Network Performance Improvement through Differentiated Survivability Services in WDM networks

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Core networks based on WDM technology constitute a promising and viable solution to support emerging applications requiring high availability, reliability and QoS guarantees. Due to the enormous bandwidth offered by these networks and the increasing number of "mission critical" applications, survivability is becoming an essential network design aspect. This paper focuses on providing resilience in WDM optical networks supporting differentiated survivability traffic requirements. The work is based on the backup multiplexing technique in order to facilitate efficient resource sharing and investigates different routing and wavelength assignment schemes that considerably enhance the spare capacity utilization. A simple approach that can be used to assign different classes of service supporting varying restoration requirements is proposed and significant network performance improvement has been demonstrated through relevant simulations.

OCIS codes: *060.4257, 060.4261, 060.0060*

1. Introduction

Optical networking employing wavelength division multiplexing (WDM) is capable of carrying tremendous amount of information and is expected to be extensively used to support the requirements of next generation networks and the future Internet. The deployment of WDM technology enables the routing of multiple lightpath connections utilizing different wavelength channels in an optical fiber. A lightpath is an optical connection between two end points (nodes) provisioned by identifying a route with available capacity in the optical network. The set-up of this connection is performed by appropriate configuration of any optical node present in the path. In WDM networks a number of issues need to be addressed when provisioning lightpaths. One of these is the requirement that a lightpath must occupy the same wavelength across the selected path due to the immaturity of all-optical wavelength conversion technologies, which is known as the wavelength continuity constraint. Given a connection request from source to destination node in such a network the problem of computing a route and assigning a wavelength to the connection is the so called routing and wavelength assignment (RWA) problem. This work considers mesh WDM networks with dynamic traffic conditions and without any wavelength conversion capabilities. The physical links are assumed to comprise a fixed number of wavelengths and when a new connection request arises an appropriate route and an available wavelength are selected to form the lightpath. The primary objective of this approach is to identify efficient RWA schemes able to minimize the blocking of new connections due to bandwidth limitations.

WDM networks with dynamic traffic patterns can easily provide guaranteed timeliness using simple resource reservation schemes and dedicating the entire bandwidth of a lightpath to a certain application. This partially satisfies real-time critical applications which usually require not only strict timeliness but also fault-tolerance. Fault-tolerance is an essential requirement in high speed networks since a single link failure causes loss of services that carry an enormous amount of information that may lead to significant revenue losses. Therefore it is indispensable for WDM networks to have resilience mechanisms in place to be able to reroute/restore the affected traffic upon a failure.

These resilience mechanisms can be classified according to the different requirements requested by various applications supported by the network. Ideally it would be desirable to provide 100% resilience guarantee to all types of traffic supported by existing and future networks, but this may be unnecessary and wasteful in terms of resource utilization resulting in cost inefficiencies. For example some applications, such as email, do not require the same level of resilience with real-time business transactions. Thus, a more efficient resilience scheme suitable for a network supporting a variety of applications would be a scheme that provides different level of network survivability to different traffic types in accordance with the respective Service Level Specifications (SLS) maximizing the network utilization [1]. Therefore in a network environment such as the new global and business oriented internet an important requirement will be to provide differentiated survivability services to different types of traffic enabling higher priority demands to exploit higher network availability [2,3].

This paper aims at providing resilience in WDM optical networks supporting differentiated survivability traffic requirements. The first part of the work is focused on fault-tolerance for high priority, high resilience traffic through the backup multiplexing technique [4]. The use of the backup multiplexing technique is selected in order to facilitate efficient resource sharing. In this framework different routing and wavelength assignment schemes that considerably enhance the spare capacity utilization are investigated and proposed. Through the proposed novel wavelength assignment scheme (that dedicates a consecutive number of wavelengths to protection lightpaths) a performance improvement of about 4% to 14% is observed compared to commonly used techniques. Moreover a simple method that can be used to assign different classes of service supporting varying restoration requirements is proposed and significant network performance improvement has been demonstrated through relevant simulations. More specifically our extensive simulations revealed a significant blocking probability reduction of up to 12% by assigning preemption authority to high-priority traffic over lower-priority traffic due to the accomplished efficient resource reuse.

