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Protection Methods Analysis in a Hybrid C/C+L Optical Network

Soheil Hosseini[1,2], Ramón J. Durán Barroso[1], Ignacio de Miguel[1], Óscar González de Dios[2], Noemí Merayo[1], Juan Carlos Aguado[1], Patricia Fernández[1], Rubén M. Lorenzo[1], Evaristo J. Abril[1]

[1] *Universidad de Valladolid, Valladolid, Spain*

[2] *Telefónica Innovación Digital, Madrid, Spain*

e-mail: soheil.hosseini@uva.es, rduran@tel.uva.es

ABSTRACT

The use of multi-band elastic optical networks (MB-EONs) over C+L bands is considered as a realistic medium-term solution to extend the capacity of current C-band optical networks. In this kind of networks, different levels of survivability can be offered, as we showed in a previous work in which we analysed the impact of these techniques in fully upgraded C+L networks. However, postponing the high CAPEX cost of activating the L-band for all the optical fibers within a network has shifted the attention of the network operators to partially upgraded networks. Thus, we now focus on partially upgraded networks and demonstrate that it is necessary to modify the protection method that we previously proposed for fully upgraded networks in order to efficiently work in these environments. The performance of the modified method is then evaluated in terms of request blocking ratio in both partially and fully upgraded networks, and we show that the introduced variation outperforms the original method.

Keywords: elastic optical network, multi-band network, survivability, network upgrade, blocking performance.

1. INTRODUCTION

Band division multiplexing (BDM) is defined as a strategy to increase the capacity of existing optical fibers by moving from the conventional C-band to the other spectral bands such as O-, E-, S-, L-, and/or U-bands [1]. As lighting up different spectral bands for network capacity increase follows the strategy of pay-as-you-grow [2], upgrading all fibers of the network would potentially increase the cost. Therefore, rather than fully upgrading an Elastic Optical Network (EON) in which different spectral bands of all the fibers are usable, a partial upgrade is recommended to reduce the relative cost of capacity enhancement.

In the scope of partial upgrade, in [3], we have proposed a heuristic for upgrading the optical fibers from the C-band to the L-band based on their usage. In this way, in every step of network upgrade, the most used fibers when using the primary shortest paths are migrated first to work over C+L bands. Then, in [4], we introduced an integer linear programming (ILP) formulation which proposes a set of potential fibers for the migration. In that paper, the goal of the objective function is set on maximizing the number of shortest paths that could use the L-band if a lightpath is to be established using those routes. In [5], we have presented three different heuristics for performing the partial migration of a network taking into account that different number of EDFAs over different fibers leads the fibers to have different cost of upgrade.

Increasing the network capacity through lighting up the L-band makes the incorporation of the survivability a must. Based upon the fact that failure in amplifiers is more common than fiber failures [6], we proposed in [7] different techniques to provide protection against, at least, amplifier failures in fully-migrated C+L optical networks. This paper is an extension of that work [7], and our objective is to adapt the protection technique in [7] to be able to operate efficiently in a partially migrated network in which not all links have been migrated to support the L-band, and to evaluate its performance in terms of blocking probability.

2. PARTIAL MIGRATION

For performing the partial migration, this paper considers the upgrade of those fibers that are suggested for the migration in the NSFNet, JPN12, and DT topologies in every upgrade scenario of our previous research [4]. In this regard, if a fiber belongs to the set of candidate fibers for the migration, it will benefit from additional spectrum resources provided by the L-band. Otherwise, the C-band will be used. A better explanation of the concept of partial migration is given using the considered small-scale optical networking topology shown in Fig. 1.

In Fig. 1, it is assumed that for going from node B to node D, there is a precomputed path, specified by the red dotted arrow. In addition, green dashed arrow indicates the precomputed path between node A and node E. The example network includes four bidirectional links, among them only two of the links (BC and CD) have been upgraded to the L-band. Based on the above-mentioned assumptions, it is concluded that path BD can use either the C-band or the L-band in the phase of resource allocation, and that is because both of the existing links of the path BD support both bands. On the other hand, an end-to-end connection through path AE can only use the C-band, as links AB and DE only support C-band but not L-band. Therefore, path AE does not benefit from the partial upgrade of the network, and it should work over the C-band to assure the spectrum continuity constraint of connections using that path.

