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Enhancement of blocking performance in all-optical wdm networks via wavelength reassignment and route deviation

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Abstract

This paper deals with the problem of improving the performance of all-optical Wavelength Division Multiplexing (WDM) networks in terms of blocking probability. Blocking in such network architecture is caused mainly by the so-called wavelength continuity constraint (wcc), which requires a provisioned lightpath to occupy the same wavelength on all the links along its route. To alleviate the effect of wcc on the blocking performance, a rerouting strategy is proposed. The main idea behind this strategy lies in ensuring the creation of wavelength-continuous routes for the connections that are blocked due to wcc. Particularly, the proposed rerouting strategy is built upon two main pillars, namely wavelength reassignment and route deviation. The former strives to keep the physical route followed by the lightpath intact, while the latter changes the route of the lightpath when wavelength reassignment proves to be ineffective. The performance of the rerouting strategy is studied through extensive simulations in the context of networks employing the least congested path (LCP) routing algorithm and the first-fit (FF) wavelength assignment strategy. The reported results show that the proposed rerouting strategy can guarantee significant enhancement in terms of blocking probability while achieving near-optimal performance for networks utilizing a small number of wavelengths per fiber.

Keywords: All-optical networks. Wavelength reassignment. Lightpath rerouting. Performance analysis.

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1. Introduction

Wavelength Division Multiplexing (WDM) holds the promise of catering for the large bandwidth requirements of the ever-emerging bandwidth intensive applications, such as video-on-demand, grid computing, and peer-to-peer file sharing. In all-optical WDM networks, optical connections referred to as lightpaths are established under the wavelength continuity constraint (wcc), whereby a lightpath is assigned the same wavelength on all the links of its route. Under such conditions, optical cross connects (OXCs) with no wavelength conversion capabilities are employed to route **the signal** in the optical domain (i.e., without electronic processing) as it travels from source to destination. The absence of wavelength converters in all-optical WDM networks decreases the operations cost of the network, but increases the connection blocking probability reducing as a result the throughput of the network [1 – 3]. Therefore, one of the major challenges in the context of all-optical optical networks without wavelength conversion is the enhancement of blocking probability performance. This paper tackles such a challenge by proposing a novel call rerouting strategy. The main purpose of the proposed strategy is to wisely manage the resources used in the optical network in such a way that **allows** more optical connections to be provisioned into the network.

The establishment of an all-optical lightpath **can be** a two step process: A route is first chosen to carry the lightpath, and then, a free wavelength satisfying wcc is selected along the route. This is **referred to as** the Routing and Wavelength Assignment (RWA) **problem**. It has been widely accepted that adaptive routing algorithms (such as Least Congested Path routing [4]) present better performance in terms of blocking probability as compared to static routing algorithms (such as fixed routing and fixed alternate routing [5]). It was also reported in [6] that the first-fit wavelength assignment algorithm has pretty good performance when it comes to connection blocking probability. Inspired by these observations, this paper analyzes the performance of the proposed rerouting strategy by considering an all-optical network that utilizes the Least Congested Path (LCP) routing algorithm along with the first-fit (FF) wavelength assignment strategy. A dynamic traffic model is adopted in the performance analysis and as such session

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requests are assumed to arrive at and depart from the network in a random manner. LCP selects the path having the maximum number of available wavelength channels out of the ***k*** pre-calculated disjoint paths between the origin and destination nodes of the session in order to route the request. The FF algorithm then assigns to the routed connection the lowest indexed wavelength satisfying wcc.

The proposed rerouting strategy works hand in hand with the RWA algorithm to achieve the purpose of reducing the blocking experienced by the incoming connection setup requests. In particular, the reduction of the blocking probability is expected to be realized by the rerouting strategy as follows. Once a connection request arrives at the network, the RWA algorithm tries to route the connection into the network. If the connection cannot be established, the rerouting strategy is activated to help the network accommodate this connection. This is done through an attempt first to perform a wavelength reassignment for a carefully selected pool of the live connections (i.e. already present in the network) with a view to accepting the blocked connection. If such an attempt fails, then a redirection (i.e., deviation) of the physical route associated with the previously selected pool of connections is tried in a bid to setup the blocked connection. If both the wavelength assignment and the physical route redirection attempts are not successful in saving the connection that was denied access to the network, the latter is blocked.

Blocking probability differentiation is needed in optical networks. This is especially true since the different connection requests that the network receives may emanate from customers having different service profiles and hence different QoS requirements [18]. Under this condition, the received connection setup requests must be treated in a way that accounts for the various priority levels of the customers generating these requests. More specifically, the network manager should ensure that high priority clients experience a smaller blocking probability than low priority ones. This paper shows how the proposed rerouting strategy can be adapted to achieve blocking probability differentiation during the course of connection setup. In this context, the main idea lies in serving incoming connection setup

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requests differently through total or partial activation of the rerouting strategy as will be explained further in the sequel.

