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Migration Strategy from C-Band Elastic Optical Network to C+L Multiband Optical Network

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***Abstract*— Multi-band elastic optical network (MB-EON) is a promising technology to extend the bandwidth of the current elastic optical networks in the middle term. The migration from current networks to MB-EONs should be made carefully taking into account both the required cost and the bandwidth requirements. This paper focuses on the necessity of looking for a trade-off between the links to be upgraded during the migration from the standard C-band to the L-band and the acceptable level of capacity increase. Therefore, it makes two contributions to efficiently upgrade current elastic optical networks: firstly, a planning method to decide which fibers should be upgraded to exploit C+L band; and second, one heuristic for solving the routing, band, modulation level, and spectrum assignment (RBMLSA) problem during network operation. Simulation results demonstrate that, thanks to use of these proposals, the upgrade of a set of the fibers could be viewed as a fully convincing middle term solution by the network operators to get around the huge cost of the whole network migration to C+L line system.**

Keywords*— multi-band networks, optical fibers, transmission capacity, provisioning

I. Introduction

The capacity crunch issue induces network operators and the researcher community to find alternative solutions for supporting the ever-increasing network traffic demand. The concepts of spatial division multiplexing (SDM) and band division multiplexing (BDM) make the network capacity upgrade feasible [1]. Multi-core fibers (MCFs), multi-mode fibers (MMFs), and multi-fiber transmission (MFT) are the main media for realizing SDM technology [2]. Reaching the capacity of Petabit/s/fiber would be the result of setting up MCFs/MMFs. However, as the deployed optical cabling infrastructure is based on standard single mode fibers, SDM realization with MCFs/MMFs requires a complete fiber plant renewal, which imposes a huge capital expenditure (CAPEX) cost to the network operator [3]. Moreover, one of the main problems with the SDM implementation via MFT is related to the availability of fibers. Even for incumbent operators, the number of unused fibers is scarce. Increasing the number of fibers could require civil work, which is slow and CAPEX demanding, or leasing dark fiber from an infrastructure operator. Therefore, the exploitation of the full potential capacity of the already deployed fibers is the main motivation for proposing multi-band elastic optical networks (MB-EONs) as the future technological choice. As moving towards other spectral bands from the conventional C-band to other bands of the existing fibers makes the entire capacity of 54 THz accessible, MB-EONs is considered as a practical solution [4]. In this paper we focus on the extension from C-band to C+L bands.

As it is mentioned, the network capacity increase through at least a short-term practical solution (i.e., MB-EON) is vital to adapt the network to the unceasing Internet traffic growth. However, according to the physical layer architecture of C+L line systems, for the implementation of these networks, operators should deploy new L-band ready erbium doped fiber amplifiers (EDFAs) and reconfigurable optical add-drop multiplexers (ROADMs) [5]. Thus, making a tradeoff between the capacity upgrade and the imposed cost is necessary. In other words, it is not essential to equip all network fibers with multi-band devices for performing migration from the C-band to C+L transmission bands. To this end, in this paper, a network performance assessment in terms of the number of upgraded fibers to C+L bands is carried out. This paper makes two contributions: i) a planning strategy to decide the set of the fibers to be upgraded with C+L amplifiers; ii) a heuristic to solve the dynamic routing, modulation level, band, and spectrum assignment (RMLBSA) problem with two versions. Scenarios with different number of fibers upgraded from current C-band to fully upgraded network are considered for the evaluation. The employed methodology in support of our proposed idea and the simulation results are discussed in Section II and Section III, respectively.

II. Methodology

In this section, a heuristic approach for connection accommodation in a network, whose optical fibers are moved towards the C+L-band step by step is studied. To this end, a planning strategy is introduced to do the migration from the C-band to the C+L-band in an effective way. Then, during network operation, a heuristic is proposed to solve the RBMLSA problem when serving on-demand incoming connection requests. Our proposals are clarified in the following subsections.

A. Network Planning

This phase starts with computing the shortest paths between each source-destination pair. Based on these pre-calculated shortest paths in terms of the number of the hops, the optical fibers are prioritized for band upgrade depending on the number of times that they might be utilized to establish a

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lightpath between each source-destination pair. Accordingly, whenever the network operator desires to improve the capacity of the network through the exploitation of other spectral bands, optical fibers are slowly migrated to C+L band based on their priority. In other words, the network operator provides the multi-band devices for those fibers which are more exposed to congestion. Later, we will analyze the impact of upgrading different numbers of fibers following the policy we have just explained.

B. RBMLSA Scheme

Once the network has been upgraded, when a connection establishment request is received, the RBMLSA algorithm which we propose next is executed. For addressing the routing problem, the K-shortest paths algorithm is used, and we consider two approaches: length-based and hop-based routing.

