Multiband Seamless Network Upgrade by Exploiting the E-band

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Abstract *We investigate the exploitation of the E-band in multi-band optical networks. A guard band of 14 THz is selected to isolate E- from C- and L-bands minimizing stimulated Raman scattering on already operating channels. Network simulations show double of supported traffic over the same infrastructure.*

Introduction

IP traffic is foreseen to continue its geometric progression[1],[2]. Operators will aim at maximizing network capacity by exploiting the already deployed optical fibers[3]. Specifically, they intend to postpone – as much as possible – the installation of new cables as this requires large investments[4]. The use of additional bands, beyond C, is a cost-effective solution to accommodate future traffic in already deployed fiber cables[5]–[10]. The large availability of deployed ITU-T G.652D fiber[3] which present loss below 0.4dB/km from L- to O-band makes multi-band (MB) feasible. Nevertheless, a unique control plane is needed to optimize the per-band power, due to the inter-band cross-talk induced by the stimulated Raman scattering (SRS), which transfers power from higher to lower frequencies. SRS enhances the non-linear impairment (NLI) generation caused by the Kerr effect in the bands at lower frequencies – i.e., C and L – and enhances power loss and consequently the amplified spontaneous emission (ASE) noise effect in the bands at higher frequencies[11],[12] – i.e., O, E, S. This implies that, in general, the activation of additional bands can impact the traffic already existing in other bands. Thus, network operators might have to enforce potentially traffic-impacting actions on the already working connections to guarantee their quality of transmission (QoT): e.g., traffic re-routing, change of transmission parameters. A smoother upgrade without the need of taking operational procedures on active traffic is preferred.

In this paper, assuming an existing C+L system, we propose to activate the E-band to increase the total number of channels while adopting a proper guard band between C and E-bands. The objective is to design the guard band such that the impact of the E-band on the traffic in C- and L-bands is negligible, thus significantly reducing SRS. This avoids QoT degradation for the channels already operating in the C and L-bands, which is paramount for seamless upgrades. Being transparent lightpaths mostly impaired by Gaussian disturbances (NLI and ASE noise), the generalized signal-to–to-noise ratio (GSNR) is adopted as a figure of merit to estimate the QoT when exploiting coherent technologies[13],[14]. Then, we consider a Spanish reference backbone network (SBN) with 30 reconfigurable optical add and drop multiplexers (ROADMs) and 112 uni-directional links, defined by Telefónica, and set the guard band to minimize the GSNR penalty when introducing the E-band. For the C+L band transmission, we consider typical commercial EDFA amplifiers, while for the E-band we assume the characteristics of the prototype proposed in[15]. A guard band of 14 THz between the C+L band and the E-band has been adopted to minimize the impact of the E-band on the C+L band channels. It is shown that the E-band introduces negligible cross-effects on the GSNR, i.e., $\leq$0.1 dB, supporting that the proposed MB solution enables a seamless upgrade of the C+L band line system. Moreover, nevertheless the guard band, dynamic network simulations show that we can accommodate twice the traffic of C+L band when exploiting the E-band.

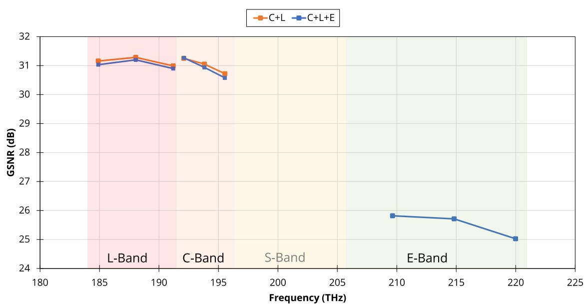

Fig. 1: Single span GSNR power after 60 km.