The rest of this manuscript is organized as follows. Section 2 describes the rerouting framework and introduces its main underlying concepts. In Section 3, a selection of major related studies is summarized. Section 4 evaluates the benefits of the rerouting strategy under study through discrete event simulation. Finally, Section 5 concludes the manuscript.

2. Description of the proposed rerouting strategy

2.1. Generic description of rerouting strategy

As pointed out earlier, the considered rerouting strategy comes into play whenever the establishment of a lightpath via the RWA algorithm turns out to be impossible. Particularly, the rerouting strategy intervenes to remove the cause of the blocking allowing therefore the accommodation of the blocked call. Blocking in an all-optical network is mostly due to the inexistence of a wavelength continuous route from the source of the connection to its destination. In view of this, the rerouting strategy strives to rescue the blocked connection by trying to create a wavelength-continuous path. This is accomplished by first identifying those already established connections stopping the newly received call from being established and then applying the wavelength reassignment and route redirection techniques to these connections. **The proposed rerouting strategy organizes the identified live connections into different sets based on their associated wavelengths. So, for each wavelength λ_i, a set L_i containing the connections using λ_i is created. In this manner, retuning the connections of L_i to a wavelength different than λ_i liberates λ_i and therefore allows the provisioning of the blocked incoming request. If wavelength reassignment fails, then path deviation for each of the connections in L_i is attempted until either the blocked request is admitted to the network or path deviation is found to be insufficient. In the latter case, the incoming connection request is blocked.**

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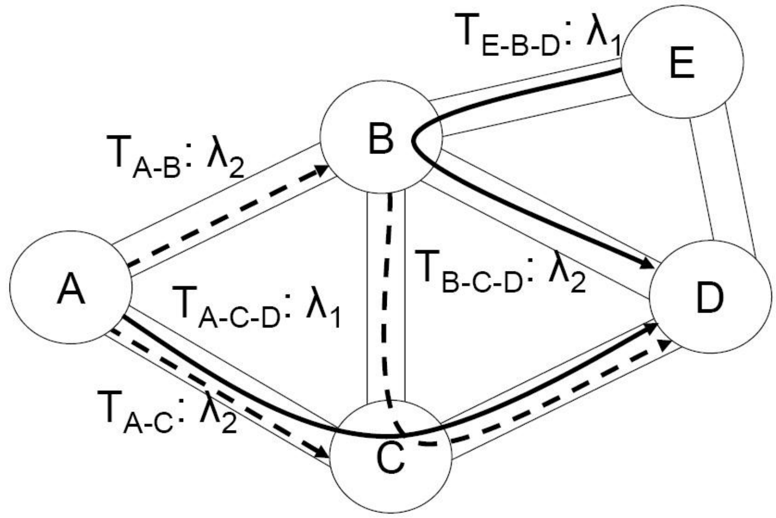

Fig. 1. A sample network topology.

In an attempt to keep the route changes to a minimum, **wavelength reassignments are given a higher priority than route deviations**. **This is motivated by the following observation. Wavelength reassignment is a process whereby the wavelength used by an existing optical connection is retuned while its physical path is preserved. This has the merit of reducing the circuit disruption period since the old and the new routes traverse the same switching nodes and only wavelength retuning needs to be considered. In contrast, path deviation involves finding a new route for the connection and allocating wavelengths along that route. Obviously, this results in a longer disruption time and thus makes path deviations less desirable than wavelength reassignments.** In this way, route redirections take place only if wavelength reassignments are found to be insufficient for accepting the blocked connection. The details about how wavelength reassignments and route deviations occur are provided next in the context of a specific example where the sample WDM optical network topology shown in Fig. 1 is considered.

2.2. Example delineating operation of rerouting strategy

As shown in Fig. 1, five connections are already setup in the network on node pairs AB, AC, AD, BD and ED. Let us denote these connections by $T_{A\text{-}B}$ (a 1-hop path passing

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through link A-B), $T_{A\text{-}C}$, $T_{A\text{-}C\text{-}D}$ (a 2-hop path traversing links A-C and C-D), $T_{B\text{-}C\text{-}D}$ and $T_{E\text{-}B\text{-}D}$ respectively. The paths used and the wavelengths occupied by these connections are indicated by the arrows and the labels associated with them. For convenience, it is assumed that each connection request requires a single wavelength of bandwidth and that two wavelength channels are supported by each fiber in the considered network. These wavelengths are denoted by λ_1 and λ_2. Suppose now that a connection request *t* addressed to node D arrives at node A and that the LCP routing algorithm pre-calculated the 2-disjoint paths A-B-D and A-C-D between A and D. Since neither of these two paths allows the establishment of connection *t*, the network manager resorts to the proposed rerouting strategy to try to accommodate *t*.

