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Multifiber vs. Ultra-Wideband Upgrade: A Techno-Economic Comparison for Elastic Optical Backbone Network

Rana Kumar Jana(1), Md Asif Iqbal(2), Neil Parkin(2), Anand Srivastava(1), Arvind Mishra(3), Jitendra Balakrishnan(3), Phillip Coppin(3), Andrew Lord(2), Abhijit Mitra(1,2)

(1) Dept. of Electronics and Communication Engineering, IIIT Delhi, India, ranaj@iiitd.ac.in
(2) Applied Research, Adastral Park, BT, UK
(3) Sterlite Technologies Limited

Abstract. We report the evolution of cost-per-bit with the growth of core optical network traffic while comparing multifiber and ultra-wideband solutions. Results show that ultra-wideband systems can save 30% of the total cost while using 22.2% less upgrades than multifiber C band system. *©2022 The Author(s)*

Introduction

Upgrading the existing backbone optical network infrastructure is critical to support the exponential growth of global IP traffic. Recent work [1] suggests that C band-based current core network infrastructure will be thoroughly exhausted during the next ten years based on traffic growth rates of 30%. As a solution to this fiber capacity crunch, multiple parallel fibers and alternative fiber bands appear as potential candidates, along with their individual pros and cons. For example, transmission over multiple bands can use the full capacity of the existing infrastructure; however, the quality of the transmission becomes susceptible to nonlinear impairments such as Inter-channel Stimulated Raman Scattering (ISRS) [2]. In addition, the multiband system needs the development of several advanced amplifier modules to transmit over different bands. On the contrary, multifiber can still use the existing amplifiers, but the leasing or deployment of extra fibers is needed to ensure parallel transmission.

Several investigations have been reported recently to analyze the performance of these two technologies. For example, in [3], the authors upgraded specific links of a multifiber-based C+L band system by considering population metrics of different geographical locations. Furthermore, the authors in [4] show the advantage of multifiber deployment for the Telefónica-Spain national network. In [5] authors capture the impact of fiber leasing on the cost-per-bit for two geographically diverse networks. Practically, the placement of extra fibers in the network can be possible only by leasing or deploying whole new fiber cables. So, instead of single fiber leasing or deployment assumption, in this paper, we have taken realistic assumptions and demonstrated the strategy of extra whole cable deployment at different required positions in the network. The impact of additional cable deployment with traffic growth is analyzed in this paper. Two scenarios, namely, multifiber C band (nC) and multifiber C+L band (n(C+L)), are considered in this study, where notation n is used to resemble the multifiber scenario. A techno-economic comparison is performed between the nC and n(C+L) in terms of capital expenditure and cost-per-bit of the network, while assuming a bidirectional single fiber pair in all of the links of the network initially.

Building Blocks for Techno-economic Comparison

This section explains the physical layer model, followed by the proposed strategy for link upgrade, and the cost model of the system, which are the fundamental building blocks for techno-economic comparison between multifiber and ultra-wideband systems.

A. Physical Layer Model: Fig. 1 shows the underlying physical layer model for the C band-based multifiber and C+L band-based ultra-wideband system.

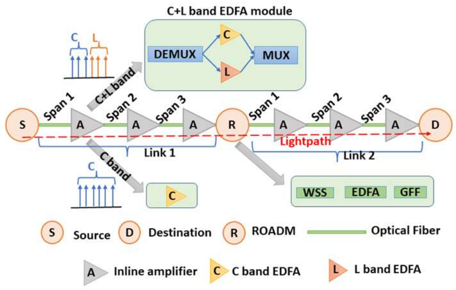

Fig. 1: Physical layer model.

