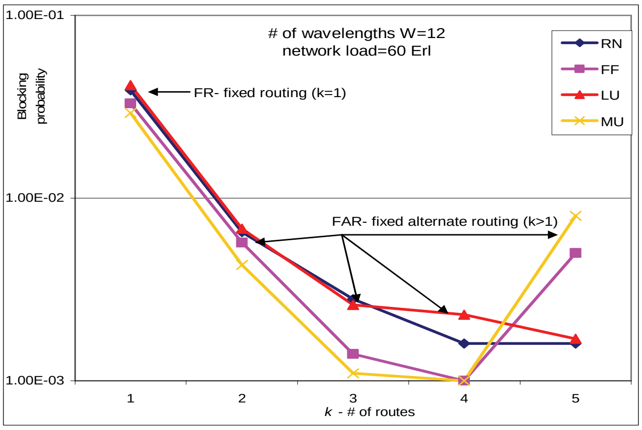


Fig. 3 The blocking probability as a function of the number of routes for various wavelength assignment methods – FR/FAR

The results given by Fig. 3 show that fixed routing (*k*=1) is significantly poorer compared to the fixed alternate routing (FAR) algorithm when the network performance is measured in terms of call blocking probability. It can also be seen, that the greatest improvements in blocking probabilities compared to fixed routing (*k*=1) could be achieved in the cases when the number of alternative routes is *k*=2 or at most *k*=3, but when the number of routes is larger than *k*=3, the improvements are not so significant. Moreover, if a number of alternate routes *k* is more than 4, the results for blocking probabilities can be worse, because in this case the longer candidate routes can be chosen and so more resources in a network could be consumed. Therefore, for each node pair *(s,d)* in considered network topology, it is adequate to predefine only few alternate routes in order to obtain much better performances compared to fixed routing algorithm.

When FR or FAR is used, with increasing the traffic load in network, the blocking probability of the network increases significantly. This can be seen from the results given in Fig. for different wavelength assignment methods in a case of FR and FAR algorithms.

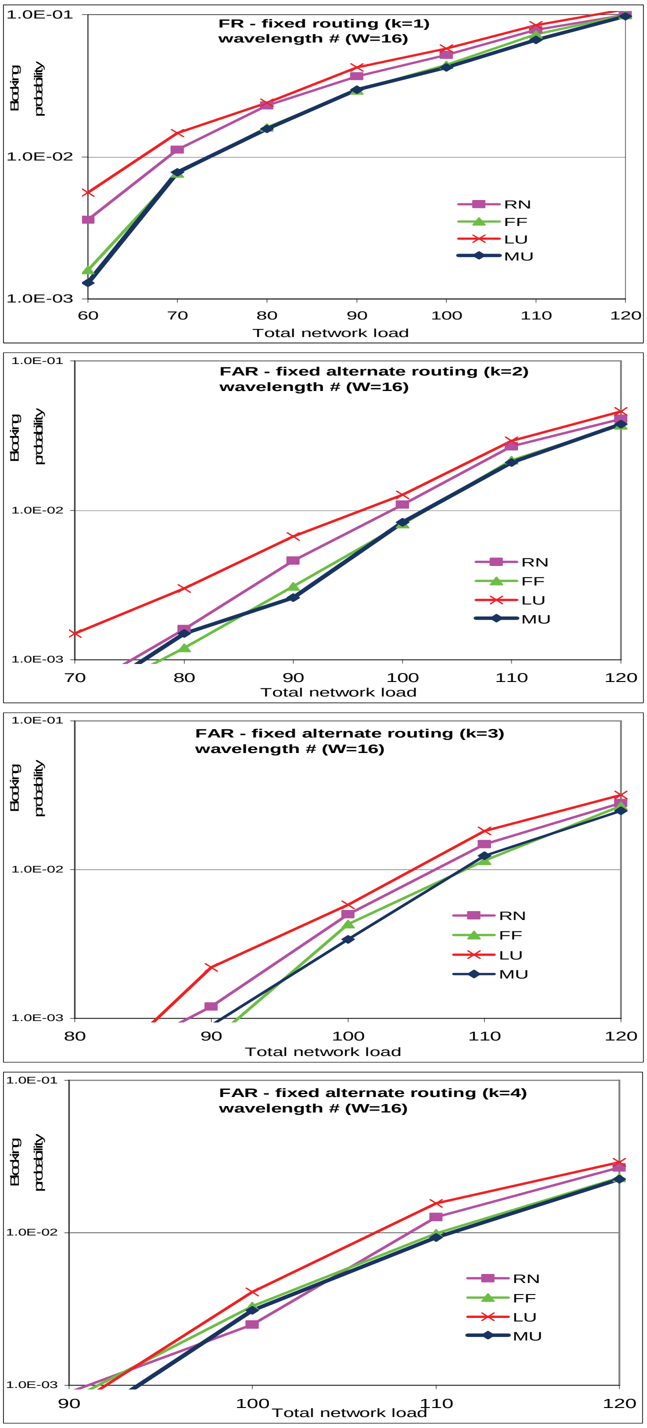
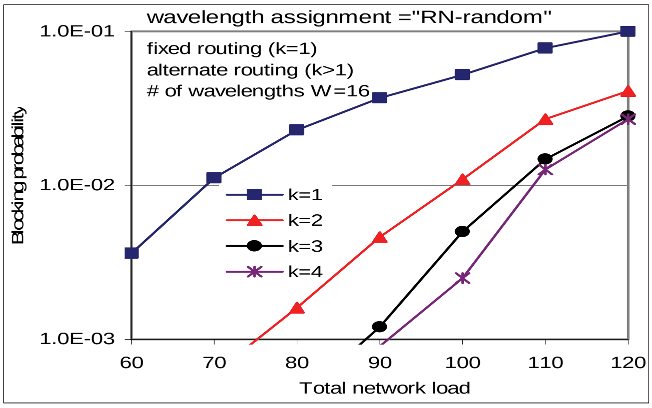
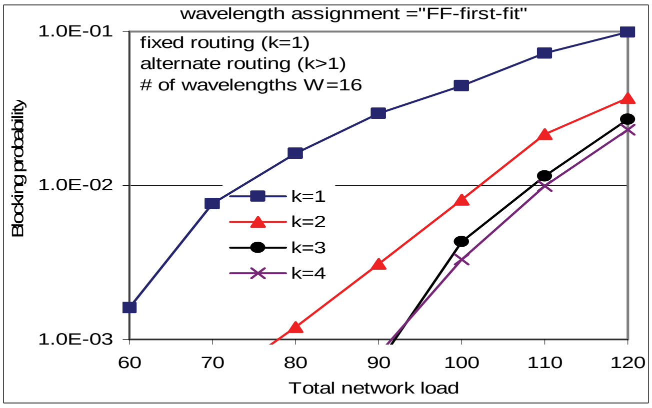
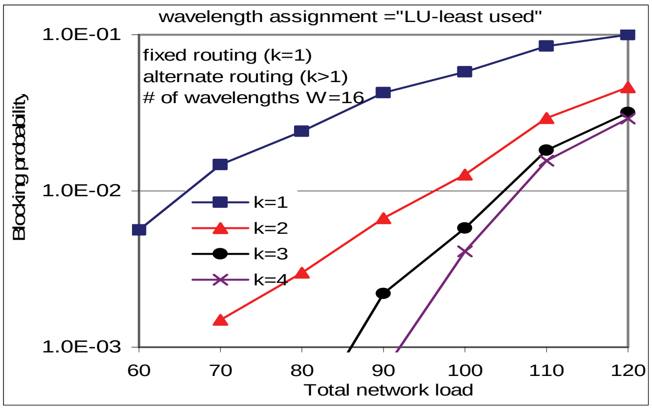