The rerouting strategy proceeds to identifying the connections preventing the provisioning of *t*. More precisely, for each of the two paths A-B-D and A-C-D, two sets L_1 and L_2 are constructed. Observe that $L_{i,\, i=1,\, 2}$ is used to store the connections occupying λ_i and thus stopping *t* from being allocated a wavelength of λ_i. In the context of this example, L_1 for the A-B-D path ends up storing $T_{E\text{-}B\text{-}D}$, which is the sole connection using λ_1 along that path. Similarly, $L_2 = \{T_{A\text{-}B}\}$ for A-B-D whereas $L_1 = \{T_{A\text{-}C\text{-}D}\}$ and $L_2 = \{T_{A\text{-}C}, T_{B\text{-}C\text{-}D}\}$ for A-C-D. Once the different sets are put together, wavelength reassignment on both paths is attempted by examining the L_i sets one at a time and in an ascending order of the cardinality of these sets. Ties are broken by considering first the sets corresponding to the lowest indexed wavelengths. So, the L_1 sets with a cardinality of 1 are considered first in the specific context of this example meaning that the $T_{E\text{-}B\text{-}D}$ and $T_{A\text{-}C\text{-}D}$ connections are examined first. It is clear that reassigning one of these connections to λ_2 will have the benefit of liberating λ_1 and as a result making it available for the establishment of connection *t*. In this example, the wavelength reassignment technique eventually succeeds in reassigning $T_{E\text{-}B\text{-}D}$ to λ_2 allowing *t* to be established along A-B-D on wavelength λ_1. Had the reassignment of $T_{E\text{-}B\text{-}D}$ to λ_2 been unable to allow for the acceptance of *t*, the wavelength originally used by $T_{E\text{-}B\text{-}D}$, λ_1 in this case, would not be retuned to λ_2. In other words, the wavelength reassignments per set are effected and made permanent only if they lead to the provisioning of the blocked connection.

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In case the wavelength reassignment technique fails to provision the blocked connection *t*, the network manager activates the route deviation policy. This policy examines the sets of connections to be rerouted (i.e., the L_i sets) in an order consistent with the one adopted by the wavelength reassignment policy. That is, the route redirection technique will consider the L_1 sets first, as in the previous case. $T_{E\text{-}B\text{-}D}$ will be thus processed by the route deviation policy. Assume that two routes are pre-calculated by the LCP routing algorithm for node pair ED and that these two routes are E-B-D and E-D respectively. The proposed route deviation policy uses LCP to redirect $T_{E\text{-}B\text{-}D}$ to a different route, with the other route being chosen according to the least congested path routing rule. In this example, E-D is picked and an attempt is made to redirect $T_{E\text{-}B\text{-}D}$ to the route E-D. If such an attempt is successful, the provisioning of the blocked connection *t* becomes possible along route A-B-D on wavelength λ_1. Otherwise, the process of path deviation is repeated for the remaining L_i sets until either the connection *t* is successfully provisioned or all the sets are examined without success in which case the connection *t* is blocked.

To further illustrate the operation of the proposed rerouting strategy, a formal pseudo-code description of the wavelength reassignment and route deviation policies are given in the Appendix.

2.3. Quality of service (QoS) differentiation framework

This subsection looks into possible means for using the proposed rerouting strategy to achieve QoS differentiation during the connection setup phase. Suppose that the incoming connection setup requests are classified into three priority levels, namely the gold, the silver and the bronze priority levels. To realize blocking probability differentiation, the network operator may envisage handling the received connection requests according to the following three guidelines:

1. **Drop blocked bronze connection requests,**
2. **Apply the proposed wavelength reassignment policy when trying to rescue blocked silver connections,**

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3. **Use the proposed rerouting strategy (wavelength reassignment coupled with path deviation) to help blocked gold connection gain access to the network.**

The proposed QoS differentiation framework is expected to enable network operators to create more profitable network architectures. As a matter of fact, optical operators are constantly on the lookout for generating new revenue streams by deploying services having different QoS requirements and consequently different priority levels. In this respect, proposals like the one discussed in this subsection not only helps network operators keep up with such trends but also allows them to manage the setup of connection requests consistently with the priority levels of received connection requests. The impact that the framework has on the blocking probability of each service class is thoroughly investigated in section 4, which highlights the QoS differentiation feature characterizing the proposed framework.

3. Related works

The rerouting strategy defined in this paper is designed around two policies, namely a wavelength reassignment policy and a route deviation policy. This section highlights the novelty of each of the proposed policies.

In [7], Move-to-Vacant Wavelength Retuning (MTV-WR) was proposed to combat blocking due to wcc and in [8] an algorithm with a reduced time complexity was developed. These previous studies report a reduction in terms of blocking probability by 30 % on average, however, the performance exhibited by the wavelength reassignment policy investigated in this paper is much more significant as will be shown later on. The authors in [9] proposed yet another wavelength reassignment policy that is designed for a class of all optical networks employing the fixed routing strategy. As a distinguishing feature from their policy, the one studied in this paper is adapted to the more realistic and the more widely used LCP routing algorithm. For benchmarking purposes, the Minimum Overlap wavelength to Least Congested (MOLC) reassignment policy considered in [9] together with a version of MOLC that we adapted to LCP routing are used as benchmark schemes in the numerical results section.