In the length-based approach, when a connection request arrives at the network, the algorithm searches through its potential paths, and the path with the minimum length (l) in km is selected. Any other potential paths whose length is equal to l will be stored in a data structure. If all of the links of the selected path are equipped with multi-band devices (i.e., the L-band is lit up), in the phase of band selection, the priority will be given to the L-band. On the other hand, if at least one of the links only supports the C-band, for ensuring the continuity constraint of resource allocation (i.e., the same block of frequency slots should be assigned in all the links that a lightpath goes through), the C-band should be used. However, instead of doing this directly, it is first checked whether any of the other stored paths (all of l length) could use the L-band. This process will be repeated while investigating any of the paths returned by the K-shortest paths algorithm to take the full advantage of the L-band of the upgraded fibers. Although getting several potential paths with equal distance when running the K-shortest paths algorithm does not occur frequently, this procedure leads to improve the blocking ratio.

On the other hand, many times the K-shortest path, when executed in terms of hops, retrieves several paths with the same number of hops. Therefore, applying the hop-based algorithm brings about better results in terms of blocking probability. In the hop-based resource allocation method, among different paths with the same number of hops, the path with the ability of utilizing the L-band would be prioritized.

In this paper, the efficient utilization of spectrum allocation is met by considering two different levels of modulation, QPSK and 16QAM. Applying a high level of modulation leads to efficient usage of spectrum resources. However, there is a trade-off between the spectral efficiency of a modulation format and its robustness to physical impairments (limiting the transmission distance). In MB-EONs, the maximum optical reach depends not only on the modulation level but also on the spectral band which is selected for serving a connection request. This dependency is expressed in Table I for QPSK and 16QAM in the network with C and L-band optical fibers.

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

III. Performance Evaluation

The evaluation of the algorithms has been accomplished using a Python simulator over the NSFNET topology with 14 nodes and 21 bidirectional optical links. A bandwidth wastage of around 400 GHz due to the essential guard-band that must be taken into account between multiplexer and demultiplexer structures of C-band and L-band is the penalty of considering the most common architecture for the implementation of C+L line system [6]. In this scenario, we assume that following this architecture shrinks the range of the L-band to 516 frequency slots, while the range of spectrum in C-band is partitioned into 320 slots, in which the capacity of each slot is 12.5 GHz. Connection requests arrive in a dynamic manner following a Poisson process, and the source as well as the destination of them are selected randomly according to a uniform distribution. The demanded bandwidth for every connection is randomly chosen from 12.5 GHz to 300 GHz in steps of 12.5 GHz. A guardband with the size of 12.5 GHz is set between two different optical connections that are adjacent in terms of their occupied slots. The results are based on 10^5 arrived connection requests, which are starting to be counted after warming-up the network with 10^4 connections.

Fig. 1. shows the bandwidth blocking ratio (BBR) versus traffic load with different number of links upgraded: from the current C-band elastic network to the fully upgraded one. The selection of the links to be upgraded follows the planning heuristic described in Section II.A. Then, the RBMLSA problem is solved using the heuristic of Section II.B using $K = 1$ shortest path in terms of distance. When using only one path, it is important to select the shortest one in length to use the best modulation level as possible and reduce the number of slots required to establish the connections.

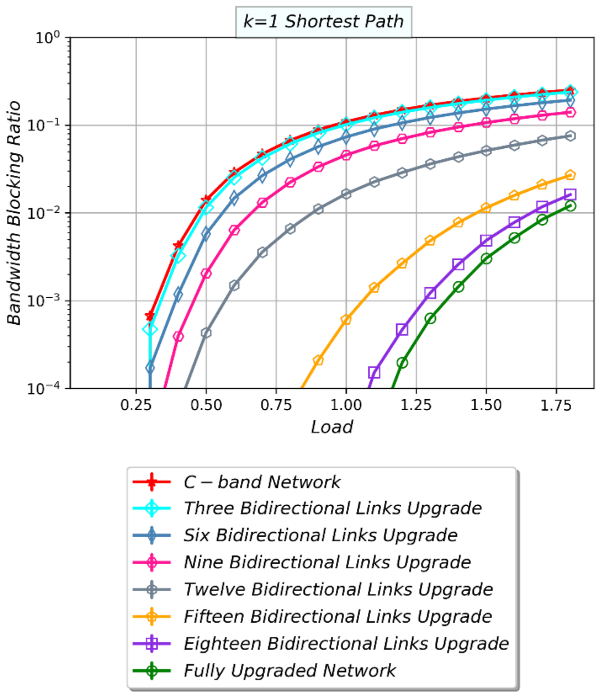

Fig. 1. Bandwidth blocking ratio depending on the network load. Shortest path (K=1) is used as routing strategy

Fig. 1. shows that the BBR is reduced as the number of upgraded links increases. In fact, supposing 10^{-3} as an acceptable value of BBR, the fully migrated network can transport more than 400% of the traffic of the initial C-band network. Note that the ratio in the available bandwidth of the C+L network compared with the C-band option is 262%. It is also possible to see that when up to 9 bidirectional links are upgraded (43 % of the total), the network achieves a good reduction of the BBR and huge reduction is achieved from this point. Upgrading 12 fibers, the BBR is reduced more than one order of magnitude and the maximum load supported by the network (with BBR $<10^{-3}$) is double of the C-band network.

