Network Performance Improvement in Survivable WDM Networks Considering Physical Layer Constraints

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ABSTRACT

This paper focuses on survivable optical networks and studies in detail the network performance improvement that can be achieved when jointly considering network resilience and physical layer constraints. The protection scheme used is path-based shared protection known as backup multiplexing. In the proposed solution routing and wavelength assignment for both primary and protection paths are jointly performed considering their physical performance. Simulations comparing the proposed solution with alternative schemes aiming at maximising sharing of protection resources have shown substantial network performance improvement in terms of blocking probability reduction when jointly addressing resilience and physical layer performance requirements.

Keywords: WDM, survivable networks, resilience, routing and wavelength assignment algorithms, physical layer constraints

1. INTRODUCTION

Optical networking exploiting wavelength division multiplexing (WDM) is extensively used in existing telecommunications infrastructures and is expected to play a significant role in next generation networks. An important aspect of optical networks particularly in the context of WDM is fault-tolerance, as a single link failure may cause loss of enormous amounts of information. The provision of resilience in WDM optical networks is realized by either proactive protection [1] or reactive restoration [2]. In addition, traditional routing and wavelength assignment (RWA) algorithms in optical networks make the routing decisions based only on network level parameters such as connectivity and available capacity, without considering the details of the physical layer. When an available path and wavelength are identified, the connection is assumed to be feasible. However, future high speed optical networks are expected to be either fully transparent (signals are transported end-to-end optically) or comprise large domains of transparency. In these networks, the optical signals experience the accumulation of physical impairments through transmission and switching, resulting in some cases in unacceptable signal quality. To address this issue, impairment aware (IA) RWA methods that consider the physical layer impairments have been proposed [3].

Our previous work on resilience requirements of traffic requests in WDM networks has revealed that the protection paths are highly susceptible to physical layer impairments as they are commonly longer than the primary paths [4]. This has a direct impact on the overall network performance in terms of blocking probability as a number of protection paths and therefore the corresponding primary paths are blocked due to unacceptable signal quality. To overcome this issue we propose to jointly address resilience and physical layer performance requirements through the design and implementation of a suitable RWA method. The performance of the proposed algorithm is compared with conventional routing approaches and evaluated through simulations exploring relevant trade-offs. Significant network performance improvement in terms of blocking probability reduction is shown for specific network conditions.

2. SCENARIO UNDER STUDY

The work presented in this paper focuses on proactive protection, i.e. at the time that the primary path is assigned, one or more alternative paths -backup paths- are also identified and the relevant network resources are reserved for protection purposes in case of a failure. The specific protection method applied is path-based and employs shared protection known as backup multiplexing. According to the shared protection scheme and under the single link failure assumption, if two or more primary paths are link-disjoint their protection paths can share the same wavelength channels. The shared path-protection scheme offers improved resource utilization compared to the dedicated-path protection alternative, as introduced in [5], while it is still able to offer 100% survivability to a single failure. In addition to taking into consideration the protection requirements of the connection requests, this work jointly performs routing and wavelength assignment for both primary and protection paths considering their physical performance. More precisely, not only the availability of optical bandwidth is considered, before primary connections and their protection paths are established and reserved respectively, but also their quality in terms of bit error rate (BER). The BER of primary and protection paths is calculated through the quality factor *Q* and compared against a predefined threshold value ($B_{thresh} = 10^{-15}$) to decide whether they are of acceptable quality. The analytical model of *Q*-factor for the performance evaluation of a static unicast IA-RWA has been used to integrate different types of degradations [6]. The impairments considered in the *Q*-factor evaluation include amplified spontaneous emission noise (ASE), cross-phase modulation (XPM) and four-wave mixing (FWM) assuming that they follow a Gaussian distribution. Also, optical filtering and the combined self-phase modulation/group velocity dispersion (SPM/GVD) effects were introduced.

To evaluate the effectiveness of the proposed solution two cases are studied: a) IA-RWA applied for both primary and protection paths and b) IA-RWA used for the primary path and minimum hop routing applied to the protection paths. Simulation results show substantial blocking probability reduction when IA-RWA is used for both primary and protection paths.

3. ALGORITHM SPECIFICATION

Our work has concentrated on solving the online RWA/resilience problem, i.e. traffic requests arrive and get served sequentially without knowledge of future incoming requests. This makes this contribution suitable mostly in the context of traffic engineering. In addition, it is assumed that only a single link failure can occur in the network at any instance of time and re-routing of already established connections is not allowed. The model does not take into consideration any wavelength conversion capability of the network and thus wavelength continuity across any path is a tight constraint in the problem definition.