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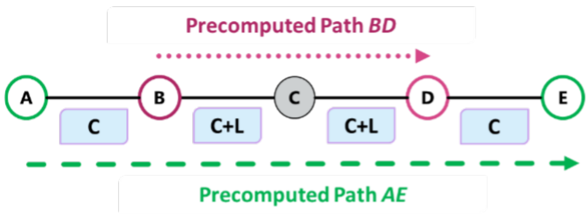

Figure 1. The four-node network topology for defining the partial migration.

3. RESILIENCY AGAINST FIBER AND/OR AMPLIFIER FAILURES

In this paper, the performance of a protection technique which relies on the use of separate amplifiers architecture (i.e. using different EDFAs to amplify each band) [8] is analyzed in a partially upgraded network. The aim is to provide protection, at least, against EDFA failures, although in some cases, protection against fiber failures is also provided. Moreover, this technique can be complemented with the use of classical path protection (which provides protection not only against EDFA failures but also against fiber cuts), thus enabling the provision of service level agreement (SLA) differentiation, as we proposed and discussed in [9].

Fig. 2 represents the method of classical protection in a C+L band system. Reserving the resources over two link-disjoint paths provides the established connections with data persistence against single EDFA failures as well as fiber failures simultaneously. In the classical path protection method, two link-disjoint paths are selected for the primary and backup connections. Then, in the phase of band selection of the RBMLSA algorithm, the algorithm checks whether all the links in the selected paths are migrated to the L-band or not. If the answer is true, the L-band is prioritized. Otherwise, or in case of not finding the required resources for serving the connection in that band, the C-band spectrum slots would be analyzed.

In [7], we proposed a protection technique for fully upgraded C+L networks, called “hybrid approach”. Several variants were analyzed, but we present here the one that gave the best results. When using that technique, primary and backup connections are routed through the same path, but the L-band is dedicated to primary connections, and the C-band is employed for backup connections. Considering the use of the separate amplifiers architecture (also shown in Fig. 2), this method ensures survivability against single EDFA failures (but not against fiber failures). If there are insufficient resources to establish the primary and backup connections in that way (which may occur since the available spectrum in the C-band is less than in the L-band), a second phase is run where it is checked whether it is possible to establish them using two link-disjoint paths (the primary using the L-band, but allowing the backup to use either the C or the L band). If the second phase is successful, the established connection is protected against both amplifier and fiber failures. It is worth noting that, in [7], a fully upgraded network was considered so all links had, potentially, spectral resources in the L-band. Moreover in that paper it was also demonstrated that the use of the hybrid approach instead of the classical method leads to a reduction of the bandwidth blocking ratio of the network.

In this paper, we focus on partially upgraded networks, where there are links not upgraded to C+L-band. In those scenarios, directly using the hybrid approach as defined in [7] leads to a very high blocking ratio. This is because the fibers that have not been upgraded to the L-band become the limiting factors. Therefore, in this paper, we consider a variation of the hybrid approach where in the second phase of the hybrid approach, the primary connections are able to use the whole spectrum of both C+L bands rather than only the L-band. The backup connections can use C+L bands like in the proposed hybrid approach of [7].

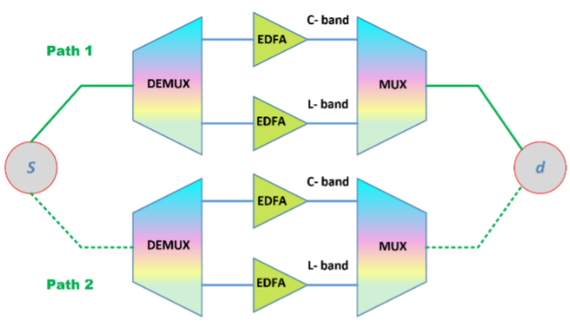

Figure 2. Example of the use of disjoint paths in classical path protection and the use of separate amplifiers (i.e., a different EDFA to amplify each band).

4. SIMULATION SETUP AND RESULTS

In this section, the performance of the highlighted protection methods in different upgrade scenarios is evaluated in terms of request blocking ratio. To this end, a MB-EON simulator has been developed in Python. In the simulation, we assume an environment where connection requests arrive at the network following a Poisson process. In case that the requirements for a certain connection request (primary and backup) are fulfilled, the connection is established. Otherwise, it is blocked. Regarding the accommodated connections, when the associated holding-time, which is set according to an exponential distribution is over, the corresponding allocated resources are released. All results are shown in average with 95% confidence interval.

