# Dilemma for Multi-Band Network Migration: Single-Band or Multi-Band Transceivers


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***Abstract*—Operators have two alternatives to acquire new transceivers when migrating from current C-band optical networks to C+L multi-band optical networks: i) multi-band C+L transceivers, or ii) separate single-band C and single-band L transceivers. The deployment of these new transceivers, along with the other costly components required, delays the completion of a fully upgraded network on which the L-band is active on all network links. Therefore, the concept of partial migration during the network planning phase has been proposed. This paper attempts to shed light on the question of which type of transceivers should the industry focus to help operators in the migration of their networks from the C-band to the C+L-bands. Simulation results demonstrate that the employment of multi-band transceivers does not lead to a significant reduction in the number of required additional transceivers that should be installed for different levels of partial migration. Additionally, we present a techno-economic study about this issue, demonstrating that, in fact, the use of single-band transceivers leads to lower costs.**



***Keywords—multi-band optical networks, network migration, transceivers, multi-band transceivers, techno-economic analysis.***


## I. Introduction

The demand for bandwidth-intensive applications and services driven by the impending 5G technology is prompting network operators to increase the capacity of optical networks [1]. Band division multiplexing (BDM) is a promising cost-effective solution to scale up the already installed fibers. L-band ready erbium doped fiber amplifiers (EDFAs) make C+L band systems a practical solution to achieve a capacity increase up to ~11.5 THz [2]. Moreover, C+L band systems are also considered as a cost-effective solution. For instance, it has been demonstrated that the network capacity upgrade using multi-fiber ($n \times$ C-band) transmission induces higher cost compared to the employment of C+L bands for long-haul networks [3]. On the other hand, in a partially/fully upgraded network, the routing, modulation level, and spectrum assignment (RMLSA) problem that should be addressed in elastic optical networks, transforms to the routing, band, modulation level, and spectrum assignment (RBMLSA) problem [4]. This is because the spectral resource selection and allocation process must be carried out taking into account that more spectral bands have been lit up and not only the C-band. Although it is more cost-effective than other alternatives for increasing the bandwidth provided by optical networks, such as space division multiplexing (SDM), a full upgrade of the network from the conventional C-band to C+L-bands requires the deployment of new costly equipment. Therefore, a partial migration of the network is seen as a practical solution to increase capacity while maintaining costs at an acceptable level [5-8]. In [8], we analyzed the effects of partial migration with a focus on link equipment, specifically amplifiers. In this paper, our focus is on transceivers. We begin with the realistic premise that current operators are already operating their networks in the C-band and have an adequate number of transceivers for this purpose. To accommodate higher traffic loads using both the C and L bands, operators have two alternatives:

- Option A: acquire single band transceivers, i.e., C-band transceivers for new lightpaths established over that band, and L-band transceivers for those to be established in the L-band.
- Option B: acquire new multi-band transceivers capable of operating in both C+L bands.

This paper provides insights into the matter of choosing one of these options, considering that the network operates dynamically. Through simulation analysis, we offer an estimate of the potential savings in the number of transceivers if the multi-band option is chosen, and we also present a techno-economic analysis. This information empowers network operators to make more informed decisions by taking equipment costs into account. Additionally, this research could be valuable for the optical industry in order to decide in which direction to lead the transceiver development efforts.

## II. Planning the Migration to C+L Bands: Transceiver Acquisition

Since the investment in network operations must be carefully chosen based on annual financial results, and the utilization of network links is imbalanced, partial migration emerges as the most realistic option for transitioning a network to C+L bands. All network migration planning strategies should consider the current normal operation in the C-band, making maximum use of the existing equipment to reduce overall investment. Taking into account that optical fiber capacity upgrade expenditures are geographically-dependent, the authors of [5] introduced a novel network design framework to minimize the total cost of network upgrade. In that paper, the L-band spectrum is exploited either through the deployment of line interfaces in specific existing fibers or through installing/leasing new optical fibers. Ahmed *et al.* [6] proposed different cost-efficient heuristics to gradually upgrade a C-band network to C+L bands. In that paper, selected batches of links are upgraded to the L-band periodically, evaluating the estimated upgrade costs. In [7], we


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proposed an integer linear programming (ILP) formulation to plan the upgrade of optical links depending on the number of EDFAs to be upgraded.

In the aforementioned studies, the transceivers that should be purchased in order to realize the C+L band systems were not considered, even though they have an important impact on the upgrade costs. In this paper, the set of links to be upgraded will be determined based on the method proposed in [7]. However, we now shift the focus to transceivers, and analyze the question of whether it is worthwhile for network operators to invest in multi-band transceivers to accommodate increased network traffic loads, as opposed to using separate C-band and L-band transceivers for that aim. Our study is based on the premise that network operators already have C-band transceivers deployed in the network. However, as traffic increases and the network should be upgraded, the acquisition of new transceivers becomes necessary. If the network operates dynamically, having multi-band transceivers offers more flexibility, as these transceivers can be employed for establishing connections in any band to adapt to traffic conditions. The question is whether that advantage is significant enough.

