Effect of Fill Margin on Network Survivability for C+L Band Optical Networks

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Abstract *Network survivability for multiband networks is investigated for geographically diverse networks. Results show that in smaller networks, multiband systems can save 55.6% of the connection failures, compared to C-band systems even at 0 dB OSNR cushion, which is required to absorb adjacent channel impairments.*

Introduction

Upgrading the core optical network beyond the existing C-band is necessary for supporting the exponential growth of global IP traffic[1]. Recent studies suggest that operations over the multiband can be a short-term, cost-effective solution for minimizing network upgrade cost and the cost-per-bit in the long run[2]. However, to assess the overall potential of the multiband solution, network reliability due to component failures needs to be studied.

This work considered the inline amplifier failure scenario and showed the benefits of multiband systems compared to conventional C-band systems. Our approach measures the overall protection space of the network and the quality of the allocated lightpaths in two geographically diverse networks. As a final step, we show the effect of the required OSNR cushion variation for absorbing adjacent channel impairments (called Fill Margin (FM)) on the achievable protection space and reliability of the network.

Physical Layer Model

Figure 1 shows the physical layer model for the multiband system.[2]. The inline Erbium-Doped Fiber Amplifiers (EDFA) module consists of C band (Noise Figure (NF) of 5.5 dB) and L band (Noise Figure (NF) of 6.0 dB)[3] amplifiers for compensating the previous span losses along with DEMUX/MUX element (insertion loss of 1 dB). Every Reconfigurable Optical Add-Drop Multiplexer (ROADM) block consists of Gain Flattening Filters (GFF) elements to mitigate the effect of Inter-channel Stimulated Raman Scattering (ISRS)[4] and EDFA module for compensating switching loss through the Wavelength Selective Switches (WSSs) losses[5]. The quality of the lightpath is determined by the Optical Signal-to-noise ratio (OSNR), and it can be expressed as follows:

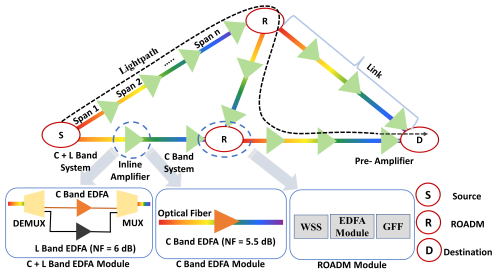

Fig. 1: Physical layer model.

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

where f, N_L, P^i_{ASE}, $P^i_{NLI}(f)$, P^i_{ch}, and $P^{R_i}_{ASE}(f)$ denotes channel of interest, number of traversed links, Amplified Spontaneous Emission (ASE) noise power, nonlinear impairment power in the i^{th} link, channel launch power, and ASE noise power from the ROADM block, respectively.

Protection Strategy

This section discusses the proposed methodology that has been considered for ensuring 1+1 protection in the network. In this work, we consider only single-band (either C or L band) inline amplifier failure scenarios for a multiband system (such as the C+L band), and hence, the provisioning of the backup lightpaths is prioritized over the same route as primary lightpaths using the alternate band. If the spectrum is unavailable in the primary route then alternate routes are explored (like conventional C-band system) for backup path provisioning in the multiband system. Figure 2 shows the flow of the protection strategy where the possibility of provisioning one dedicated backup lightpath and one primary lightpath is explored for every requested connection in the network. If a backup lightpath is not feasible in the network for certain connections, only primary lightpaths are allocated for them. When the network reaches its targeted capacity, the process of resource allocation ends.

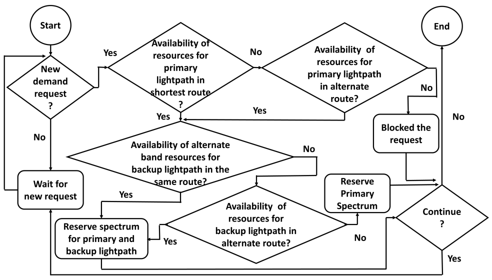

Fig. 2: Flowchart of 1+1 protection strategy.