The rest of the paper is organized as follows. Section 2 provides a brief summary of the state-of-the-art survivability schemes and explains our traffic differentiation approach beyond them. In section 3 notations and assumptions used throughout the simulations are provided and the description of our algorithm is discussed along with our proposed RWA and differentiation schemes. Section 4 presents the simulation parameters applied in this work and analyzes the results obtained through the simulations. Finally section 5 includes the conclusions of the paper.

2. Proposed survivability scheme

Network survivability can be defined as the capability of the network to provide continuous services in the presence of failures resulting in lightpath disruptions. Due to the large amount of traffic at the lightpath level, resilience mechanisms are highly critical and many schemes have been proposed to address this issue [5]. Survivability can be broadly classified in two types: dynamic restoration and pre-designed protection. In dynamic restoration [6, 7] the backup lightpath discovery procedure is initiated after a primary lightpath fails. This procedure might not result in a backup lightpath identification due to lack of network spare capacity and therefore this method does not guarantee successful recovery. In pre-designed protection [8-10] on the other hand a backup lightpath is computed and wavelength channels are reserved for it at the time of establishing the primary lightpath. If a backup lightpath can't be found under current network conditions, the connection request is blocked. A database of restoration paths for this method can be populated by dynamic restoration. Hence is possible to implement a single restoration algorithm able to be used "preemptively" before a failure occurs as part of a pre-designed protection method and dynamically after the occurrence of a failure not previously considered. The advantages offered by the pre-designed protection method compare with dynamic restoration are the shorter restoration times and the 100% restoration guarantee.

A further classification of the pre-designed protection method is performed based on link or path protection schemes. In the link based method the failed link is replaced by a new path which is merged with the unaffected portion of the primary path, to constitute the backup path. This method constraints the choice of the backup paths and requires more spare resources than the path-based method [11], which computes a complete end-to-end backup path from the source to the destination of the failed primary path. In the path-based method, wavelength channels on the backup path can be either dedicated or shared. If dedicated the wavelength channels assigned to a specific backup path cannot be assigned to other backup paths whereas in the shared method, backup paths can share wavelength channels under the single link failure assumption, if their primary paths are link-disjoint. This is known as backup multiplexing and provides improved resource utilization [4]. Specifically in [12], it was shown that the total resource requirement for the dedicated backup method is 260-265% of the requirement without lightpath protection, and it can be reduced to 186-195% by considering backup multiplexing.

In this paper survivability is provided by implementing the backup multiplexing technique under dynamic traffic demands where existing lightpaths cannot be rerouted and future lightpath requests are not known. We differentiate traffic demands to three classes of service in what concerns network recovery performance, and adopt the concept of resilience priority classes to maximize network resource utilization. We considered three types of lightpaths: 1) high priority protected lightpaths, 2) unprotected lightpaths and 3) low priority preempted lightpaths. A high priority protected lightpath has a working path and a diversely routed backup path. The wavelength channels on the working path of the high priority protected lightpath are dedicated to that lightpath and carry user traffic under normal operating conditions. Both the working and the backup lightpaths are identified before the provisioning of the working path. In this case the wavelength channels on the backup path are shared among different high priority lightpaths. Wavelength channels are shared to ensure that any single fiber-link failure on the working path of any high priority lightpath can be restored. An unprotected lightpath is not protected with a backup path and upon any failure along the lightpath a dynamic restoration mechanism is initiated to provide an alternative route without any guarantees. Finally low priority preempted lightpaths are unprotected lightpaths that allow preemption of their utilized resources in case of a high priority lightpath failure. Under this scheme the wavelength channels allocated for the low priority lightpaths can be shared with the backup routes of the high priority lightpaths.

3. Algorithm Description

In this section, we describe our routing and wavelength assignment algorithm that computes a primary and a backup lightpath if required by a given traffic demand and assigns wavelength channels to these paths.