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The concept of path deviation was originally explored in the design of telephone networks [10]. This concept was defined as the process of switching an active circuit from one path to another path without changing its source and destination. A survey of path deviation techniques for circuit-switched telephone networks can be found in [11]. An analysis of route deviation in the context of circuit-switched telephone networks is also given in [12].

It was not until recently that path deviation started to be applied to optical WDM networks [13 – 15]. The authors of [13] proposed a departure-triggered path deviation strategy. In this regard, on the occurrence of a connection departure event in the optical network, lightpaths having both a source and a destination on the path of the departing connection become subject to path deviation in order to optimize resource usage in the network. The authors in [14] consider the path deviation of a single connection upon the occurrence of a departure event. In [15], both departure-driven and arrival-driven path deviations are studied.

The path deviation policy discussed in this paper differs from previous policies in that it restricts path redirections to those already established connections whose deviation contributes to the setup of a blocked connection. This has the advantage of reducing the number of route deviations taking place in the network while at the same time improving the overall connection blocking probability. Another difference between the proposed deviation policy and the ones studied in [13, 15] stems from the fact that unlike [13, 15], this paper applies the deviation policy to the case of all-optical WDM networks without wavelength conversion. Even though [15] considers the case of all-optical WDM networks, this paper differs from [15] in that: 1) it uses path deviation only upon the failure of the wavelength reassignment policy to accommodate a blocked connection; 2) path deviations are effected only if they prove to be successful in allowing for the acceptance of the blocked connection. This results in a smaller number of deviations and a better blocking performance as asserted by the results given in the next section.

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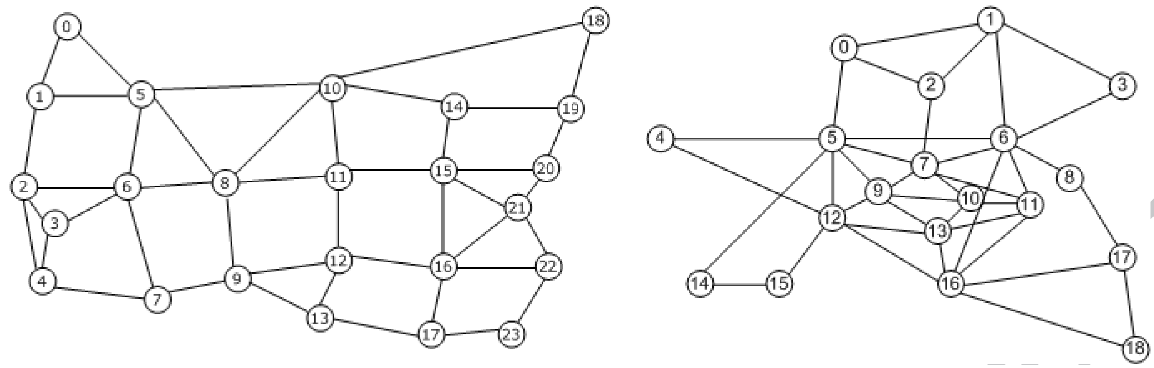

(a) USBN topology with 24 nodes and 43 links **(b)** EON with **19** nodes and 38 links

Fig. 2. Network topologies used in the simulation study.

4. Simulation study and numerical results

A discrete event simulator was developed to examine the performance of the proposed rerouting strategy in the context of two well known backbone networks, namely: a) the US Backbone Network (USBN depicted in Fig. 2(a)) and b) the European Optical Network (EON given in Fig. 2(b)). USBN has 24 nodes and 43 bidirectional fiber links while EON consists of 19 nodes interconnected through 38 bidirectional links. The data pertaining to the physical topologies of these networks were taken from [16, 17]. The simulation study is built upon the following assumptions:

- The connection requests arrive according to a Poisson process and the connection holding time follows an exponential distribution with a mean normalized to unity.
- Each connection request has a bandwidth requirement of one wavelength unit.
- The capacity of each fiber link is chosen to be 8 wavelengths in each direction.
- The LCP routing algorithm with two disjoint paths per node pair is used to route the received connection requests, while wavelengths are allocated for the provisioned connections according to the first-fit wavelength assignment strategy.

4.1. Metrics used for performance analysis and benchmarks

The metrics used to evaluate the performance of the rerouting strategy are the following:

(1) *The overall blocking probability*: The ratio between the number of connections denied access to the network and the total number of received connection requests.

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(2) *Average number of reassigned calls per wavelength reassignment process*: The mean number of calls reassigned via the wavelength reassignment policy to accommodate a blocked call in the network. This provides insight into the perturbation to the network caused by the wavelength reassignment technique.
(3) *Average number of reassigned calls per occurrence of the path deviation event*: The average number of calls deviated by the proposed path deviation policy.

In each simulation run, 100 000 connection requests uniformly distributed among all node pairs are considered. Each plotted value of the above-presented metrics is averaged over multiple simulator runs to ensure that a very narrow 95% confidence interval is achieved.