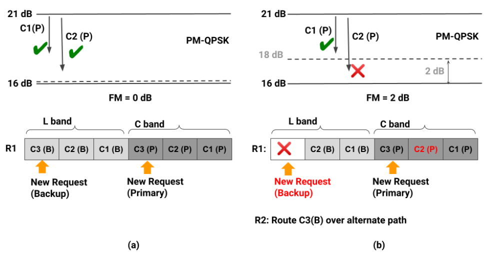

Fig. 3: Concept of Fill Margin. (a): Tolerable degradation up to 16 dB threshold for the existing connections C1(P) and C2(P), FM = 0 dB, (b): Due to FM of 2 dB, the addition of C3(B) degrades the C2(P) beyond 18 dB, thereby triggering the backup lightpath route R2.

Effect of Fill Margin on Network Protection

Fill Margin (FM)[6],[7] is a well-studied metric for link designing in optical networks, and it is defined as the required OSNR cushion that is needed to absorb the effect of channel loading on the existing connections in the network. Mainly, FM is employed to protect against the non-linear impairments from the nearby channels and allows the network operators to maintain the quality of the lightpath. However, the FM can severely impact the network survivability in the multiband scenario. The additional spectrum resources of the multiband system can be used to provide protection in the network. Figure 3 shows such a scenario, where the C-band system is used for provisioning primary connections (denoted by: C1(P), C2(P)) and their dedicated backup connections (denoted by: C1(B), C2(B)) are provisioned over L-bands on the same route. If any new connections (say, C3(P) and C3 (B)) appear, then depending on the choice of FM, the situation may arise to allocate a backup lightpath in an alternate route. Considering an FM of 0 dB, upon the addition of a new request, an operator may allow the OSNR of existing lightpaths to degrade up to the threshold, however, for FM 2 dB, the new threshold for tolerable degradation will be 2 dB higher than the original threshold. Therefore, as any new connection arrives under high FM, the likelihood of the OSNR drop beyond the new threshold will be higher. This may prevent the allocation of backup lightpath over the same route, and consequently, spectral space over an alternative route shall be utilized leading to higher spectrum occupancy.

Simulation Setup

In this work, two diverse network topologies, namely, BT-UK network (22 nodes, 35 links, average link length 147 km) and USA24 network (24 nodes, 43 links, average link length 991 km)[8] have been considered for simulation. Lightpaths are allocated into the network with individual launch power of 0 dBm while considering three available modulation formats (PM-QPSK, PM-8QAM, and PM-16QAM) at 64 GBuad, with channel spacing of 75 GHz[2]. A traffic growth rate of 35% with baseline traffic of 20 Tbps is considered in the network while using a biased traffic matrix generator[9]. Average results of multiple seeds with less than 5% margin of error at a 95% confidence interval are reported in the following section.

Results and Discussion

We evaluate the performance of the proposed protection strategy in terms of the overall protection space of the network, and the quality of the allocated lightpaths under different FM conditions. Protection space is an indicator of how many requests in the network have a backup lightpath over which it can be routed in an event of single C-band or L-band equipment failure. The quality of lightpaths and associated capacity is decided while comparing the OSNR of a lightpath against OSNR thresholds of PM-QPSK, PM-8QAM, and PM-16QAM.

The effect of FM variation on the protection space in the BT-UK network is captured in Fig. 4. For a targeted capacity of 80 Tbps with 0 dB FM, the C+L band system allocates 55.6% more demands than the C-band system in the network with 1+1 protection. As the FM of the network enhances, the flexibility of backup lightpath establishment in the same route as of primary is reduced in the C+L band system. Hence, backup lightpaths for the C+L band system start routing over longer link disjoint paths leading to the reduction of the quality of backup lightpaths and overall protection of the network. Figure 4 shows that increment of FM from 0 to 2 dB, reduces the protection space by 9.6% for C+L band system as multiple backup paths are allocated over lower order modulation formats (as shown in Fig. 5). Moreover, if the targeted capacity of the network is increased along with FM enhancement, the probability of spectrum availability in alternate band/route is reduced and as a result, the protection space reduction (PSR) for the C+L band system can also further reduced as indicated in Table 1.