Fig. 2 exhibits the simulation results of the length-based RBMLSA strategy in terms of bandwidth blocking ratio using $K = 3$. As it can be observed in Fig. 2, the improvement in the BBR compared with C-Band network is even higher. Therefore, by upgrading 12 bidirectional links it is possible to reduce the BBR in almost two orders of magnitude.

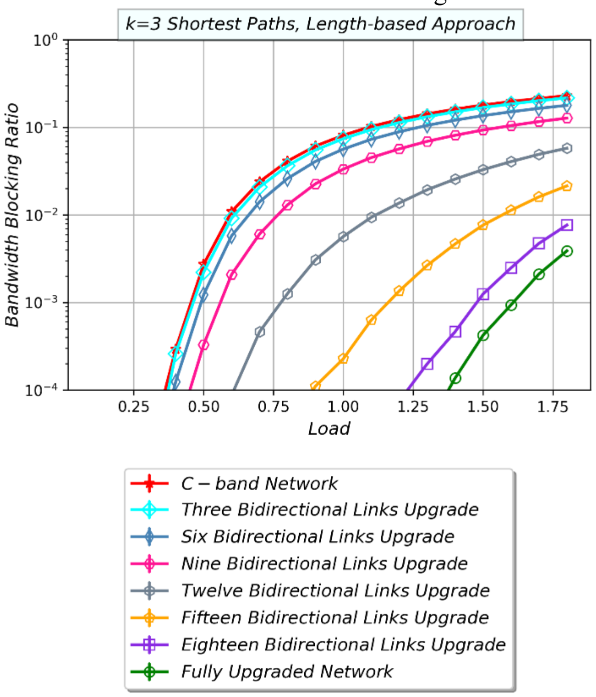

Fig. 2. Bandwidth blocking ratio of length-based RBMLSA depending on the network load. K in K-shortest paths algorithm is set to 3

Fig. 3 summarizes the previous results and compares the two approaches for solving the RBMLSA problem: hop-based and length-based when K is set to 3. It represents the load increment with an acceptable value of BBR (BBR$<10^{-3}$) with different number of upgraded fibers. As can be seen in that figure, the improvement is more noticeable from the upgrading of 9 fibers. However, a good increment of the load supported by the network can be obtained without upgrading all the fibers of the network. Moreover, the heuristic based on hops exploits better the L-band and it achieves better results than the one based on length when only a subset of fibers are upgraded. This is an important conclusion as most of proposals to solve RBMLSA problem when considering C-band or fully migrated networks use distances as it allows to use the best modulation format as possible. However, as shown in Fig. 3, it is better to use the hop-based approach.

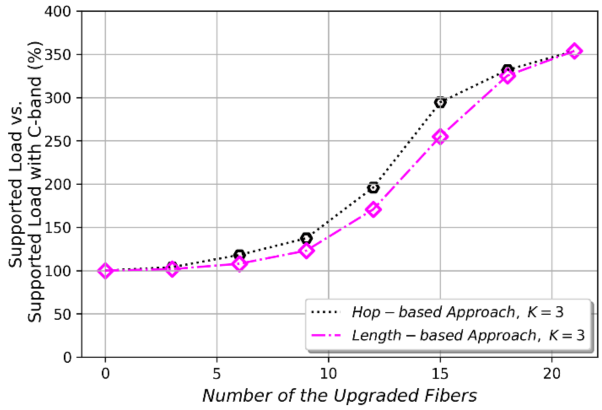

Fig. 3. Supported load with different number of upgraded fibers respect to employing only C-band

IV. Conclusions

In this paper we have evaluated the migration of the current elastic optical networks using C-Band to multiband optical networks using C+L bands. One planning strategy was proposed to determine which fibers should be upgraded (upgrade in the amplifiers). Then, it is combined with two heuristics to solve the RBMLSA problem during network operation. The simulation study performed shows that networks will support more traffic thanks to the use of C+L multiband networks. However, it is not necessary to upgrade all the fibers to achieve a good increment in the supported traffic load. Therefore, finding a trade-off between the number of upgraded fibers and a satisfactory blocking ratio is important. Finally, the proposed heuristic to solve the RBMLSA problem based on hops leads to better results than using the shortest length paths when the network is not fully migrated.

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