Assumptions and Definitions

Initially we introduce the main definitions and assumptions used by our algorithm. We assume that all requests have a bandwidth demand of one unit and can be classified to class 1 if a link disjoint backup path is required along with their primary path to provide guaranteed protection or class 2 if just dynamic restoration is acceptable. The physical bandwidth of each link l can be divided into the following three parts: Al, Bl, and Rl [13]. Al represents the total amount of reserved bandwidth dedicated to primary paths carried by link l and it is not allowed to be shared. B_l is the total bandwidth occupied by all backup paths on link l and unlike A_l it can be shared by some backup paths, provided that their associated primary paths are disjoint. Specifically if two primary paths share a common link (so they are not disjoint) they will be both affected by a single network fault on this link. Therefore, their backup paths cannot share any common bandwidth since it will be necessary for both paths to be activated simultaneously in case of their common primary link failure. Finally, the residual bandwidth R_l is the difference between the physical bandwidth on link l and the total consumed bandwidth (A_l + B_l). For any future primary path established on link l, R_l is the only available bandwidth that can be used whereas for setting up a backup path on link l for a new primary path a, the available bandwidth $S_l(a)$ consists of two components : the residual bandwidth R_l and the portion of B_l (denoted by $?_l(a)$) that is able to be shared for carrying this backup path. Since primary paths do not share bandwidth their cost is the number of hops or links that they traverse. On the other hand the cost of a backup path is the number of free wavelengths used by it on each link it traverses. If a wavelength is not free and it is currently used by some primary lightpath (either of class 1 or class 2), it can not be used by the backup path. If a wavelength is not free and it is currently used by a set of backup lightpaths S, it can be used by the new backup path with no extra cost (zero cost) if and only if its primary path is link-disjoint with the primary route of each and every backup lightpath in S. If a wavelength is free, it can be used by the backup path with the cost value equal to one. Unlike primary paths, the path cost of a longer backup path may cost less than that of a shorter one, because of bandwidth sharing. This cost function approach leaves a higher number of wavelengths available for use from future requests, thus improving the network performance. The main scope of our proposed RWA scheme as well as our resilience differentiation approach is to maximize resource reuse. Through extensive simulations we demonstrate how the restoration capacity increase affects the overall network performance.

Proposed Algorithm

The proposed algorithm solves the routing and wavelength assignment problems in two separate steps. Routing is implemented based on the Dijkstra's algorithm to compute a primary and a backup path for the given demand. The wavelength assignment algorithm assigns wavelength channels to the primary and backup paths favoring resource sharing between the current demand and the already established requests. We assume that the network nodes have no wavelength conversion capabilities therefore a lightpath is not allowed to occupy different wavelength channels along its route.

In Figure 1 the flow chart of the algorithm is presented. After the initialization phase in which the algorithm collects network topology information (i.e. number of nodes, number of links, wavelengths per fiber, network connections, backup path wavelength assignment scheme) and constructs the required matrixes to monitor the network state (Al,Bl and Rl), connection requests arrive for random source and destination pairs. First independent of the request service requirement a primary lightpath is established through the primary lightpath computation phase. This phase consults the R_l matrix and assigns costs to the network links based on the following approach. If a link has no free wavelengths its cost is set as infinite and it is not considered by the Dijkstra algorithm for the path computation. If available wavelengths exist on the link the cost is set to be inversely proportional to the number of these wavelengths offering this way a degree of load balancing. After weights are assigned to the network links, the widest shortest path routing algorithm takes place, calculating a number of shortest paths and selecting the first one that traverses the minimum number of hops and for which at least one common free wavelength exists on all its links. If no path is found the connection is blocked, and the blocking probability due to primary path blocking is increased. If at least one path is calculated, a list of possible wavelengths that can be allocated for it is identified and the first wavelength is chosen (assuming that they are sorted in increasing order) to form the primary lightpath. After the primary lightpath is ready to be established the A_l and R_l matrixes are updated to reserve the appropriate wavelength and the algorithm proceeds to the examination of the demand service requirement. If the request belongs to class 2 traffic and preemption is enabled B_l matrix is also informed to allow sharing of the allocated wavelength from future backup paths of class 1 traffic that has the authority to preempt class 2 lightpaths.