Fig. 4 The blocking probability for different wavelength assignment methods as a function of network load – FR/FAR

From Fig. 4 it can be also seen that the blocking probabilities (for the same network loads) in a case of FAR algorithm are much lower than those for FR algorithm.







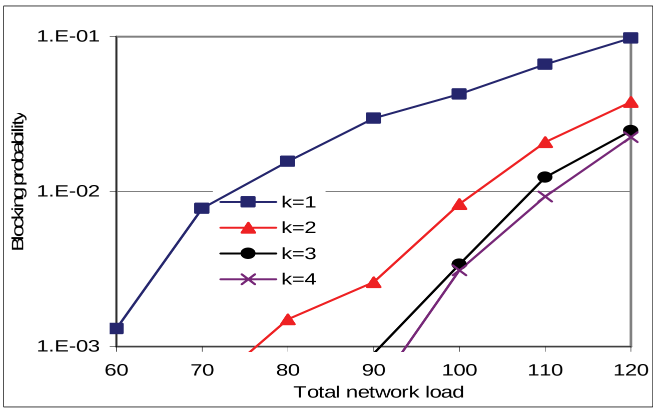


Fig. 5 Blocking probability vs. network load for different wavelength assignment techniques – FR/FAR

Fig. 5 depict the blocking probability versus network load for the considered optical WDM mesh network topology employing *random* (RN), *first-fit* (FF), *least-used* (LU) and *most-used* (MU) wavelength assignment techniques, when fixed and fixed-alternate routing algorithms are performed. The results for most used wavelength assignment are similar to the first fit wavelength assignment technique The random the least used techniques gives poorer performances than the most used and first fit wavelength assignment for different network loads.

IV. Conclusion

The routing and wavelength assignment procedure in a case of dynamic traffic demands has the goal to minimize the number of blocked connection requests in a given network. In this paper, we developed a software module to simulate two routing and four wavelength assignment methods in order to obtain the call blocking performance in a concrete optical WDM network topology. We performed a lot of simulations in order to compare the efficiencies of the considered RWA algorithms.

Results show that the fixed alternate routing with no more than three alternate routes performs much better than the fixed routing algorithm for various network loads. Also, the obtained results show that the most-used wavelength assignment technique outperforms the other three considered methods, but also the first-fit method is comparable to the most-used in terms of call blocking probability.

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