Fig. 3 shows the request blocking ratio for the classical path protection method and the hybrid approach (with the variation introduced in this paper) when the network is partially upgraded through the migration of 3, 9, 15, and 18 bidirectional links in the NSFNet topology (Fig. 3.a) and in the DT network (Fig. 3.c). As the JPN12 topology has 17 bidirectional links, we have also considered a 12 bidirectional links upgrade scenario instead of the impossible 18 links upgrade (Fig. 3.b). The set of fibers to migrate in each case was selected using the method proposed in [4]. As shown in Fig. 3, lightpath protection using the hybrid approach leads in most of cases to lower blocking ratio when compared to the classical method (an exception for this behavior is obtained in the NSFNet for an 18 links upgrade). For the NSFNet and DT topologies, hybrid and classical methods have almost the same performance when a few links are upgraded (e.g., 3 bidirectional links upgraded), while the JPN12 topology is the one that holds a greater advantage for the hybrid approach in different upgrade scenarios. We also obtained the bandwidth blocking ratio with similar results and conclusions for all the studied topologies, but to save paper space, those results are not included.

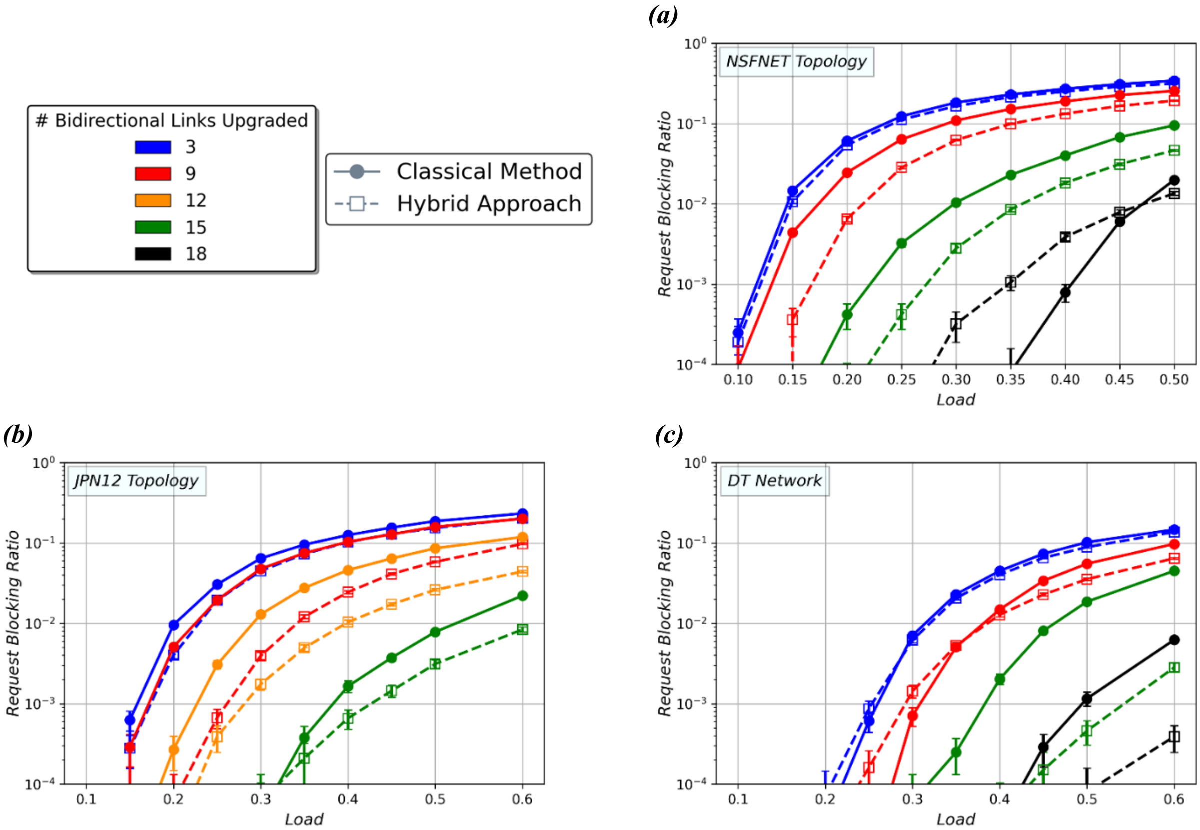

Figure 3. Request blocking ratio depending on the network traffic load in the ***a)*** *NSFNet topology,* ***b)*** *JPN12 topology, and* ***c)*** *DT network under different upgrade scenarios.*

