When Is Operation Over C+L Bands More Economical than Multifiber for Capacity Upgrade of an Optical Backbone Network?

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Abstract *Network operation over C+L bands compared to multifiber C band is investigated for capacity upgrade of optical backbone networks. C+L bands provide more benefit in larger networks (geographies) even for low fiber lease cost.*

Introduction

Network capacity enhancement to handle the exponential traffic growth while incurring lower capital expenditure is crucial for network operators. Possible solutions to increase network capacity are Multiband and Multifiber technologies. However, according to the geographical size of the network, the cost of additional equipment and fiber lease cost may vary, thus influencing the choice of technology for a network upgrade.

Recently, an optimum way to multifiber C+L bands link upgrade has been studied for the Italian network, considering geographical population locations[1]. Similarly, it has been shown that the Multiband Elastic Optical Network (EON) needs a higher migration cost than that of the parallel fiber system for the Telefónica-Spain national network[2]. However, considering a larger geography, lower fiber lease cost may strongly influence the choice of upgrade while incurring a lower cost-per-bit. In this work, the effect of fiber lease cost on network cost upgrade (measured in cost-per-bit metric) for geographically-diverse networks--BT-UK and Indian network[3]--has been analysed while operating over C+L bands, and compared with multifiber (nC) band.

Physical-Layer Model

Physical-layer model of C+L bands operation is shown in Fig 1. The inline amplifier module is the same as in[4], where the gain of the Erbium-Doped Fiber Amplifier (EDFA) is equivalent to the previous span loss. We use a Gain Flattening Filter (GFF) for Inter-channel Stimulated Raman Scattering (ISRS) compensation at each Reconfigurable Optical Add-Drop Multiplexer (ROADM). Thus, ISRS accumulates over multiple spans and Amplified Spontaneous Emission (ASE) noise at the ROADM EDFA $P_{ASE}^{R_i}$ is frequency dependent. Nonlinearity associated with the i[th] optical link is represented by P_{NLI}^{i}. We consider Noise Figure (NF) of 5.5 dB and 6 dB for C band and L band amplifiers, respectively[5]. Total inline ASE noise in the i[th] link is represented by P_{ASE}^{i}. All system parameters are the same as in[4].

Total Optical Signal-to Noise-Ratio (OSNR) can be written as:

$$\frac{1}{OSNR(f)} = \sum_{i=1}^{N_L} \left(\frac{P_{ASE}^{i} + P_{NLI}^{i}(f)}{P_{ch}} \right) + \left(\frac{P_{ASE}^{R_i}(f)}{P_{ch}} \right) \quad (1)$$

Cost Model

For economic comparison between C+L bands and nC band EON, we consider the cost of all the inline equipment, as shown in Table 1. Cost of each equipment is relative to the cost of a C band EDFA. Cost of L band equipment is assumed 20% higher than C band equipment.

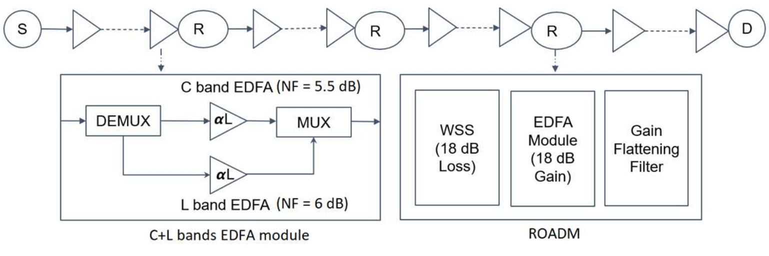

Fig. 1: Multihop path for OSNR estimation.

Typically, costs of ROADM and EDFA are more for C+L bands vs. nC band EON. However, dark-fiber lease cost is very significant for nC band scenario. In this work, fiber lease cost variation with respect to network operator's geography has been considered. For a European country, it is approximately 0.33x (~ $1308) per fiber/km/year for five years of leasing package[11]. But lease cost in Indian network is about 0.007x (~ $ 29) per fiber/km/year, i.e., much less than Europe. Below, BT-UK and Indian networks are studied.

Tab. 1: Approx. relative cost of different equipment (EON).