Physical layer assessment

We consider the SBN topology exploiting transmission over ITU-T G.652D fibers. Fiber span lengths range from 30 km to 60 km. We assumed the network is operated by C+L band line systems relying on typical commercial EDFAs characterized by average noise figures of 4.2 dB and 4.7 dB for the C- and L-band, respectively. Note that we consider the frequency dependence of the amplifier characteristics. We consider for the E-band an Nd^{3+} doped fiber amplifier (NDFA) as proposed in[15]. Then, we test the impact of turning-on E-band and we design the guard band with the aim of keeping the MB network upgrade seamless for QoT on the already deployed traffic. So, we shift the guard band (Δf) between C+L-band and E-band from 12.5 THz up to 14 THz by shifting the entire E-band WDM comb. We assume to operate on the 75 GHz WDM grid and suppose a C-band of 4 THz and a L-band of 6.9 THz: thus, 92 and 54 wavelengths, for the L- and C-band, respectively. While, for the E-band, we assume to transmit 146 wavelengths.

For physical layer assessment, we consider GSNR as QoT metric and use a disaggregated approach for the physical layer abstraction[14], where a lightpath is abstracted as an additive Gaussian noise channel and each network element introduces the proper amount of disturbances: ASE noise (amplifiers) or NLI (fibers). Specifically, for the QoT estimator, we use the GNPy library[16],[17], where the SRS cross-talk is accurately calculated and the NLI is evaluated using the generalized GN-model[11],[12],[18]. Power levels and spectral tilts are first optimized on the C+L line system regardless of the presence of the E-band comb, and subsequently, on the E-band line system according to the method proposed in[19]. Then, QoT is evaluated in the case of C+L band only, and then in case of C+L+E band transmission. Following the disaggregated approach, we carried out the investigation for each length of fiber span, evaluating the related GSNR. Table 1 reports the average GSNR of the C- and L-bands in the absence of E-band channels and when the E-band is activated for different values of the guard band. It is also reported the penalty – introduced by the upgraded of the E-band – as the difference between the C+L GSNR and the C+L+E GSNR in dB units. It can be observed that, in general, the impact of the E-band on the C+L comb is small because most of the E-band channels are beyond the peak of the Raman efficiency. However, even at the maximum considered value for the guard band, i.e., 14 THz, we cannot achieve a complete isolation – between E and C+L – because of the long tails of the Raman efficiency. Nevertheless, the impact is significantly low, being less than 0.1 dB. Since our goal is to minimize the disturbance of the E-band over the C+L band line system, for the remainder of our analysis we select a guard band of 14 THz.

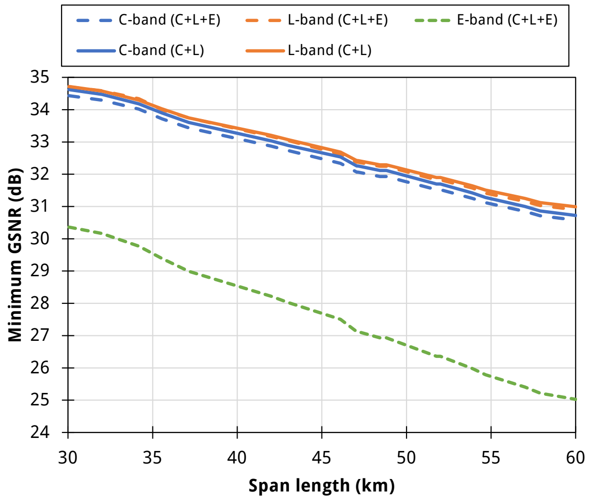

Fig. 2: Minimum per band single span GSNR.

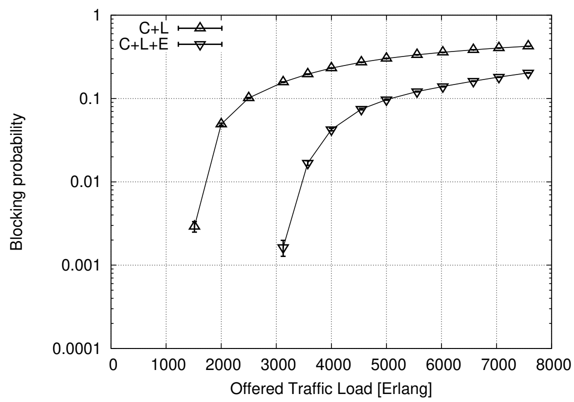

Fig. 3: Blocking probability versus traffic load.

