SLA-Differentiated Protection in Multi-Band Elastic Optical Networks

Soheil Hosseini
Universidad de Valladolid
Valladolid, Spain
0000-0003-3006-5297

Ramón J. Durán Barroso
Universidad de Valladolid
Valladolid, Spain
0000-0003-1423-1646

Ignacio de Miguel
Universidad de Valladolid
Valladolid, Spain
0000-0002-1084-1159

Óscar González de Dios
Telefónica I+D
Madrid, Spain
0000-0002-1898-0807

Noemí Merayo
Universidad de Valladolid
Valladolid, Spain
0000-0002-6920-0778

Juan Carlos Aguado
Universidad de Valladolid
Valladolid, Spain
0000-0002-2495-0313

Edward Echeverry
Telefónica SA
Madrid, Spain

Patricia Fernández
Universidad de Valladolid
Valladolid, Spain
0000-0001-5520-0948

Rubén M. Lorenzo
Universidad de Valladolid
Valladolid, Spain
0000-0001-8729-3085

Evaristo J. Abril
Universidad de Valladolid
Valladolid, Spain
0000-0003-4164-2467

***Abstract*—A novel protection mechanism for C+L multi-band optical networks is introduced. It provides two levels of protection based on service level agreement (SLA) differentiation. We demonstrate that this technique can reduce the request blocking ratio for all SLAs.**

Keywords—multi-band, elastic optical networks, survivability, service level agreement, lightpath provisioning.

I. INTRODUCTION

The ever-increasing bandwidth requirements of new applications and services makes it essential to increase the capacity of optical transport networks [1], and multi-band elastic optical networks (MB-EON) are envisioned as a promising solution. Along with the C-band, lighting up the L-band provides a commercially available line system with a total accessible bandwidth of around 11.5 THz [2]. Thus, this paper is focused on C+L MB-EONs. These networks are based on the establishment of all-optical circuits or lightpaths. In dynamic scenarios, for each connection request, the routing, band, modulation level, and spectrum assignment (RBMLSA) problem must be solved. On the other hand, the implementation of survivability strategies (i.e., the ability of the network to withstand failures) is a mandatory requirement for all operators. In survivable MB-EONs, classical path protection techniques can be applied by reserving additional resources to establish a backup lightpath when solving the RBMLSA problem for each incoming request. The application of these techniques leads to a higher use of resources and, therefore, to higher blocking ratios. However, not all users/services require the same level of protection against failures. For instance, connections can be split in "gold" and "silver" categories, the former having more stringent requirements on survivability. As we will demonstrate in this paper, this issue can be exploited in MB-EONs to provide different levels of protection depending on service level agreements (SLA) and improve network performance.

II. SLA-DIFFERENTIATED PROTECTION IN MB-EON

The most common architecture for implementing C+L line systems is based on the use of a demultiplexer/multiplexer structure and an erbium doped fiber amplifier (EDFA) per band (Fig. 1 [3]). Thanks to this architecture, instead of offering classical path protection to all connections, we propose to differentiate and offer two different levels of dedicated protection against single failures: EDFA path protection (for "silver" connections) and classical path protection (for "gold" connections). The former only provides survivability against single EDFA failures, but this is the most prevalent cause of failure in transmission networks [4]. In EDFA path protection, the primary and backup lightpaths are established over the same end-to-end path but using the L-band for the primary and the C-band for the backup one (thus, each path uses different amplifiers, and the network is protected against a single EDFA failure). The classical path protection strategy offers survivability against single failures in both fibers and amplifiers by using disjoint paths for the primary and backup lightpaths. In this method, the primary and backup lightpaths can use the full C+L spectrum. In both alternatives, the most spectrally efficient modulation format, which complies with the maximal optical reach (Table I [5]) is selected. Since EDFA and path protection offer different levels of protection, they can be used to serve different requests depending on the protection level associated to their SLAs. In this way, connections associated to the "gold" SLA use classical path protection while connections associated to the "silver" SLA implement EDFA path protection. Note that the use of multiband and the amplifier

TABLE I. EFFICIENT AND QUALITY-AWARE TRANSMISSION BASED ON OPTICAL REACH

Modulation Level	Multi-band Optical Reach (km)	
	C-band	***L-band***
QPSK	1800	1600
16QAM	370	330