If the established demand requires a backup path (class 1), the flow control moves to the backup computation phase. Here the available bandwidth $S_l(a)$ consisting of the residual bandwidth (R_l) and the portion of the backup bandwidth ($?_l$) that can be shared as described earlier is first identified excluding the links utilized by the primary path. Then based on this available bandwidth ($S_l(a)$), for each wavelength an auxiliary graph is generated representing the current network state. For this new topology formulation link costs are assigned based on the following strategy: On the links for which the wavelength under consideration belongs to $?_l$ a zero weight is assigned and if it belongs to R_l a unit cost is assumed. On the other hand links on which the wavelength is already allocated (by primary lightpaths) are not considered in the auxiliary graph and cannot be used for the backup calculation. An attempt to find a lightpath for each wavelength follows and if no lightpath is found for any wavelength the connection is blocked due to backup path blocking, requesting from the algorithm to roll back the updates of A_l and R_l previously performed by the primary path computation phase. In case of multiple backup lightpaths computations the algorithm must allocate one, based on the selected wavelength assignment scheme. If the random pick (RP) wavelength assignment scheme is selected the lightpath is chosen randomly from the set of the available lightpaths. For the last fit (LF) scheme the lightpaths with minimum cost are identified and the last one (when sorted in increasing order) is selected, whereas for the first fit (FF) the first one from the minimum cost lightpaths is allocated. In the final step of the algorithm Bl and Rl are updated for the links which residual bandwidth is used.

