Transport Network Upgrade exploiting Multi-Band Systems: S- versus E-band

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Abstract: Exploiting bands beyond C+L can effectively upgrade network capacity, but Stimulated Raman Scattering (SRS) affects wideband-transmission, potentially degrading active channels. Upgrades exploiting E- and S-band are compared in terms of capacity and number of reconfigurations. © 2022 The Author(s)

1. Introduction

The exploitation of bands beyond C and L (e.g., S and E bands) is an effective solution to accommodate traffic increase without installing new fibers in the network [1–3]. In such wideband transmission scenario, Stimulated Raman Scattering (SRS) [4] is highly relevant, as it generates a power transfer from higher to lower frequency channels. This may imply a quality of transmission (QoT) degradation on the running channels in the C- and L-band [2]. Consequently, when planning a network upgrade to S- or E-band, the impact of SRS on the running channels in the C+L-band should be accounted for. Indeed, because of SRS, some channels in C+L-band may experience a QoT below the FEC threshold, thus requiring reconfigurations, such as changing them to a lower order modulation format or re-routing them. The former may imply a bit rate reduction, thus additional channels should be setup in order to guarantee the original end-to-end capacity. A possible solution to mitigate this problem is to set a guard band between E and C, consequently limiting the impact of SRS [5].

In this paper, network upgrade based on S- and E-band is analyzed starting from a C+L-band system. Network-wide performance is used to compare both upgrade options in terms of supported traffic increase and reconfigurations required on the active channels in the C+L-band. The results suggest that upgrading to the E-band can be more effective, as it provides a comparable traffic increase while limiting reconfigurations in C+L-band channels.

2. Physical layer assessment

The QoT metric used in this work is the Generalized Signal-to-Noise Ratio (GSNR), considering both Amplified Spontaneous Emission (ASE) noise, generated by the amplifiers, and Non-Linear Impairment (NLI), generated by the fiber propagation. The NLI is computed using the Generalized Gaussian Noise model [4] accounting for SRS, adopted to estimate the QoT of new channels (in S- or E-band) and of already active channels in C+L-band. The power levels and spectral tilt of the already up and running C+L system are computed following the approach proposed in [6]. A Thulium-doped fiber amplifier (TDFA) is assumed for S-band amplification, with average noise-figure of 6.5 dB [7]. The amplifiers for all the other bands (C-, L- and E-band), the network fiber span lengths range (from 30 km to 60 km) and the guard-band between C- and E-band (14 THz) are described in [5]. In this work, we assume optical interfaces operating with a symbol-rate of 64 GBaud and a 75 GHz WDM grid, capable of allocating 92, 54, 125 and 146 channels in L-, C-, S- and E-bands, respectively.

Fig. 1(a) shows the GSNR profile versus frequency of a 57.0 km span length for the 3 scenarios used in our network performance evaluation: C+L, C+L+E and C+L+S. In C+L-band scenario, the average GSNR is 31.57 dB and 32.0 dB for C- and L-band, respectively. When the E-band is added to the system, we obtain average values of 31.6 dB, 31.9 dB and 27.51 dB for C-, L- and E-bands, respectively. These results show that adding the E-band almost does not change the QoT in an already operative C+L-band system. Regarding the C+L+S scenario, the GSNR average values are 31.3 dB, 31.3 dB and 27.8 dB for C-, L- and S-bands, respectively, showing a higher degradation in the C+L-band system, especially on the L-band. In order to guarantee that – all lightpaths within a band – will meet the required QoT levels, the control plane uses the minimum GSNR value within each band as a reference for all channels in that band. In Fig. 1(b) we present the minimum GSNR versus span length (from 30 km to 60 km) for each scenario per band in solid (C+L), dashed (C+L+S) and dotted (C+L+E) lines. For all span lengths tested, the degradation of adding the E-band to the system is virtually negligible, with the highest degradation value of 0.25 dB and 0.21 dB for C- and L-bands for 30 km, respectively. The highest degradation provided by the addition of S-band to a C+L-band system is 0.92 dB for C-band and 1.3 dB for L-band, also for a 30 km span length. Fig. 1(b) also shows that, mainly due to the lower attenuation profile, the minimum GSNR