We consider networks operating dynamically, where lightpath requests and releases are controlled by the network control plane in a dynamic manner. When a new lightpath request arrives at the control plane, it must run an RBMLSA algorithm to allocate resources and establish the lightpath if feasible. We consider an RBMLSA method which prioritizes the establishment of new connections in the C-band, given that the network already has a high number of transceivers for this band. This policy reduces the number of new transceivers to be acquired, at the expense of a potential performance loss. To address the routing problem, we employ the K-shortest paths algorithm (in terms of hops) [9]. Then, the method searches sequentially for available spectrum in the C-band for each of those paths. If not found, it explores the L-band, but only if all the links in that path have been migrated. In both bands, the Best-Fit policy is employed for solving the spectrum assignment [10]. The modulation level depends on its maximum optical reach for each spectral band [11] to account for physical impairments. We employ 16QAM, QPSK, or BPSK. Once frequency resources are assigned, transceivers are allocated at both the source and destination nodes. As the aim is to identify new transceivers to be purchased, if there are no idle transceivers for a new connection, we assume instant acquisition of new transceivers along the simulation with no restrictions. Note that the simulation, and the assumption of instant acquisition, are used as planning mechanisms. In this way, we keep track of the total number of transceivers required, and thus determine how to dimension the network and the number of new transceivers that should be purchased.

In Option A, single-band transceivers are considered. If a lightpath is to be established in the C-band and there are available C-band transceivers at the source and destination, those resources are used, eliminating the need for new equipment. If no idle resources are available, new C-band transceivers must be acquired. The same process applies if the lightpath is to be established in the L-band (in that case acquiring L-band transceivers).

In Option B, only multi-band transceivers will be acquired. If a lightpath is to be established in the C-band and there are idle C-band or multi-band transceivers at the source and destination nodes, the control plane utilizes them for the request. Otherwise, new multi-band transceivers will be acquired. If the lightpath is to be set up in the L-band and no idle multi-band transceivers exist, new multi-band transceivers will be purchased.

## III. SIMULATION SETUP AND NUMERICAL RESULTS

We have analyzed the two options in the NSFNet topology, with 14 nodes and 21 bidirectional links. To this end, a multi-band elastic optical network simulator has been developed in Python. For every migrated fiber, a guardband of 400 GHz must be allocated between the C-band and the L-band [12], leading to 516 frequency slots of 12.5 GHz for the L-band, and 320 slots for the C-band. Connection requests arrive one by one following a Poisson process, and the source and destination nodes are randomly selected according to a uniform distribution. The requested data rate of each request is randomly chosen from 12.5 Gb/s to 300 Gb/s in steps of 12.5 Gb/s also according to a uniform distribution. Moreover, a 12.5 GHz guardband between adjacent connections is considered. When the simulation is launched, it is assumed that every node in the network is equipped with 26 C-band transceivers, which can be used by any outgoing link as required at any time. That configuration leads to bandwidth blocking ratio, BBR < $10^{-3}$ in the current C-band operation, i.e., for no migration, and for the current traffic load, assumed to be 0.2).

Fig. 1 represents total BBR depending on the traffic load for different scenarios of partial migration. The traffic load is defined as in [8], which is a normalized version of the classic definition of traffic load in Erlangs. As expected, upgrading more fibers results in better dynamic performance. According to Fig. 1, the improvement in the supported traffic load while maintaining BBR < $10^{-3}$ can be increased approximately 1.5 times through the migration of 18 bidirectional links to the C+L bands. Here, as it is mentioned, during the band selection of an upgraded link, the C-band is prioritized over the L-band. However, according to some preliminary results (not shown in the paper), the blocking ratio could be further improved if priority were given to the L-band, even if it requires a higher number of new transceivers. Nevertheless, the aim of this paper is to analyze the most cost-effective solution.

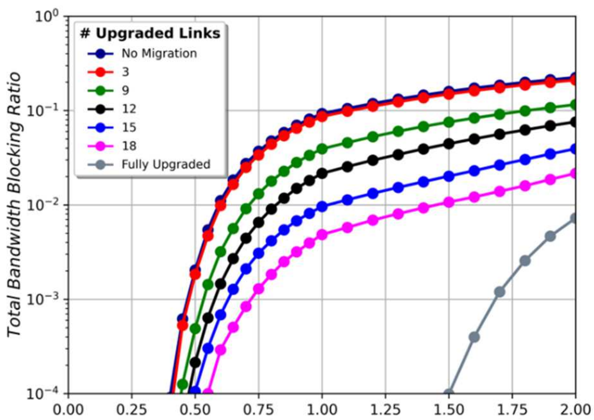


Fig. 1. Bandwidth blocking ratio for different number of links upgraded.