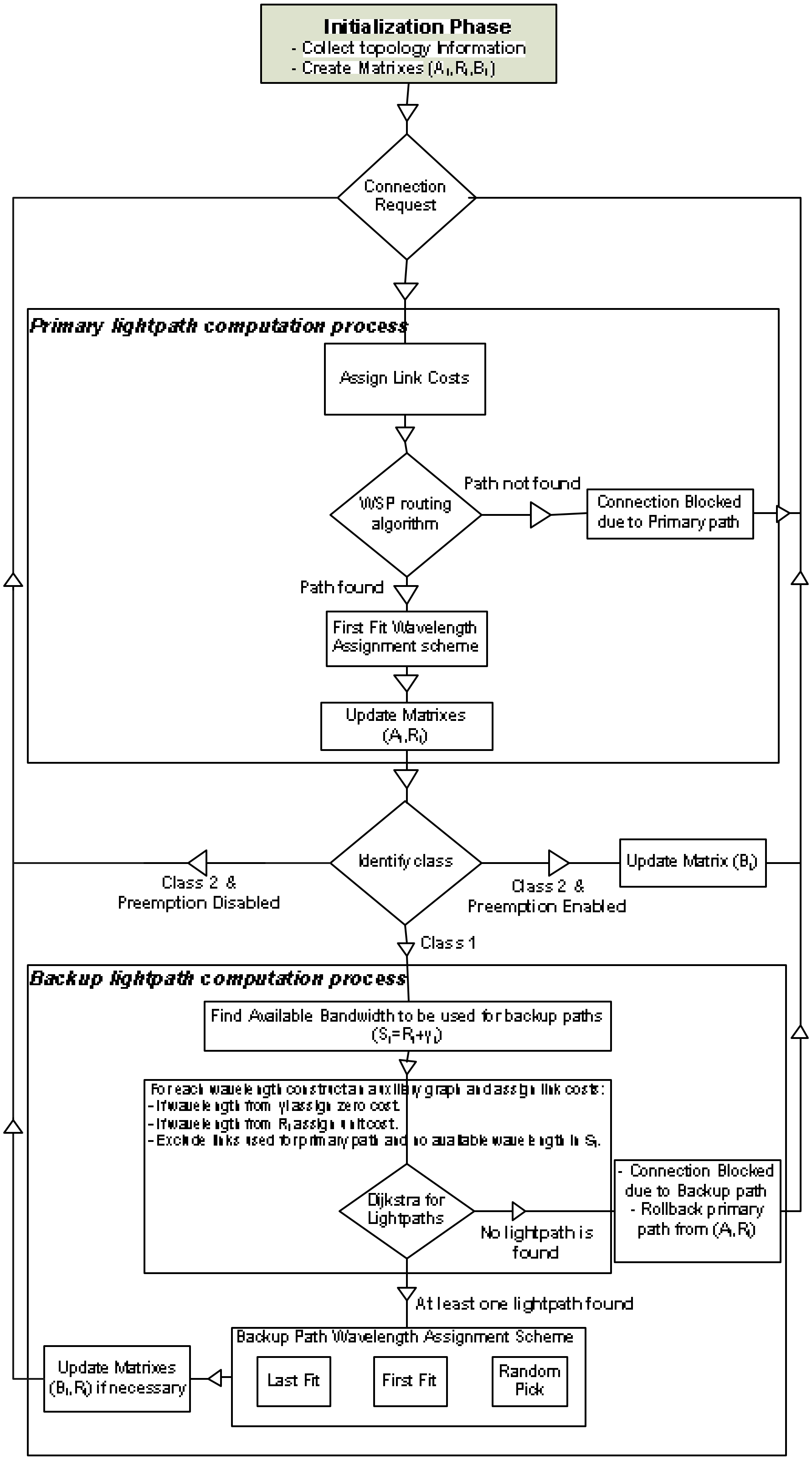


Fig. 1. Flowchart of the proposed algorithm

4. Performance Study

We performed simulations of dynamic provisioning on several representative backbone mesh topologies. The results presented here are generated based on the Pan-European test network (figure 2) defined by COST 239 [14] that has 11 nodes and 26 links and are representative of results for other mesh network topologies. Links are considered bidirectional and if a link failure occurs the traffic flow in both directions will be disrupted. Lightpaths comply with the wavelength continuity constraint and connections requests are equally likely to have any of the network nodes as its source or destination. Also we assume that calls arrive one by one and their holding time is long enough to consider that accepted calls do not leave (incremental traffic). A connection is blocked if either a primary or a backup path can not be established. The results shown in the following figures are the average values over 20 independent experiments.

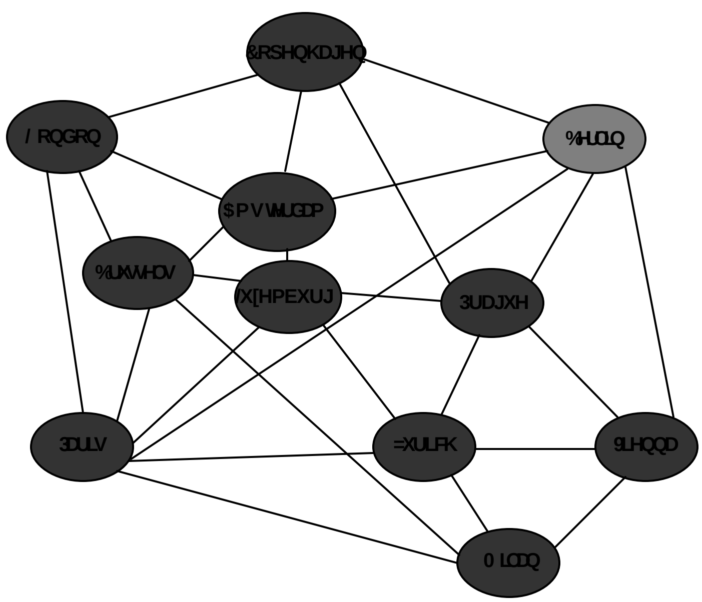
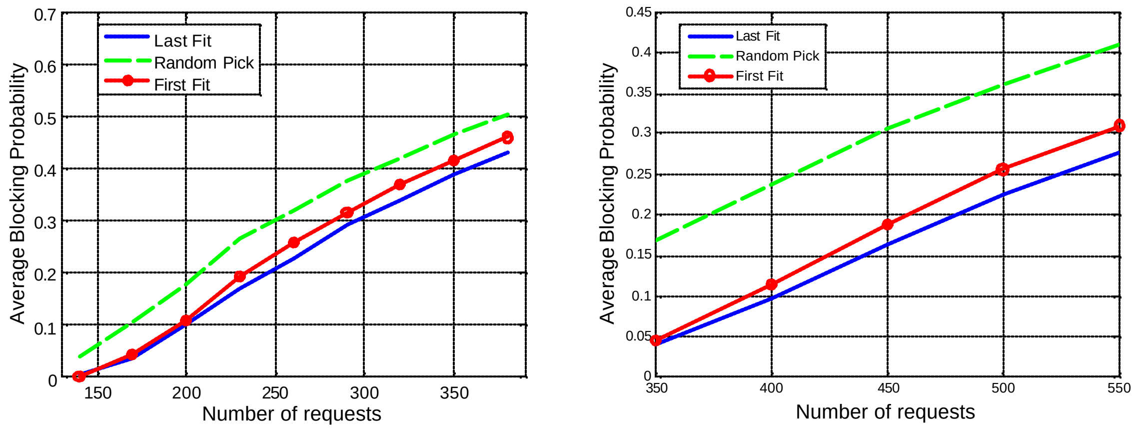


Fig. 2. Pan-European test network COST 239

First we explore the behavior of the three wavelength assignment schemes when applied for the backup lightpath establishment. First fit is the wavelength assignment scheme used for the primary path establishment through all simulation results presented.