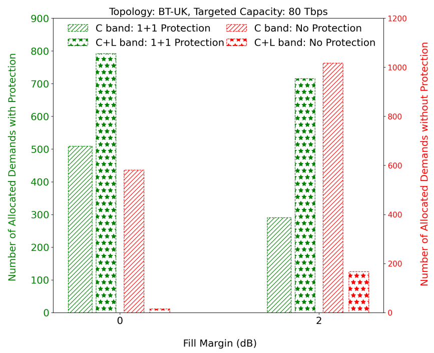

Fig. 4: Effect of FM on protection space of BT-UK network.

Tab. 1: Effect FM enhancement (0 to 2 dB) on the protection space of C+L band system in BT-UK network.

Targeted Capacity (Tbps)	**PSR** (%)
80	9.6
100	12.3
125	15.5
150	18.8

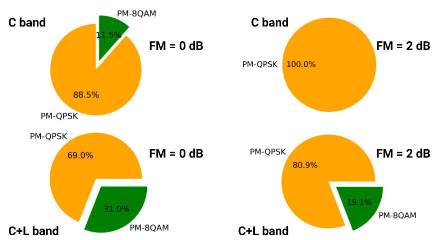

Fig. 5: Quality of backup lightpath for BT-UK network (Targeted Capacity: 80 Tbps).

As the C+L band protection strategy first explores the availability of spectral resources in an alternate band for protection in the same route of the primary lightpath, the average quality of the backup lightpath is higher compared to the C-band system (protection over a separate link disjoint path). Figure 5 shows that 31% of backup lightpaths can be placed with PM-8QAM for the C+L band with 0 dB FM, whereas it becomes only 11.5% for the C-band system. As all the

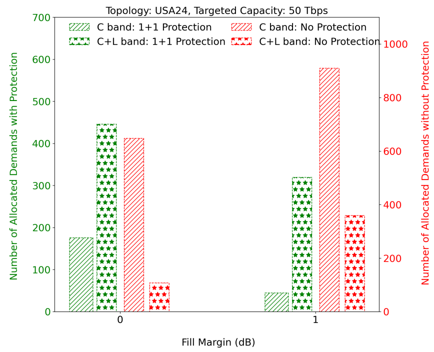

Fig. 6: Effect of FM on protection space of USA24 network.

backup lightpaths are placed using link disjoint alternate routes in the C-band system, the longer link length of the backup lightpath majorly supports low-quality modulations such as PM-QPSK.

Nevertheless, the impact of FM enhancement provides lower protection in C-band since the average quality of the backup lightpath is further reduced from the lowest available modulation format PM-QPSK. Figure 4 shows that the protection space of the C-band system reduces by 42.8% due to the 2 dB FM increment in the BT-UK network. The numerical result indicates that the availability of high-quality based backup lightpaths in the C+L band system provides a gain of $\sim$146% protection space compared to the C-band even in the presence of 2 dB FM.

In the case of longer geography such as the USA24 network, the presence of long link length degrades the average quality of lightpath. In addition, the increment of FM further reduces the achievable protection space in the network. Figure 6 shows the impact of FM variation on the survivability of the USA24 network. Results indicate that a variation of only 1 dB FM can reduce the protection gain by 74.4% and 28.2% in C and C+L band systems, respectively. Nevertheless, the C+L band system still outperforms compared to the C-band system even in the high FM scenario due to its inherent protection space.

Conclusions

This study shows that the C+L band system can ensure more reliability compared to the C-band system for ensuring connection survivability in smaller (BT-UK) and as well as larger networks (USA24). Increasing the FM allows the operators to maintain the signal quality, however, the trade-off would be in terms of achievable spectrum space. Hence an individual allocation of FM for every lightpath may be required to find the right balance between signal quality and protection space in C+L band networks.

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