Four connection setup strategies serve as benchmarks, namely:

(2) A rerouting-free adaptive RWA algorithm that uses the LCP routing algorithm and the first-fit wavelength assignment strategy to provision connection requests. In what follows, this scheme will be referred to as *adaptive RWA scheme without rerouting*.
(3) The *Minimum Overlap wavelength to Least Congested* (*MOLC*) reassignment policy considered in [9], which was designed for all-optical networks supporting the fixed routing algorithm. Note that with fixed routing, Dijkstra's algorithm is used to pre-calculate the shortest path in terms of number of hops for each source destination pair.
(4) *A modified version of MOLC* that is tailored for the use of the Least Congested Path routing algorithm.
(5) A rerouting-free static RWA algorithm that uses fixed routing to route connections and that assigns wavelengths to the routed connections according to first-fit strategy. This benchmark scheme will be designated as *static RWA scheme without rerouting*.

4.2. Numerical results for a quality of service agnostic all-optical network

Fig. 3(a)-(b) compare the blocking performance of the proposed rerouting strategy to that of the considered benchmark schemes as applied in USBN and EON for different values

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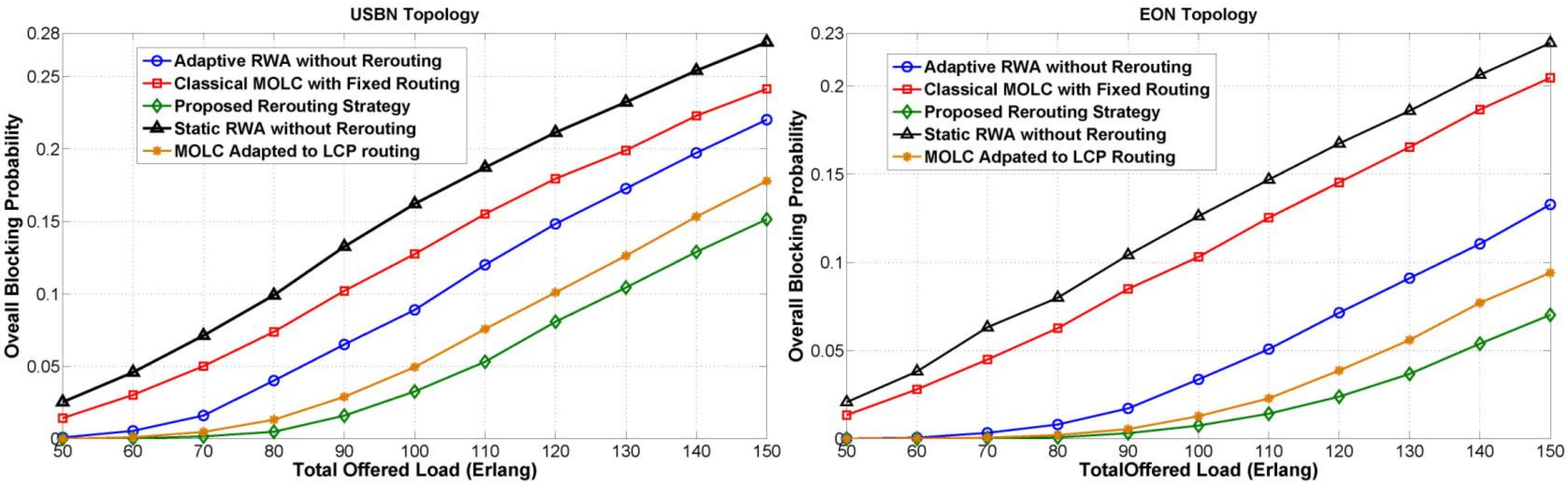

(a) (b)

Fig. 3. Blocking probability vs. load offered to network: (a) Topology USBN and (b) Topology EON.

of the load offered to the network. Considerable improvement in terms of blocking probability is observed across all load values by applying the rerouting strategy discussed in this paper. The percentage of improvement is larger for lower values of the load. For example, in the case of the USBN topology the percentage of saving relative to the rerouting-free benchmark scheme employing adaptive RWA is 32 % at 150 Erlang and 63 % at 100 Erlang. This is due mainly to the inherent ability of the rerouting strategy to reduce the number of connections that are blocked due to the inexistence of wcc-compliant lightpaths. Obviously as the load increases the percentage of improvement stabilizes since the resources in the network become rare and hence less wavelength reassignment and path deviation events can take place.