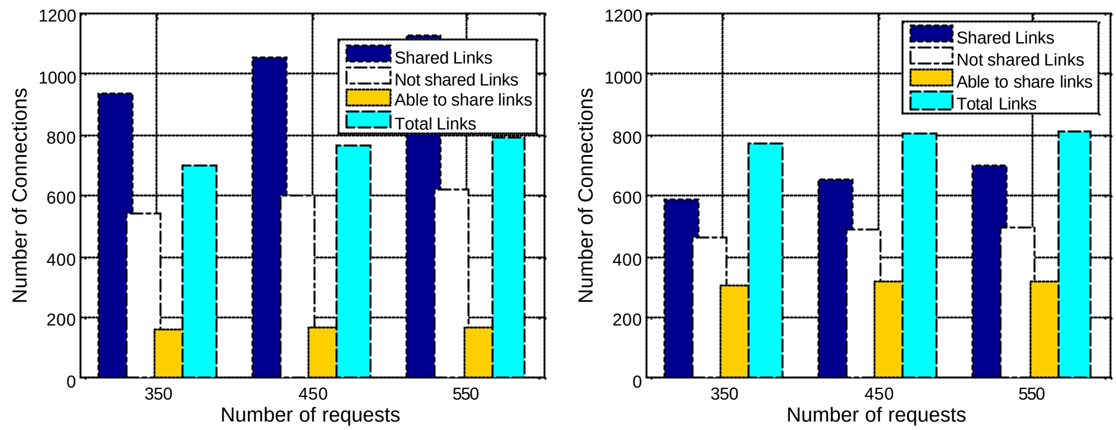


(a) (b)

Fig. 3. Network performance for the three backup path wavelength assignment schemes and for different fiber capacity (a) C=8, (b) C=16

In figure 3 the average blocking probabilities for Last Fit , First Fit and Random Pick are compared for uniform fiber capacities of C=8 and C=16 wavelengths. LF wavelength assignment scheme provides improved network performance compared with FF of around 4% and 2% for high network loads for 16 and 8 channels per fiber respectively. In addition the LF significantly outperforms RP since it can offer a blocking improvement of 14% and 8% for the two different fiber capacity parameters.

These observations can be explained and validated if we examine the difference in the restoration capacity occurring from the various wavelength assignment schemes. In figure 4 we present the link utilizations for LF and RP schemes. “Shared Links” refer to the number of links that are used more than once for path formulation, “Not shared Links” represent the links that are utilized by the primary lightpaths, "Able to share Links" correspond to the links that are able to be used for backup lightpaths and finally "Total Links" is the sum of "Not to share" and "Able to share Links".



(a) (b)

Fig. 4. Link distribution flow charts for (a) LF and (b) RP for fiber capacity C=16

It is clear that LF scheme maximizes the backup path link reuse (1100 compared to 700 of RF for 550 requests) although a small number of links are dedicated for backup paths (180 compared to 300). The increase in restoration capacity of the LF over the RP scheme is around 58% and constitutes the main reason of the lower blocking probability of the LF scheme. LF is a simple and fast wavelength assignment scheme able to increase considerably the backup link reuse by dedicating a small but consecutive portion of the wavelength band to backup paths, allowing a large amount of the precious residual bandwidth for the primary paths that are allocated based on a FF scheme.

In the next step of our simulations we analyze the results obtained by considering the coexistence of both class 1 and class 2 traffic, with the preemption authority disabled and enabled. In figure 5 we compare the average blocking probabilities when the class 1 traffic is

50% and 80% of the total requests with the case in which all the traffic is considered as class 1 traffic. The benefit offered by the preemption enabled scheme is up to 12% when half of the incoming traffic is assigned as class 1 and up to 8% when 80% is set us class 1.