Fig. 2 shows the number of C-band/L-band/multi-band transceivers to be acquired depending on the number of migrated links, and assuming that the traffic in the network increases to a normalized load of 0.6. Acquiring transceivers following Option A or Option B leads to the same BBR. Note that even in the 'no migration' scenario, new transceivers

Table 1: Number of elements and cost to upgrade the network with the two alternatives (for BBR < $10^{-3}$)

| Load | Number of links to be upgraded to L-band for BBR < $10^{-3}$ | Option A: Single L-Band and C-Band Transceivers | | | Option B: Multiband Transceivers (C+L) | |
|---|---|---|---|---|---|---|
| | | Number of C transceivers to be acquired | Number of L transceivers to be acquired | Cost of the acquired transceivers (normalized cost units) | Number of C+L transceivers to be acquired | Cost of the acquired transceivers (best case, normalized cost units) |
| 0.2 | 0 | 0 | 0 | **0.0 c.u.** | 0 | **0.0 c.u.** |
| 0.4 | 0 | 562 | 0 | **20,232.0 c.u.** | 562 | **24,278.4 c.u.** |
| 0.6 | 15 | 1325 | 114 | **52,624.8 c.u.** | 1374 | **59,356.8 c.u.** |
| 0.8 | 21 | 2316 | 269 | **94,996.8 c.u.** | 2479 | **107,092.8 c.u.** |

should be acquired, as the network was dimensioned assuming a (lower) normalized traffic load of 0.2. As shown in that figure, the number of multi-band transceivers to be acquired (Option B) is very similar to the number of additional C-band transceivers to buy if Option A is employed. Therefore, the red line, which corresponds to the L-band transceivers to buy for Option A, can be considered (roughly) as the number of transceivers that can be saved by the usage of multi-band transceivers. If 15 links are upgraded, 65 less transceivers are required if multi-band transceivers are used (1374 vs 1439).

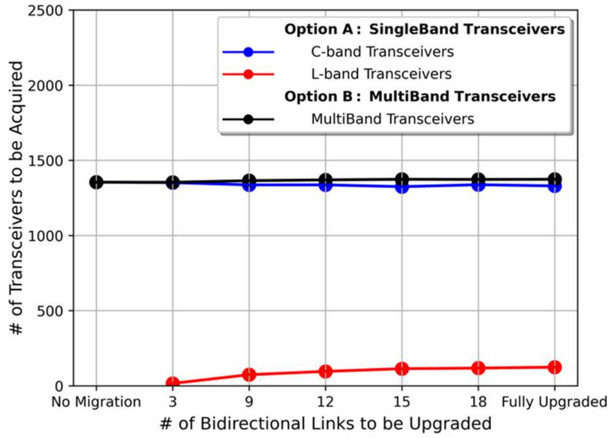

Fig. 2. Number of transceivers to be acquired (if traffic load increases to 0.6).

Table 1 provides a comparison between single-band and multi-band transceivers in terms of the number of required transceivers and the associated costs. The techno-economic model in [13] assumes that the cost of a C-band and an L-band transceiver is 36 cost units (c.u.) and 43.2 c.u., respectively (where 1 c.u is equal to the cost of a C-band EDFA). No data is provided for C+L multi-band transceivers, but it is sensible to assume a higher cost due to higher complexity. Nevertheless, in Table 1 we assume a best-case cost scenario, assuming that the cost of a multi-band transceiver is equal to that of the L-band transceiver (43.2 c.u.). Even with that optimistic assumption, the use of single-band transceivers leads to lower total costs. It should be noted that the analysis is performed on a network that operates initially with a traffic load of 0.2. Thus, the corresponding values for that load (first row of Table 1) are all zero as no upgrades are required for that load. For a traffic load of 0.6, 15 bidirectional links need to be upgraded to the L-band to achieve BBR < $10^{-3}$. In that scenario, 1325 additional C-band transceivers and 114 L-band transceivers must be purchased if single-band transceivers are used. Therefore, the total number of new transceivers would be 1439. However, this number is 1374 if multi-band transceivers are used. Considering the costs previously mentioned for each type of transceiver, the use of single-band transceivers leads to around 11.3% savings in cost (even considering a best-case cost scenario for multi-band transceivers). In fact, the cut point for the multi-band transceivers is 38.3 c.u. (for 0.6 and 0.8 loads), which is lower than the cost of an L-band transceiver. If the cost of multi-band transceivers is higher than that cut point, the use of single-band transceivers is a more cost-effective option. Hence, although the use of multi-band transceivers leads to a reduction in the number of transceivers to be acquired, the use of single-band transceivers is the most cost-effective option when considering the techno-economic model in [13].

## IV. Conclusions

We have evaluated the total transceiver costs when migrating a C-band towards a C+L multi-band network. We have demonstrated that the total number of additional transceivers required is lower if multi-band transceivers are purchased than if single-band transceivers are used (ensuring BBR<$10^{-3}$). However, the reduction in the number of transceivers does not translate into a reduction in the total cost compared to the purchase of single band transceivers (if the techno-economic model of [13] is considered). Therefore, the deployment of separate L-band transceivers when migrating from the C-band to C+L bands is a more cost-effective action than the use of multi-band transceivers.

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