It is also clear from Fig. 3(a)-(b) that the schemes using adaptive RWA algorithms outperform the ones utilizing static RWA algorithms. This is one of the reasons that led us to consider a version of MOLC that uses adaptive RWA. In doing so, a fair comparison between the rerouting strategy proposed in this paper and the MOLC benchmark scheme is guaranteed. It is important to highlight in this respect that Fig. 3(a)-(b) suggest that the proposed rerouting strategy is better than the adaptive version of MOLC when it comes to rescuing blocked connections. This observation confirms without any doubt the merit that the process of combining wavelength reassignment with

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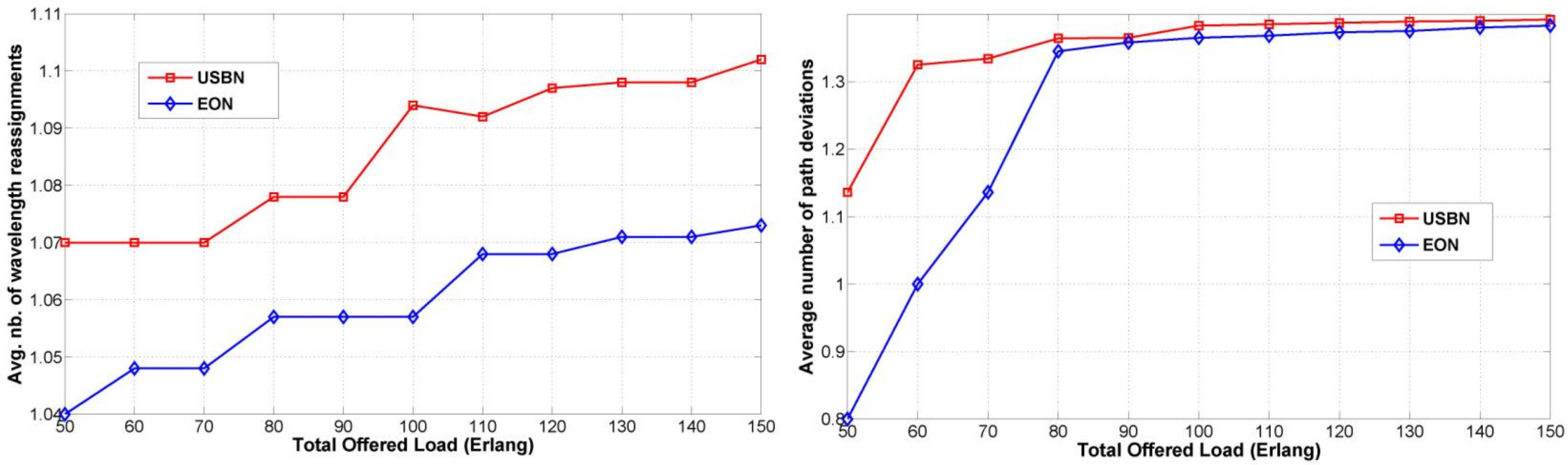

(a) (b)

Fig. 4. For USBN and EON topologies, average number of calls reassigned per:

(a) Wavelength reassignment event and (b) Pah deviation event

path deviation has and therefore highly motivates the implementation of the proposed rerouting strategy in the context of all-optical networks without wavelength conversion.

The average number of calls reassigned per wavelength reassignment event and path deviation event are graphed in Fig. 4(a) and Fig. 4(b) respectively, in the context of both the USBN and the EON topologies. The results demonstrate that the average number of reassigned calls increases slightly with the traffic loading. To provide insight into the reported values, let us consider a load value of 120 for the EON topology. For such a load value, it was found that the proposed rerouting strategy causes an average number of 1.07 connections to be reassigned a new wavelength per reassignment event. Moreover, the average number of calls deviated per deviation event was found to be approximately 1.37. Consequently, it is obvious that the proposed technique reassigns few calls and results in very little disturbance in the network. The same observations can be made based on the results reported for the USBN topology.

The first-fit (FF) wavelength assignment heuristic has been considered thus far. For completeness, the effect that the wavelength assignment strategy may have on the blocking performance of the rerouting strategy under study is investigated next.

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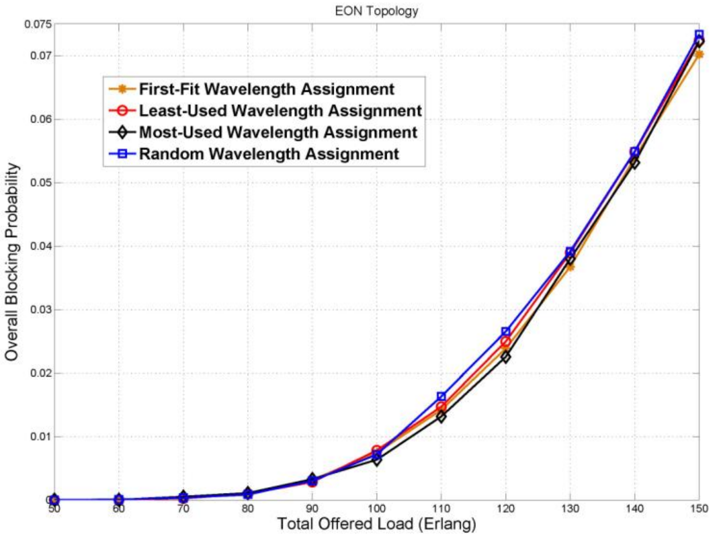
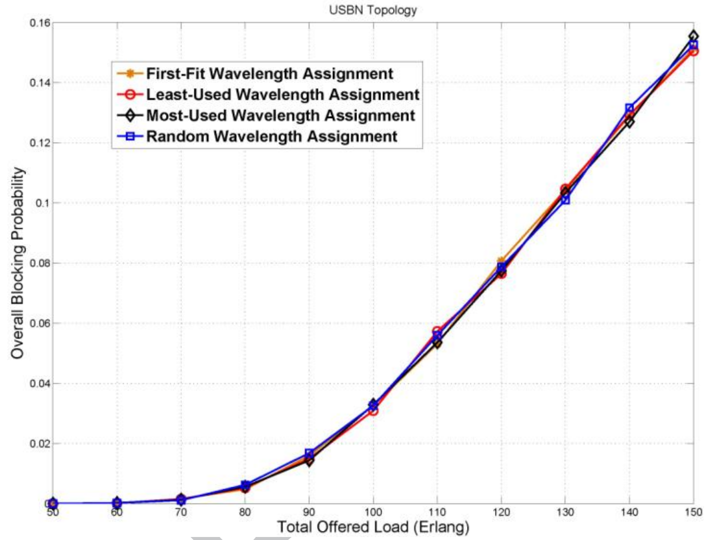