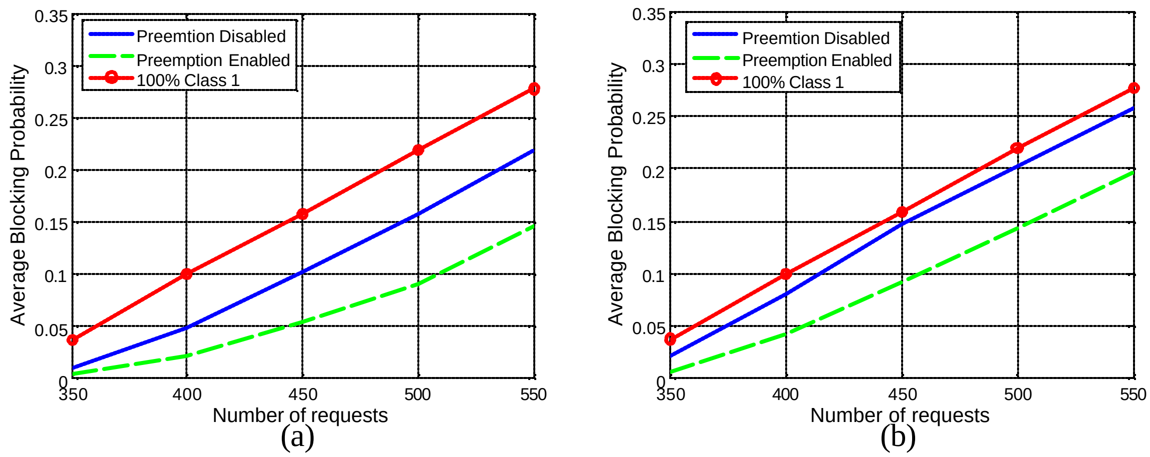


Fig. 5. Average blocking probability when (a) 50% and (b) 80% of the requested connections are assigned as class 1 traffic and LF scheme is used for C=16

For the non preemptive scheme the benefit reduces to 5% and 3% respectively indicating the superiority of the preemptive approach in terms of network performance. This improvement offered by the preemptive scheme is at the expense of the reliable provisioning of low priority traffic, which can be tolerated for many non-real time applications. The insights of the preemption and the non preemption cases are further explored in figure 6. It can be observed that the preemptive scheme although utilizing a smaller number of links compared to the non preemptive case provides an increase in the link reuse percentage since it allows the low priority class 2 traffic to be shared among the backup paths of the higher priority traffic. When no preemption is allowed the number of possible shared paths is significantly reduced since only 50% of the total demands require backup paths resulting in inefficient backup resource utilization with considerable impact on the network performance. The increase of the restoration capacity as the network load increases (from 10% to 25%) implies that the benefit of the preemptive scheme continues to rise as indicated by the blocking probability curves in figure 5.a.

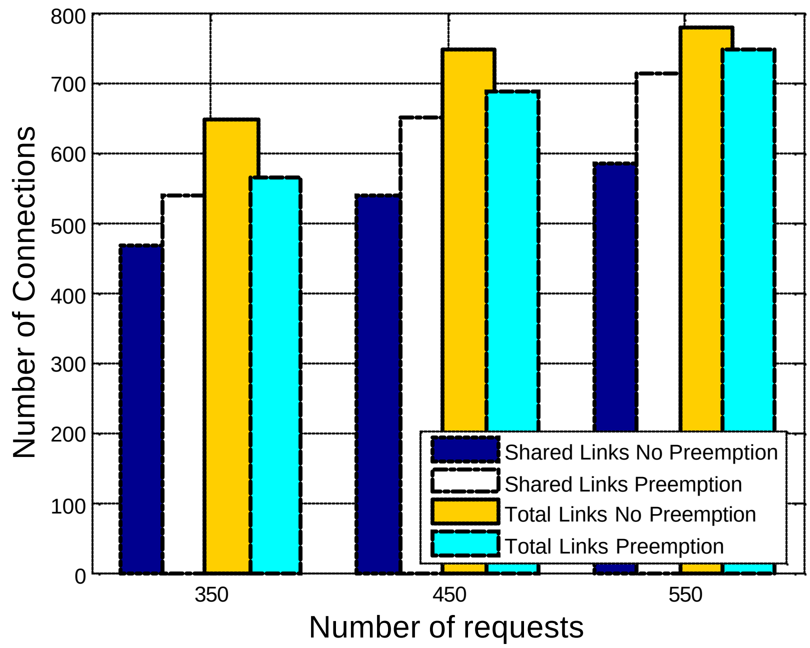


Fig.6. Shared and total link usage when preemption is allowed and not allowed for the case of 50% of class 1 traffic.