We assume that all requests have a bandwidth demand of one wavelength unit and for each request a link disjoint backup path is required along with its primary path to provide guaranteed protection. The physical bandwidth of each link (*l)* can be divided into the following three parts: A_l, B_l, and R_l [4]. A_l 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 protection paths on link *l* and unlike A_l it can be shared by protection paths, whose associated primary paths are link disjoint. 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. For setting up a protection path on link *l* for a new primary path *a*, the available bandwidth S_l consists of two components: the residual bandwidth R_l and the portion of B_l that is able to be shared for carrying this protection path. To identify path costs the relevant link weights are identified for both primary and protection paths. As primary paths do not share bandwidth their cost is the sum of the weight of each link they traverse. In the case of protection paths we give preference to wavelengths that have already been allocated as protection wavelengths by assigning to them a lower weight and therefore reinforce sharing.

The routing and wavelength assignment problems are solved in two separate steps. Routing is implemented based on the Dijkstra's algorithm to compute a primary and a protection path for a given request. The wavelength assignment algorithm selects wavelengths for the primary and protection paths allowing resource sharing between the current request and the already established requests. As explained above, connection requests follow a Poisson arrival process with exponentially distributed time duration. In the initial computation phase a primary lightpath is identified for each request. In this phase impairment aware routing (IAR) is performed by assigning the *Q* penalty as the link cost and the Dijkstra algorithm is deployed on the weighted graph to calculate the shortest path. If no path is found, the connection is blocked. If at least one path is found, a group of possible wavelengths that can be allocated is identified and the first wavelength is chosen applying the first fit (FF) wavelength assignment algorithm to form the primary lightpath. Furthermore a module that monitors the bit error rate (BER) of the provisioned primary path that checks the path quality is involved and decides whether the path satisfies the quality constraints against the predefined BER threshold. Subsequently, the protection computation phase starts with identifying the portion of the protection bandwidth that can be shared excluding the links that have been already utilized by the primary path. This results in an auxiliary graph representing the current network state. In the case of protection paths two routing algorithms are tested: minimum hop routing reinforcing sharing as described above and IAR. After the link costs are assigned, if no lightpath is found for any wavelength, the connection is blocked due to protection path blocking. In case of discovery of multiple protection lightpaths, the algorithm allocates one wavelength, based on the last fit (LF) wavelength assignment scheme. The LF wavelength assignment algorithm has been applied since it has been shown that when used in conjunction with the FF wavelength assignment algorithm for the primary paths, it maximizes the protection path link reuse [4]. As in the case of primary paths a module that monitors the BER of the selected protection path checks the path quality and decides whether the path satisfies the requirement of the predefined BER threshold.

4. PERFORMANCE STUDY

The results presented in this section, are obtained based on the Pan-European test network defined by COST 239 [7] (Figure *1*) and assuming bidirectional fibre links with 16 wavelengths/fibre. Thus, if a link failure occurs the traffic flow in both directions will be disrupted. The results shown in Figures 2 and 3 are the averages over 10 statistically independent repetitions of a provisioning experiment, and for various loads imposed on the network.

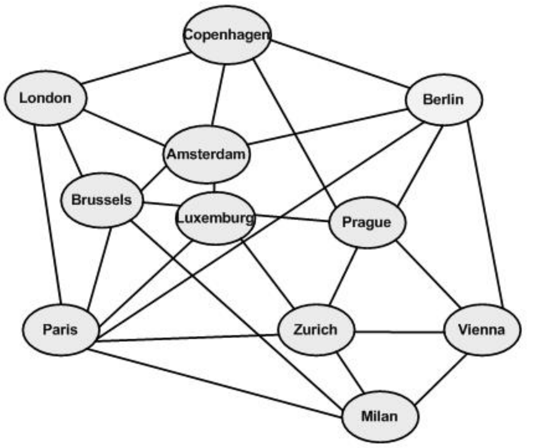

Figure 1. Test network topology defined by COST239.

Figure 2 illustrates how the network blocking probability varies with traffic load, concentrating on the blocking probability of protection paths and the total blocking probability of both primary and protection paths. The results shown were taken assuming that IAR has been used for the primary paths, while two different routing approaches have been used to discover the protection paths: minimum hop (MH) routing with reinforced wavelength sharing and IAR. These results clearly indicate that it is important to include protection requirements when evaluating network performance since protection capacity allocation gives a significant contribution to the total blocking probability of the network. In addition, Figure 2 demonstrates that even if IAR is used as the routing approach for the primary paths it is important to consider the effect of the physical impairments also in the protection paths. More specifically, in case of minimum hop routing for the protection paths, when BER monitoring is applied to ensure acceptable signal quality, the blocking probability of the protection paths becomes high. This is because a large number of protection paths do not satisfy the BER threshold criterion, which results in blocked connections. It should be noted that in general protection paths are longer than primary paths, exhibiting higher probability to be impaired. This has a significant contribution to the total blocking probability. An alternative approach that can improve the overall network performance is to apply IAR not only to the primary but also to the protection paths. As shown in Figure 2, this approach offers blocking probability reduction by 42% for low loading, compared to the MH scheme. The benefit becomes lower for higher loading since in this case there is a smaller reserve of alternative paths that can be exploited; also this is due to the fact that in general MH routing provides the ability to allow a form of load balancing in the network [4].