Equipment	Relative Cost
EDFA (C band)[6]	x
EDFA (L band)	1.2x
DEMUX[7]	0.04x
MUX[7]	0.04x
EDFA module (C+L)	2.28x
GFF at EDFA module[8]	0.2x
WSS (C band)[9],[10]	5x
WSS (L band)	6x
Transponder[10]	36x
Average fiber lease cost (per fiber per km per year)	Nx (N = 0 to 0.5)

Biased Traffic Matrix Generation

In this work, a biased traffic matrix is generated to resemble traffic flow among high-demand-generating nodes in both networks. For BT-UK, we use the population and dropped wavelength data of each node to choose source-destination pairs probabilistically. For Indian network, we use a population metric of each city[12].

Simulation Method

In this work, for techno-economic comparison between nC and C+L bands EON, cost-per-bit metric is analysed for small BT-UK and larger Indian networks. The average link length of BT-UK is 147 km, whereas for Indian network it is 531 km. The physical layer model predicts the OSNR of a lightpath. However, using the GFF specifically at the ROADMs can significantly impact the OSNR of a lightpath traversing longer links due to the high amount of accumulated ISRS. Therefore, to provision lightpaths over longer distances in the Indian network, the GFFs need to be placed after every span for equalizing the ISRS effect. A total of ten thousand 100G demands are generated to fill the network spectrum. Initially, the number of lightpaths allocated until 1% blocking is reached, is recorded for C+L bands. Then, for nC case, we start with single C band fiber links and repeat the simulation until equal number of lightpaths matching the C+L bands is achieved. During nC band operations, for the lightpath causing 1% blocking, another parallel fiber is added to the link which has the highest spectral occupancy.

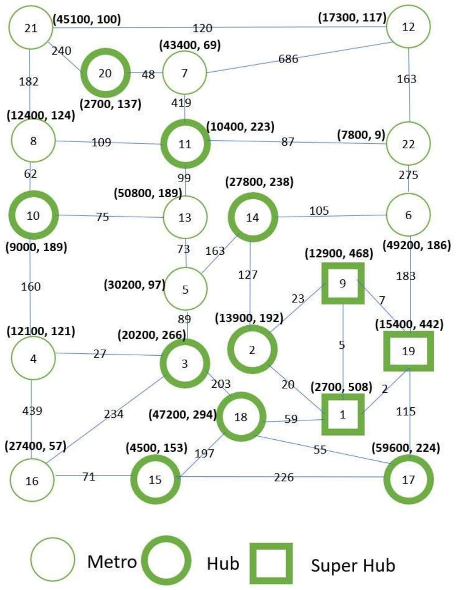

Fig. 2: BT-UK network with link length in km, and node metric in parens = (population, dropped wavelength).

Three launch powers (-5.25 dBm, -3 dBm, and -1.5 dBm) are considered. Channel bandwidth of 37.5 GHz for C+L is considered, with a guard band of 200 GHz between C and L bands. Figures 3 and 4 present average results of 100 random traffic generations while considering three shortest paths for each lightpath; and C band is considered first for filling the spectrum in case of C+L bands.

Results and Discussion

Normalized cost-per-bit performance with the increasing fiber lease cost under C+L bands and nC operation is analysed. In Figs. 3 and 4, the ***crossover point*** represented by the arrow indicates the fiber lease cost after which the operation over C+L bands will incur lower cost-per-bit. In Fig. 3, number of lightpaths on average are mentioned for different launch power. For C+L bands, as launch power is reduced from -1.5 dBm to -3 dBm, number of allocated lightpaths increases as higher-order modulation formats are used due to reduction in ISRS-based Nonlinear Interference (NLI). But, in case of nC band, ISRS effect is negligible and reduction in power reduces the OSNR of a lightpath. Thus, as launch power is reduced from -1.5 dBm to -3 dBm for nC case, more spectral resources are required by lower modulation lightpaths to match the capacity increase of C+L bands. This additional spectrum resource is provided by deployment of more

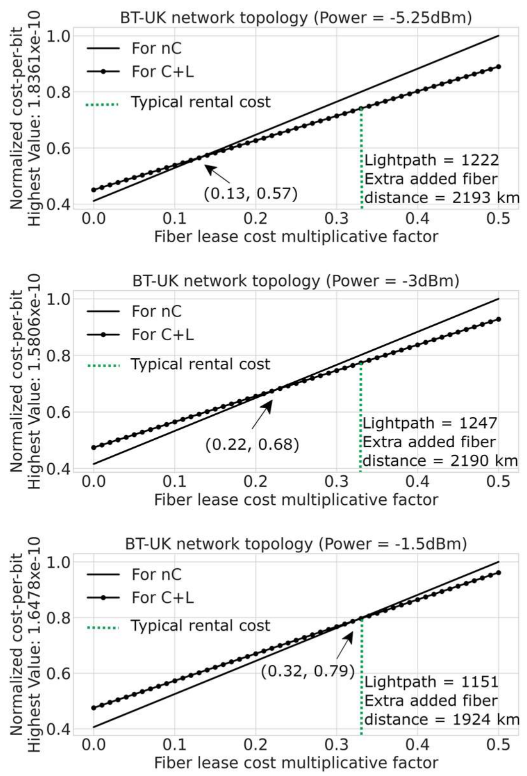

Fig. 3: Normalized cost-per-bit for BT-UK network with five years of leasing.