Finally in figure 7 we analyze the blocking probabilities of the different classes coexisting in the network when preemption is allowed. In fig 7.a 80% of the total traffic is considered as class 1 and 20% as class 2. The blocking probability of the class 1 traffic is high compared to the low priority traffic (a difference of about 10% is observed) although the overall blocking is reduced when considering this differentiation scheme. In fig 7.b the same percentage of class 1 and class 2 demands is assumed and almost the same blocking probability is observed for the two classes, causing a higher reduction in the overall blocking probability. Also in this case the blocking probability of high priority traffic is reduced considerably at least for heavier network loadings (around 8%) whereas the blocking of the lower priority traffic is increased in a much smaller scale (about 4%).

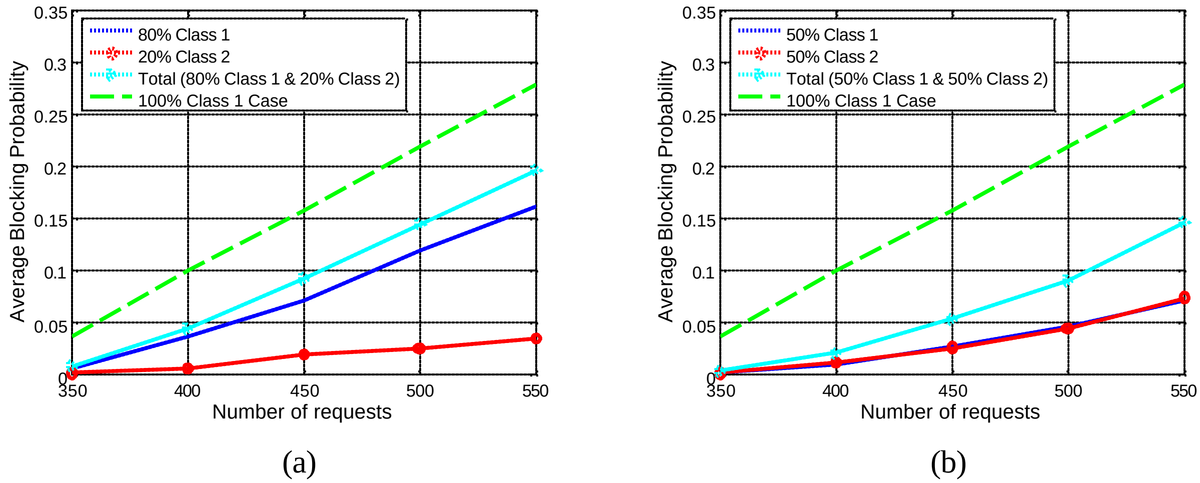


Fig.7. Analyzing the blocking probabilities of the different classes in the network when (a) 80% and (b) 50% of class1 traffic is requested.

5. Conclusions

In this paper we addressed the problem of efficiently provisioning lightpaths with different protection requirements in a dynamic WDM network environment. As a first step towards this attempt different RWA schemes were investigated with the aim to enhance the backup resource utilization and improved the network performance. Our Last Fit wavelength assignment scheme applied on the backup lightpaths that is used in parallel with the First Fit assignment method applied on the primary lightpaths demonstrated considerable improvement compare to the commonly used Random Pick and First Fit assignment schemes. Specifically LF provided a significant benefit of around 14% and 4% compare with the RP and FF cases respectively. The study presented in this paper shows that the notable improvement of the average blocking probabilities occurs due to the effective capacity reuse offered by the LF scheme over the other schemes used. In the next step of the analysis the incoming traffic is differentiated to classes of service according to their survivability requirements and the preemption of low priority traffic by higher priority demands in the event of a link failure is proposed. This technique enables the backup paths to reuse the already assigned wavelengths of low priority traffic increasing therefore the reuse of the available network resources. In this case detailed simulation results demonstrate significant network improvement of up to 12% and considerable decrease in the blocking probability of the high priority traffic.

Acknowledgements

The authors would like to acknowledge the FP6 EU funded integrated project PHOSPHORUS (Lambda User Controlled Infrastructure for European Research), IST-034115 and COST291 for providing support for this work.

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