Fig. 1 shows the spectrally resolved per-span GSNR results for the 60 span length – the mostly impaired one – where we can observe a residual yet negligible SRS effect: the C+L band suffers a minor extra non-linear penalty. Fig. 2 displays the GSNR results for the worst-case wavelength in each band, showing that SRS effect is limited to a negligible fraction of dB, thereby confirming that the proposed guard band enables a seamless MB upgrade by exploiting the E-band.

Networking results

The physical layer assessment is then used as input for a networking analysis. GSNR values of

	C+L	C+L+E Δf=12.5 THz	C+L+E Δf=13 THz	C+L+E Δf=13.5 THz	C+L+E Δf=14 THz
C-band	31.0 dB	30.4 dB	30.6 dB	30.7 dB	30.9 dB
C-band Penalty	-	0.6 dB	0.4 dB	0.3 dB	0.1 dB
L-band	31.1 dB	30.8 dB	30.9 dB	31.0 dB	31.0 dB
L-band Penalty	-	0.3 dB	0.2 dB	0.1 dB	0.1 dB

Tab. 1: Average per-band GSNR and GSNR penalty.

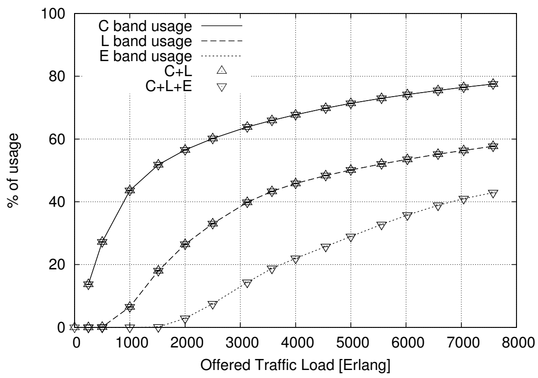

Fig. 4: Percentage of used spectrum in the C, L, and E bands versus traffic load.

each network element are added up to obtain the lightpath QoT that is compared to the transceiver requirements to set the modulation format and consequent data rate[14].

A custom built event-driven C++ simulator is used to evaluate the blocking probability of C+L and C+L+E scenarios in the SBN topology. 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) is assumed with a symbol rate of 64 GBaud. 400-Gb/s-net-rate requests is considered: 1×400-Gb/s PM-16QAM switched in 75 GHz or 2×200-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 considered for GSNR: 15.1 dB for PM-16QAM, 8.5 dB for PM-QPSK. 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; E-band is used when no spectrum continuity constraint can be satisfied in both C and L bands. Dijkstra's shortest path is assumed for path computation and first fit for spectrum assignment within a band.

Fig. 3 shows the blocking probability versus traffic load and its strong reduction enabled by the activation of the E-band. As an example, a BP=10^{-2}, with the use of E-band, is achieved with double traffic with respect to C+L band. Fig. 4 shows the percentage of spectrum used in the C, L, and E bands. In general, the used spectrum increases with traffic load. Focusing on the C band, no difference is experienced with C+L and C+L+E because no significant impact on the QoT is experienced when introducing the E-band and, consequently, C band spectrum is used in the same way in both cases. Regarding L band, at low loads, L is not used because C is enough to route all traffic. Again, no difference is experienced with C+L and C+L+E because no significant impact on the QoT is experienced when introducing the E-band. Finally, between 0 and 1500 Erlang, E is not used because C and L are enough to route the traffic. The E-band starts to be used when a relevant blocking – i.e., between 10^{-3} and 10^{-2} – is experienced with C+L band.

Conclusions

We proposed the use of E-band and the design of a guard band to reach a seamless network upgrade of an ITU-T G.652D fiber network already deploying traffic on C+L band. We set the guard band to 14 THz to practically avoid inter-band SRS cross-talk and the hypothesis has been verified: the E-band line system can be deployed and managed with negligible impact on the C+L band. Network simulations, when activating the E-band transmission, have shown a double traffic increase with respect to the use of C+L band only, nevertheless the adoption of a guard band.

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