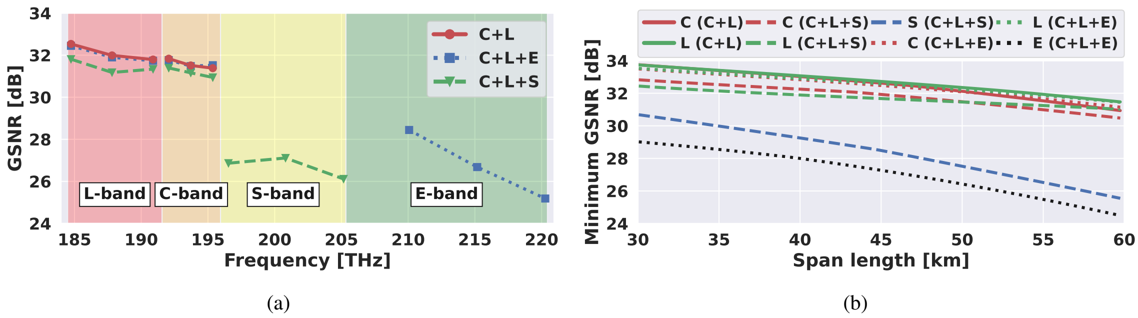

Fig. 1. (a) GSNR profile versus frequency for C+L, C+L+E and C+L+S and (b) Minimum GSNR per scenario (solid, dashed and dotted lines) per band (red, green, blue and black) versus span lengths.

values for the S-band are higher than those for the E-band across all span lengths tested. The highest difference of 1.68 dB is obtained for 30 km span length. Even with lower minimum GSNR values, the E-band can possibly overcome the throughput of S-band because of the higher spectral bandwidth, capable of allocating 21 more channels than the S-band, within the 75 GHz WDM grid. Comparing both bands' is the subject of the network analysis in Sec. 3.

3. Network analysis

Upgrades to S- or E-band are compared by means of a custom-built event-driven C++ simulator. The 30-node Spanish backbone topology is considered. Traffic follows a Poisson distribution with $1/\lambda$ mean inter-arrival time. $1/\mu = 500$s is the mean connection holding time, exponentially distributed. Polarization multiplexed quadrature phase shift keying (PM-QPSK) and polarization multiplexed 16 quadrature amplitude modulation (PM-16QAM) are assumed with a symbol rate of 64 GBaud. 400-Gb/s-net-rate requests are considered: $1\times$400-Gb/s PM-16QAM switched in 75 GHz or $2\times$200-Gb/s PM-QPSK switched in 150 GHz. The GSNR of the worst channel (also considering cross-phase modulation) is assumed for each band. The following threshold values are assumed for GSNR: $\mathrm{TH}_{\mathrm{PM-16QAM}} = 16.1\ \mathrm{dB} + \mathrm{M}$ for PM-16QAM, $\mathrm{TH}_{\mathrm{PM-QPSK}} = 9.5\ \mathrm{dB} + \mathrm{M}$ for PM-QPSK, with M a parameter describing network margins (e.g., to account for aging [8]). Path computation is based on load balancing as in [9] and first fit policy within the chosen band is used for spectrum assignment. Regarding the choice of the band, preference is given to the C band; L is used when no spectrum continuity constraint can be satisfied in the C band; S- or E-bands are used when no spectrum continuity constraint can be satisfied in both C and L bands. If the spectrum continuity constraint is not satisfied along C, L, and S or E bands, the request is blocked.

Upgrades to S- and E-band are compared in terms of blocking probability and reconfigurations required to guarantee QoT in C+L when activating the new band. In the case of E-band upgrade, a guard band of 14 THz [5] is used between E- and C-band, thus making SRS negligible and avoiding reconfigurations in C+L.