Generally, lightpaths are lit between source and destination routes over multiple links where in-line Erbium-Doped Fiber Amplifiers (EDFA) are symmetrically placed to compensate for the signal attenuation of each span. If the input signal to the EDFA consists of C and L band channels, the C+L band EDFA module is used to amplify them. This module consists of a DEMUX, band-specific amplifiers, and a MUX element for demultiplexing different band channels, amplification, and multiplexing purposes, respectively. Furthermore, the effect of ISRS is mitigated by the placement of the Gain Flattening Filters (GFF) at each of the Reconfigurable Optical Add-Drop Multiplexer (ROADM) units. In addition, an extra amplifier module is also used at the ROADM in order to compensate for the switching loss through Wavelength Selective Switch (WSS) unit. The quality of a lightpath is determined in terms of its frequency-dependent Optical Signal-to-noise ratio (OSNR), and that can be determined as follows:

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

where f, P_{ch}, P_{ASE}^{i}, P_{NLI}^{i}, and $P_{ASE}^{R_i}$ represents the channel of interest, uniform channel launch power, in-line EDFA Amplified Spontaneous Emission (ASE) noise power, nonlinear impairment power in the ith link, and ASE noise power from the EDFA of ith ROADM, respectively.

B. Link Upgrade Strategy: This section presents the proposed methodology that has been considered to upgrade specific links of the network as per the requirement of traffic growth. The links are upgraded by placing extra multifiber cables and their associated additional amplifiers. The selection of the link for upgrade is determined based on the spectrum occupancy, which has been shown in detail by the flowchart in Fig. 2. The algorithm starts with the allocation of upcoming new traffic requests while doing routing, modulation, and spectrum allocation (RMSA). If the unavailability of spectrum resources leads to the blocking of certain requests, the algorithm compares the state of current blocking probability (BP) with the predefined acceptable threshold (BP_{th}). If BP becomes equal to BP_{th}, the algorithm stops the allocation of a new connection and monitors the state of the network. As a start, it takes the route of the last blocked demand and upgrades the most congested link in the route by placing additional cables. This process of extra cable addition in the most congested link of the route continues until the upgraded links help to reroute the last blocked connection. Consequently, the allocation process of new requests is resumed after the successful rerouting of the last blocked request. The process of new connection establishment and additional cable addition continues until the network reaches its targeted capacity.

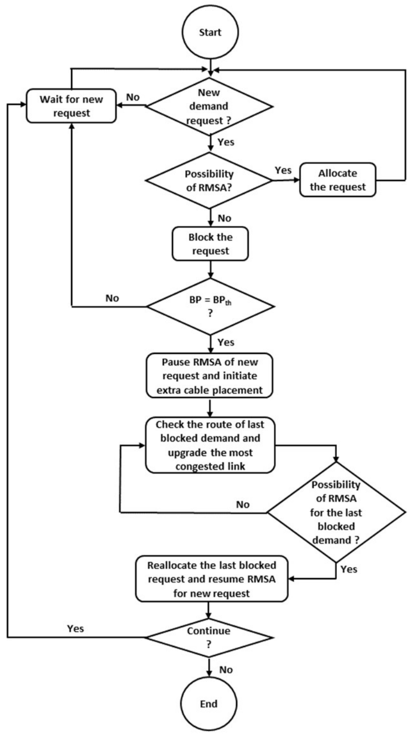

Fig. 2: Flowchart of link upgrade strategy.

C. Cost Model: In order to determine the capital expenditures for nC and n(C+L) systems, we consider the relative cost of several components while considering C band EDFA cost as a baseline, as shown in Table. 1. The cost of an L band EDFA is assumed to be 20% higher compared to the C band. As a type of cable deployment, Sterlite's 8-FC cable is considered, which is the least granular practical available cable and consists of 8 parallel fibers.

Tab. 1: Approx. relative cost of different equipment.

Equipment	Relative Cost
EDFA (C band) [6]	x (~4000 $)
EDFA (L band)	1.2x
DEMUX [7]	0.04x
MUX [7]	0.04x
EDFA module (C+L)	2.28x
8-FC Cable Purchase	0.05x / km
8-FC Cable Deployment	0.5x / km

Simulation Setup

A custom-built, event-driven Python simulator is developed to make the techno-economic comparison. BT-UK network topology [8] is considered for simulation with 0 dBm launch power, which consists of 22 nodes and 35 links with an average link length of 147 km. Moreover, a 64 Gbaud system with 75 GHz of channel spacing is considered while taking three modulation formats, PM-QPSK, PM-8QAM, and PM-16QAM [9]. On the other hand, 200 GHz guard band is considered between C and L band due to non-ideal WSS passband assumption. A biased traffic matrix [5] is generated to capture the traffic growth rate of 35% with baseline traffic of 20 Tb/s. A total of 1500 100G traffic units are considered as a targeted capacity of the network during simulation, which resembles seven years of network traffic growth with a pre-determined blocking threshold (BP_{th}) of 1%. We run the simulations for multiple seeds, and the average results are reported with less than a 5% margin of error at a 95% confidence interval.