(a)



(b)

Fig. 5. For each wavelength assignment strategy, blocking performance of proposed rerouting strategy vs. load: (a) EON topology and (b) USBN topology

Different wavelength assignment strategies are considered in addition to the FF strategy, namely the Random (R), the Least-Used (LU) and the Most-Used wavelength assignment heuristics [6]. The blocking probabilities achieved by the proposed rerouting strategy under these wavelength assignment algorithms are given in Fig. 5(a) and 5(b) for the EON and USBN topologies respectively. The random wavelength assignment scheme selects one wavelength at random out of the set of available wavelengths while the least-used (most-used, respectively) strategy chooses the wavelength that is the least used (most used, respectively) in the network. It is important to note that the LU and the MU schemes require additional storage and computational cost and as such are not preferred in practice [6]. Nonetheless, they are used for benchmarking purposes. As per the reported results, MU is found to exhibit the best performance under low load with the other approaches not far behind. It is clear also that the R scheme presents the worse performance compared to the other strategies. This justifies the choice made in this manuscript to use the FF strategy as the wavelength assignment scheme. Even though the difference among the various heuristics is not too significant, the FF strategy appears to perform well under conditions of both low and high loads.

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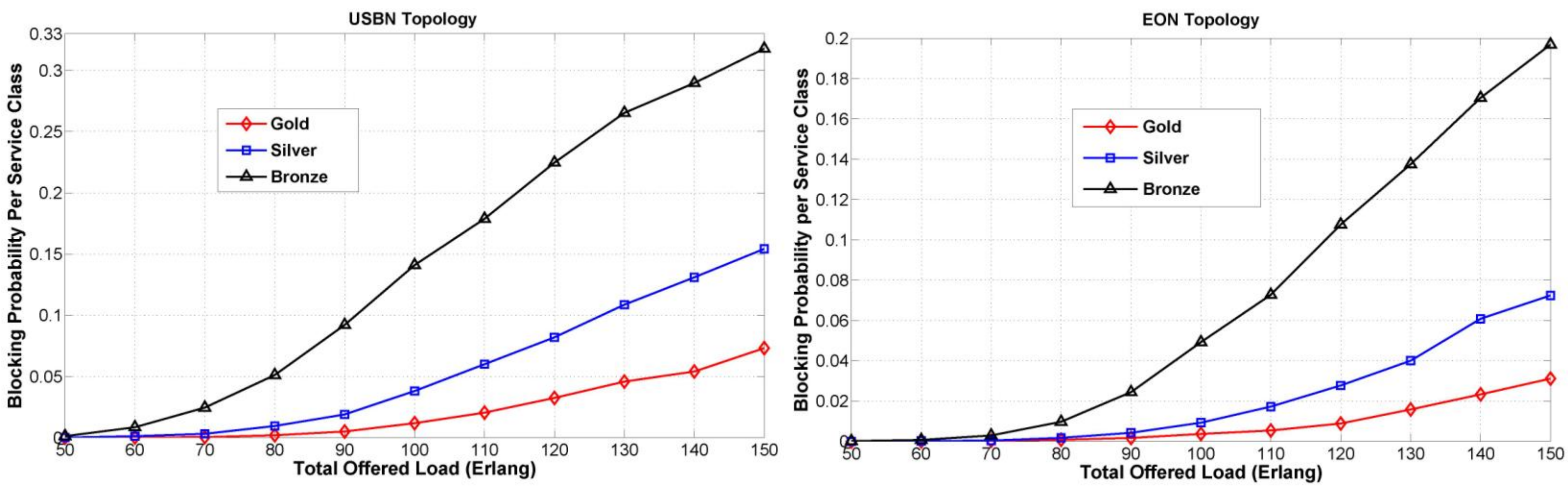

(a) **(b)**

Fig. 6. Blocking probability per class of service versus load offered to network: (a) USBN Topology and (b) EON Topology