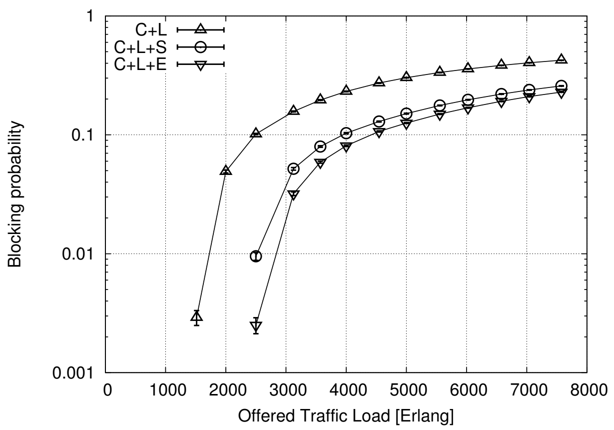

Fig. 2. Blocking probability versus traffic load with no margins

Fig. 2 shows the blocking probability versus traffic load of C+L, C+L+S, and C+L+E with $M = 0$ (no margins). The exploitation of S- or E-band results in a significant reduction of blocking probability. Upgrade to E-band performs slightly better than upgrade to S-band in terms of blocking probability (and thus of traffic increase). As an example, at a blocking of 10^{-2}, C+L+E can support around twice the traffic of C+L. Hence, the net effect of having more channels in the E- than the S-band, although these have lower GNSR, is favorable to the E-band. Moreover, we have to mention that in the case of S-band, the update is not seamless, since several routes in the C+L-band require a reconfiguration because of the impact of SRS when the S-band starts to be used. On the contrary, as mentioned above, to bring up of the E-band does not imply any reconfiguration in the channels deployed in the C+L-band.

Fig. 3(a) shows the number of routes requiring reconfigurations (e.g., re-routing, modulation format change, bit

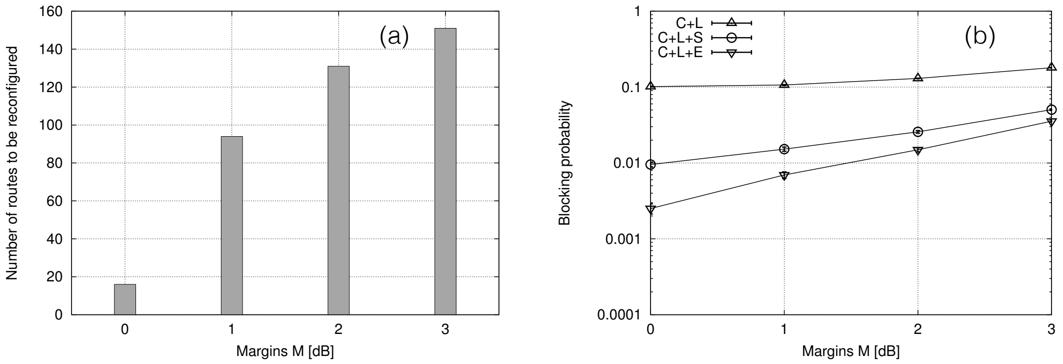

Fig. 3. (a) Number of routes requiring reconfiguration when exploiting S versus margins M; (b) blocking probability versus margins M at a load of 2500 Erlang

rate reduction) versus margins M in a C+L+S scenario. Note that the present simulations are assuming – in the case of reconfiguration – a change of the modulation format (always from PM-16QAM to PM-QPSK) with a bit rate reduction; alternatively, additional channels should be established to preserve the original bit rate. With no margins (M=0), 16 out of 870 routes require reconfigurations in C+L-band channels when using the S-band. The number of routes to be reconfigured increases with M since QoT requirements become more stringent. Consequently, more routes are critical, with a GSNR close to the threshold such that the GSNR variation due to SRS brings it below $TH_{PM-16QAM}$. As an example, with M=2dB, the channels along around 130 routes would need to be reconfigured.

Finally, Fig. 3(b) shows the blocking probability versus M at a load of 2500 Erlang. Blocking probability increases with the margins M since QoT is more stringent, translating into using more often the less spectral efficient PM-QPSK format, which results in the need to allocate more spectrum (150 GHz instead of 75 GHz). The relative behavior between C+L, C+L+S, and C+L+E is as observed in Fig. 2.

4. Conclusions

We compared network upgrades exploiting S- or E-band taking into account Stimulated Raman Scattering, assuming the availability of amplifiers, filters and interfaces compatible with these bands. Network simulations have shown that an upgrade to E-band while relying on a guard band between E- and C-band may be preferred to an upgrade to S-band. Indeed, on one hand, the two different upgrades scenarios achieve similar traffic increment (e.g., almost double traffic with E with respect to the original C+L system). On the other hand, the upgrade to E-band in the assumed network scenario does not imply any channel reconfiguration in C+L (e.g., modulation format adaptation), while the upgrade to S-band strongly impacts QoT in C+L, which results in channel reconfigurations.

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