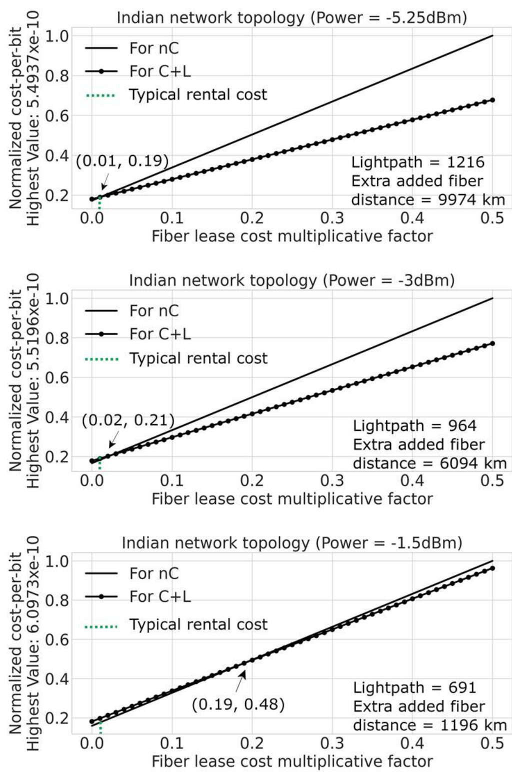

Fig. 4: Normalized cost-per-bit for Indian network with five years of leasing.

parallel fibers, which increase the system cost in nC case, even for lower fiber lease cost, thereby preponing the crossover point. As launch power is further reduced from -3 dBm to -5.25 dBm, overall cost-per-bit reduction is marginal (from 1.07xe-10 to 1.05xe-10). As power is reduced in for C+L bands, lightpaths generated increasingly belong to lower modulation formats. Thus, fewer lightpaths are allocated at 1% blocking, which leads to lower transponder cost. To match the capacity of C+L bands, nC requires marginal extra added fiber, which does not significantly impact the inline cost. Cumulatively, overall cost reduces along with reduction in network capacity, which leads to marginal reduction in cost-per-bit. Generally, when there is no fiber lease cost, C+L bands will be expensive, as shown in Fig. 3. But, beyond the crossover point, fiber lease cost for nC becomes expensive vs. C+L bands. The green dotted vertical line indicates the typical lease cost of fiber for the BT-UK network, where it indicates that C+L bands are cost-effective vs. nC case. Fig. 4 shows normalized cost-per-bit for Indian network under C+L bands and nC case. Now, -5.25 dBm launch power generates maximum number of lightpaths, and maximum number of fiber links are upgraded to generate the same amount of lightpaths in nC case.

Moreover, total upgraded fiber distance and number of generated lightpaths will play a crucial role in nC and C+L bands comparison.

At -1.5 dBm, NLI becomes significant, thereby leading to fewer lightpaths generation. So, very few fibers will be upgraded for nC case with -1.5 dBm launch power. Thus, gap between nC and C+L bands after crossover is not significant vs. other power profiles. In Indian network, although the placement of GFF at each amplifier module will increase overall inline equipment cost by ~92%, increase in number of generated lightpath is ~130%, thereby reducing cost-per-bit.

Comparing Figs. 3 and 4, note that the cross-over points appear earlier in Indian network vs. BT-UK. Since link lengths are much larger and added fiber distance is more for Indian network, nC is costlier even for lower fiber lease cost.

Considering Wavelength Division Multiplexing (WDM), number of channels causing NLI in C+L bands will be lesser, so lightpaths will be of higher capacity and cost-per-bit is expected to reduce.

Conclusion

This study shows that C+L bands EON is cost effective vs. nC band EON, particularly for larger geographies (Indian network). But, for smaller geographies (BT-UK network), C+L bands is advantageous only if fiber lease cost is high.

Acknowledgements

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