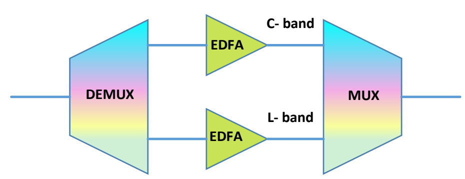

Fig. 1. Separate amplifiers architecture for C+L MB-EON

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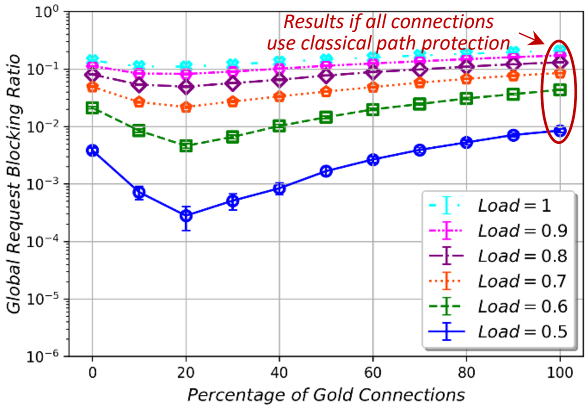

Fig. 2. Global request blocking ratio depending on the network load and the percentage of gold connection requests

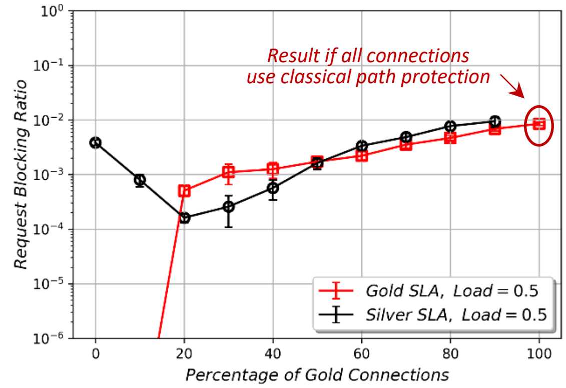

Fig. 3. Request blocking ratio of each SLA depending on the network load and the percentage of gold connection requests. Network load = 0.5

structure shown in Fig. 1, allows us to make this differentiation. Otherwise, all connections should be protected by the classical path protection strategy (i.e., 100% of connections would belong to what we now call gold category, even if some require less protection).

III. PERFORMANCE ASSESMENT AND DISCUSSION

The proposal has been assessed using a MB-EON simulator developed in Python and considering the 14-node NSFNET topology. The C+L spectrum was used, subtracting 400 GHz of guardband between the two bands [3] and dividing the spectrum into 12.5 GHz frequency slots, resulting in 320 slots for the C-band and 516 for the L-band. Lightpath requests were generated following a Poisson process demanding between 12.5 Gb/s to 312.5 Gb/s. A guardband of one slot was placed between spectrum-contiguous lightpaths. The percentage of requests associated to the gold SLA was a simulation parameter, and during the simulations, each request was randomly assigned to either the gold or silver SLA according to that parameter. Results are represented with 95% confidence intervals.

Fig. 2 displays the global blocking ratio depending on the traffic load and the percentage of gold connections. Obviously, when the traffic load increases, the blocking ratio also increases. Fig. 2 also shows that, for each traffic load, when SLA-differentiated protection is applied (i.e., not all requests belong to the same class), the global blocking ratio is always lower than if only the classical path protection method were used for all requests. Moreover, there is a sweet spot. For instance, for a traffic load of 0.5 and 20% of gold connections, the global blocking ratio is close to two orders of magnitude lower. Fig. 3 shows the blocking ratio of gold and silver requests for 0.5 network load (corresponding to the blue line in Fig. 2). In that figure, we can observe that as the percentage of gold connections decreases, its blocking ratio also decreases. For the lowest percentages of gold connection requests, silver connections are obviously the predominant type in the network. It should be noted that for silver connections, as the primary and backup lightpaths are routed through the same path (but using the L band for the primary and C for the backup) their lengths are equal, so they generally use the same modulation format (with some exceptions due to different optical reaches, Table I) and thus use the same number of slots in each band. Since the C-band consists of 320 slots and the L-band of 516, the C-band becomes the limiting factor for silver connections. Therefore, even when silver connections are the predominant type, the L band has a set of slots that can only be exploited by gold connections, and thus helps reducing the blocking ratio of gold connections in those scenarios. Again, Fig. 3 shows that thanks to the use of SLA-differentiated protection, it is possible to reduce the blocking ratio of both gold and silver connections when compared with only using the classical path protection strategy for all requests.

IV. CONCLUSION

We have proposed a strategy for SLA-differentiated protection in MB-EONs. Simulation results show that thanks to the use of the separate amplifiers architecture (Fig. 1) and protection differentiation, the blocking ratio for all SLAs can be reduced when compared with only using the classical path protection method for all requests (even if some require less protection). Moreover, there exists a sweet spot related to the percentage of gold connections, which can be leveraged by operators with suitable pricing strategies.

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