As previously mentioned, the proposed modification of the hybrid approach (L+C for Primary) provides good performance in a partially upgraded network in contrast with the original hybrid approach proposed in [7] (only L for Primary). Fig. 4 (a) compares the discussed hybrid approaches for a scenario where around 50% of the bidirectional links of the NSFNet (12 out of 21), JPN12 (9 out of 17), and DT (12 out of 23) topologies have been upgraded. It can be observed that the employment of the modified hybrid approach presented in this paper significantly reduces the blocking ratio compared to the original approach (which in fact leads to very high blocking ratios in partially upgraded networks). We did the same analysis with different levels of migration and obtained similar results: the new proposal outperforms the one in [7]. We do not include them due to the lack of space. We have also analyzed if that good behavior in a partially upgraded network for the new variation comes at a cost, compared with the original proposal, when it is used in a fully upgraded. Fig. 4 (b) compares the performance of the new and the original version of hybrid protection when they are used in a fully upgraded network. As shown in Fig. 4 (b), both options behave similar in fully upgraded network but, when the network is partially migrated, the new approach clearly overperforms the original version (Fig. 4 (a)).

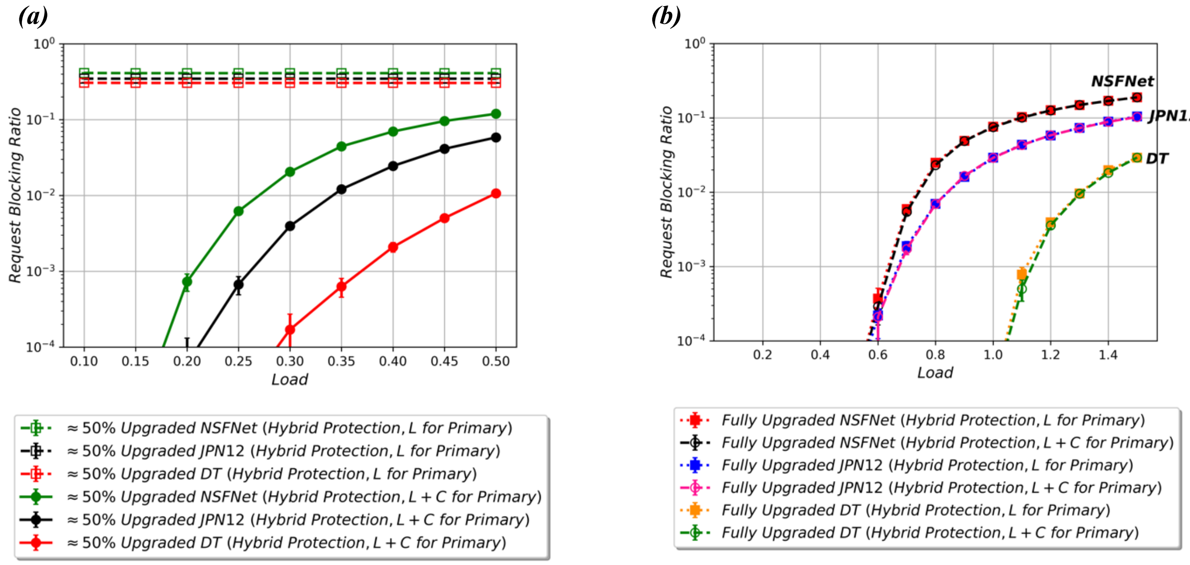

*Figure 4. Comparison of the hybrid approaches (L-band for primary connections vs. L+C bands for primary connections) in **a)** 50% upgraded and **b)** fully upgraded NSFNet, JPN12, and DT topologies.*

5. CONCLUSIONS

In this paper, we have analyzed the performance of a protection method proposed in [7], the hybrid approach, when operating in a partially upgraded network. Simulation results have shown that the original hybrid approach in [7], in which primary connections can only use L-band resources, is not effective in a partially upgraded network, as it performs poorly in terms of blocking probability. However, modifying the algorithm leads to the same performance as the original one when the network is fully upgraded and enables efficient operation in partially upgraded networks. This modification is performed by allowing the primary connections to be also established in the C-band. Classical path protection and the modified hybrid approach have been investigated in different upgrade scenarios. Simulation results indicate that the modified hybrid approach generally leads to better results in terms of blocking ratio compared to the classical path protection method. Although the hybrid approach generally works better in terms of blocking probability, the classical approach is more effective for network survivability, as it provides protection against both amplifiers and fiber failures. Therefore, as we showed in [9], the network operator can optimize the trade-off between blocking probability performance and survivability by providing two levels of protection based on SLA, on using the hybrid protection approach and another the classical path protection.

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