4.3. Numerical results for a quality of service aware all-optical network

The previous subsection dealt with the case of an all-optical network that does not support quality of service (QoS) differentiation. This subsection turns to QoS-aware all-optical networks and assumes that the incoming connection requests are arranged into three service classes referred to as gold, silver and bronze. **These connection requests are served in a way that is consistent with the guidelines underlying the QoS differentiation framework defined in subsection 2.3.**

Using the rerouting strategy to handle blocked gold connections increases to a great extent the likelihood that a gold connection gets admitted to the network. This is done without penalizing the lower priority connections that are currently in progress in the network. Compliance to the guidelines discussed in subsection 2.3 during the setup of a connection introduces QoS differentiation to the network as asserted by Fig. 6(a) – (b). These figures plot the blocking probabilities resulting from the enforcement of these guidelines. The results pertaining to the USBN topology are given in Fig. 6(a) while those relating to the EON topology are presented in Fig. 6(b).

Based on the reported results, it is observed that the gold connections experience the lowest blocking probability whereas the bronze connections have the highest blocking

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probability. This is a natural consequence of the differentiated treatment received by the incoming connection requests. More precisely, not rescuing any of the bronze requests would eventually penalize to a certain degree these types of requests and lead to a relatively high blocking probability for such requests. On the other hand, applying the wavelength reassignment policy to rescue silver connections has the effect of giving some privilege to such requests with respect to network access. This justifies the better blocking performance that silver requests experience when compared to their bronze counterparts. Finally, gold connections benefit from both the wavelength reassignment and path deviation and gain the luxury of an extremely reduced blocking performance.

5. Conclusion

This paper proposes to combine wavelength reassignment with route deviation giving birth to a novel effective connection rerouting strategy. Whenever a connection is denied access to the network, wavelength reassignment is first attempted as a means for alleviating the effect of wavelength continuity constraint. Through wavelength reassignment, a number of lightpaths existing in the network are reassigned to a different wavelength without changing their physical paths so as to enable the blocked connection to access the network. Failure to achieve such an objective via wavelength reassignment causes the network manager to enable path deviation, whereby few lightpaths experience route change in such a way so as to accept the blocked connection request. The performance of the proposed rerouting strategy was studied in the context of a simulation study with a view to obtaining an estimate of its effect on the blocking probability of optical connections. The results obtained from the developed simulation model proved that the proposed strategy is capable of achieving a great enhancement in terms of the overall blocking probability experienced by the optical connections. Moreover, the work carried out demonstrated that the rerouting strategy provides the optical operators with the possibility of achieving near optimal blocking performance by deploying just a small number of wavelengths per fiber. Finally, this paper showed that the considered rerouting strategy offers to network operators the opportunity of achieving blocking probability differentiation during the setup of connections belonging to different service classes.

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Appendix

Let G(N, E) be a graph representation of the optical network topology, with N being the set of vertices (network nodes) and E the set of edges or fiber links. Furthermore, let W denote the number of wavelengths supported by each fiber. Before presenting the details of the rerouting strategy, it is necessary to define the concept of wavelength congestion, which is at the heart of the proposed strategy. Wavelength congestion of a wavelength λ is measured by the number of links that uses λ. The least congested wavelength is thus the wavelength that is used by the minimum number of links.

In the context of the considered rerouting strategy, the wavelength reassignment and route deviation policies are applied to the sets of connections to be rerouted denoted by L_i, where i = 1, 2, …., W. **It is important to reemphasize the following. L_i is the set of live connections using λ_i and preventing the blocked connection setup request, which the rerouting strategy is trying to rescue, from being assigned a wavelength of λ_i.** A pseudo-code description of the rerouting strategy is given below:

(1) When a new call request from node S to node D is blocked, populate the sets of connections to be rerouted (L_i, i = 1, 2, …., W) with the appropriate live connections. This is done for each of the paths existing between S and D.

(2) Sort the sets in an ascending order of their cardinality.

(3) Build a list $C_{\lambda i}$ containing the wavelength congestion of each wavelength λ_i, i = 1, 2, …., W.

(4) Sort the wavelengths in an ascending order of their congestion.

(5) Enable wavelength reassignment:

```
for each set L starting from the one having the smallest cardinality.
    for each connection T in L
        for each λi starting with the least loaded one
            Reassign T to λi
        end
    end
    if all reassignments are successful
```

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Establish blocked call, break out of loops and go to (8)

end

end

(6) If wavelength reassignment is not successful, activate route deviation:

for each set L starting from the one having the smallest cardinality.

for each connection T in L

use LCP and first-fit to redirect route of T

end

if all redirections are successful

Establish blocked call, break out of loop and go to (8)

end

end

(7) If neither of steps (5) and (6) is successful, then block the connection request.

(8) Process the next connection request.

Visiting the L_i sets in an ascending order of their cardinality yields a smaller number of wavelength reassignments. In addition, reassigning connections to the least congested wavelengths balances the traffic among existing wavelengths and further improves blocking probability.

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