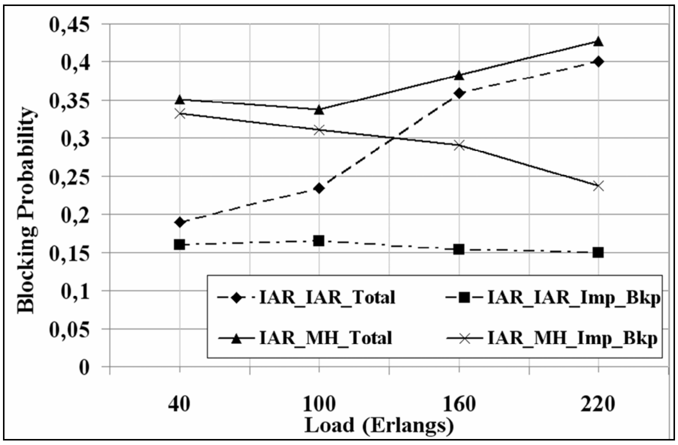

Figure 2. Blocking Probability (total and due to unacceptably high BER at the backup path).

Hence, it becomes clear that the use of IAR for the protection paths has a benefit in terms of blocking probability. However, this comes at the expense of network resource sharing. As depicted in Fig. 3, MH routing offers reduced total number of link wavelengths that are uniquely allocated to protection paths and thus enables increased resource sharing, compared to using IAR routing for the protection paths.

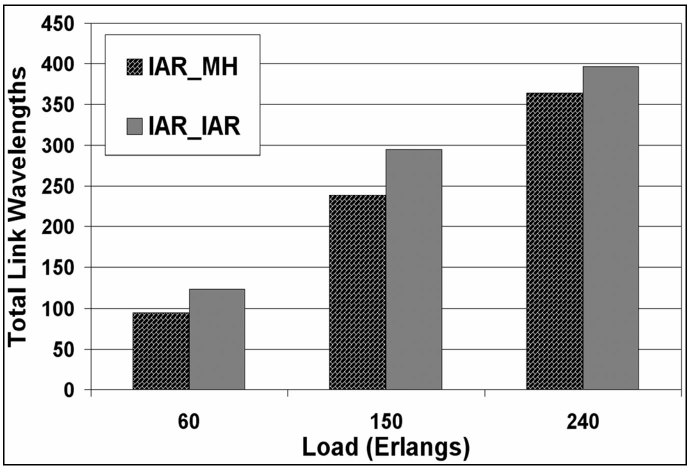

Figure 3. Total link wavelengths uniquely allocated to protection paths (not shared).

5. CONCLUSIONS

This paper studied the performance of survivable WDM networks under physical layer constraints. In this context it focuses on proactive protection and specifically on path-based shared protection known as backup multiplexing. In addition to taking into consideration the protection requirements of the connection requests, routing and wavelength assignment for both primary and protection paths are jointly performed considering their physical performance against a predetermined BER threshold. Simulations results have shown substantial network performance improvement in terms of blocking probability reduction when jointly addressing resilience and physical layer performance requirements. This is achieved through suitable selection of routing and wavelength assignments algorithms.

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REFERENCES

[1] S. Ramamurthy and B. Mukherjee, “Survivable WDM Mesh Networks, Part I - Protection,” in *Proc. IEEE Conference on Computer and Communication Societies* (IEEE, 1999), pp. 744-751.
[2] B. T. Doshi, “Optical Network Design and Restoration,” *Bell Labs Tech. J,*. 58-84,(1999).
[3] G. Markidis, S. Sygletos, A. Tzanakaki and I. Tomkos, “Impairment aware based routing and wavelength assignment in transparent long haul optical networks”, *LNCS Optical Network Design and Modeling*, Springer 2007, vol. 4534, pp. 48-57.
[4] G. Markidis and A. Tzanakaki, “Routing and wavelength assignment algorithms in survivable WDM networks under physical layer constraints, ” in *Proc. 3rd International GOPS Workshop*, Broadnets (IEEE 2008).
[5] S. Han and K. G. Shin, “Efficient spare resource allocation for fast restoration of real-time channels from network component failures,” in *Proc. IEEE Symposium on Real-Time Systems,* IEEE 1997, pp. 99-108.
[6] J. Li, K. L. Yeung, “A novel two-step approach to restorable dynamic QoS routing”, *Journal of Lightwave Technology*, vol. 23, no. 11, 3663-3670 (2005).
[7] P. Batchelor *et al.,* “Study on the implementation of optical transparent transport networks in the European environment-results of the research project COST 239”, *Springer Photonic Network Communications*, 2000, vol. 2, no. 1, 15-32.