Results and Discussion

In order to accommodate the exponential traffic growth, multiple cables are deployed in specific links of the network for both C and C+L band systems using the mentioned link upgrade strategy.

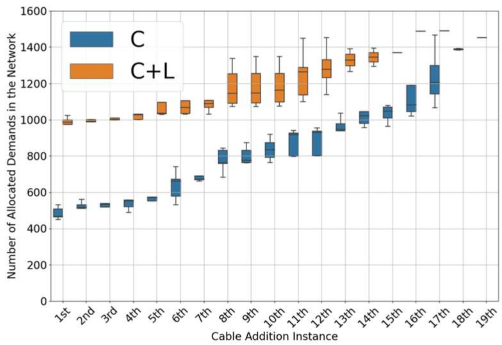

Fig. 3: Cable addition instances with traffic loading.

The instances of cable addition with the progressive traffic loading are captured in Fig. 3. The vertical bars show the variation of the cable addition instances over multiple simulations. On average, for the C band system, the first cable addition occurs after the allocation of 500 100G demands in the network, whereas the availability of extra resources in the C+L band system provides 50% more capacity and postpones this instance of the first upgrade till 1000 100G demands. Moreover, the presence of the small number of channels in the C band system results in the addition of more cables compared to the C+L band system in order to cater for the same amount of traffic. Figs. 4 and 5 show the variation of overall cost and cost-per-bit of the network with instances of cable addition and traffic loading. As the cables are added at different instances, the slope of the total cost curve rises. Due to the costly amplifier module, although the C+L band system appears costly for low traffic, a crossover happens between C and C+L band systems when allocated demand touches 600 100G capacity.

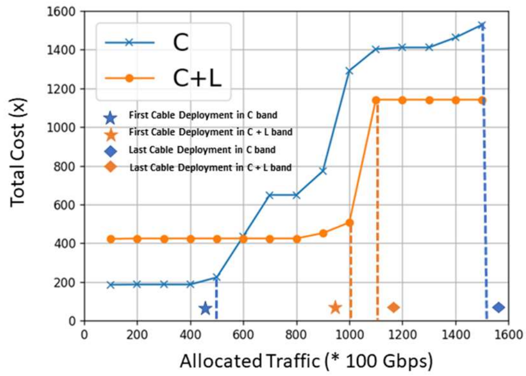

Fig. 4: Total cost variation with traffic loading.

The numerical result suggests that, out of 35 links in BT-UK, 51.4% of the links are upgraded for nC system, whereas a 22.2% reduction in the number of link upgrades can be achievable using the n(C+L), which leads to 30% total cost savings.

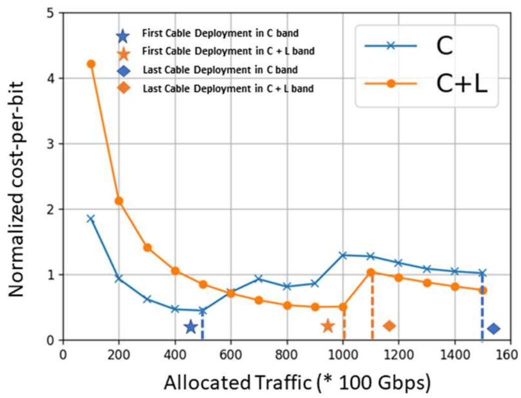

Fig. 4: Cost-per-bit variation with traffic loading.

Moreover, simulation results also show that, on average, n(C+L) can activate 41.6% fewer additional fibers than the nC case (number of extra active fibers is 24) in order to cater for the same amount of traffic and thereby indicates the availability of a large surplus capacity of n(C+L) compared to nC.

Conclusions

This study suggests that the C+L band system can postpone the need for extra cable deployment compared to the C band system and thereby minimizes the cost-per-bit in the long run.

Acknowledgements

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