Multiband Power Control Impact on the Transmission Capacity of Optical Line Systems

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***Abstract*—We apply a launch power control to a C+L+S multiband system, showing an increase in quality of transmission average and flatness, and almost doubling the offered capacity in S-band for long optical line systems.**

***Index Terms*—Optical fiber communication, Multiband transmission, High-capacity optical systems.**

I. Introduction

The continuous data-traffic increase required by 5G deployment, as well as cloud computing and data-center interconnection, will stress the actual backbone optical network infrastructure [1]. This infrastructure today is mainly based on coherent technologies using wavelength-division multiplexing (WDM) over the C-band spectrum of $\sim$4.8 THz, supporting up to 64 channels in a 75 GHz grid.

In order to provide more capacity with those systems, several upgrade scenarios have been proposed such as: (1) the activation of already deployed dark fibers, if available (replicating the C-band systems), (2) the deployment of new fibers (possibly allowing new technologies such as multi-core/multi-mode fibers), or (3) transmission over the standard single-mode fibers (SSMF) low-loss multiband of $\sim$50 THz, ranging from L- to O-bands [2], as shown in Fig 1. The fiber availability required by (1) is not always present. The second upgrade scenario does not take advantage of already installed systems, greatly increasing the capital-expenditure (CAPEX). Moreover, multi-core/multi-mode fiber technologies are still in the research phase and are not viable in the short-term. On the other hand, multiband capacity upgrade (3) relies on already installed fiber structure minimizing the CAPEX, although requiring the development/installation of new devices, such as transceivers and amplifiers, for each spectral band. This makes this option the most promising, with C+L-band systems already commercially available.

Despite the aforementioned advantages of multiband optical transmission, these systems also bring some challenges, mainly related to: frequency dependency of attenuation, chromatic dispersion (Fig. 1) and nonlinear coefficients; different amplifiers gain and noise-figure for each band; and the impact of stimulated Raman scattering (SRS), namely its interaction with nonlinear interference (NLI) [4]. The SRS is an important effect in multiband systems, with a higher impact for the spectral spacing of $\sim$ 13 THz. The SRS leads to the power depletion (loss) of high-frequency channels, requiring higher gain to recover this loss and consequently being more affected by amplified spontaneous emission (ASE) noise, and a power enhancement of low-frequency channels, being more affected by the NLI generation.

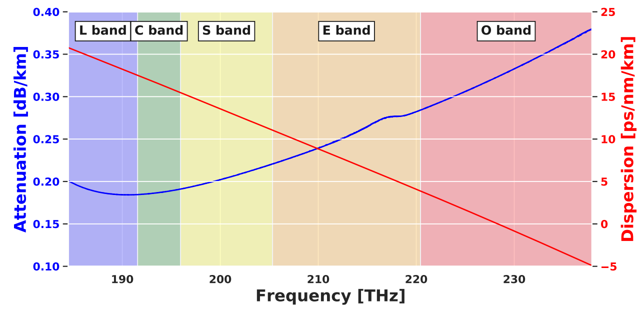

Fig. 1. Attenuation and chromatic dispersion of SSMF in L- to O-bands.

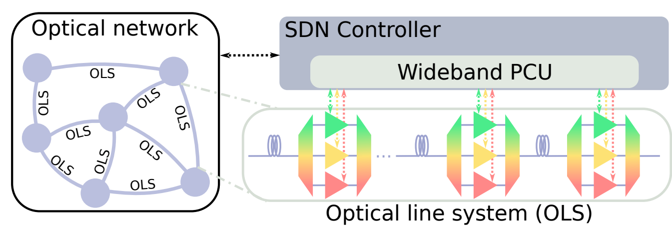

Fig. 2. Illustration of multiband PCU performing the power control for an OLS inside an optical network.

In order to reduce the SRS impact on the quality of transmission (QoT), assessed in this work by the generalized signal-to-noise ratio (GSNR) [5], the power launched into the optical fiber needs to be optimized. This can be realized by the multiband power control unit (PCU), part of the software defined networking (SDN) controller, on a per-band basis, setting each amplifier working point for all-optical line system (OLS) inside an optical network, as illustrated in Fig. 2. This control intends to maximize the average GSNR, while still enabling a flat GSNR profile per band.

II. Methodology and Results

The launch power control is performed span-by-span, following a disaggregated approach [5] using the local-optimization global-optimization (LOGO) [6] approach per-band, operating the amplifiers gain/output power and related tilt. On top of it, we define a set of power offsets (corresponding to the increase or decrease of LOGO reference optical power) and tilts to compensate the SRS, and select the profile

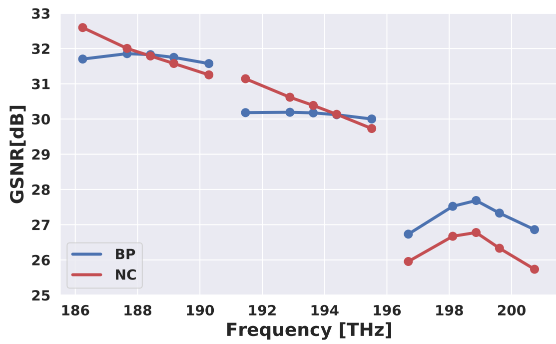

Fig. 3. Single 75 km span GSNR profiles comparing launch power control (Best profile – BP) with flat input power (LOGO).

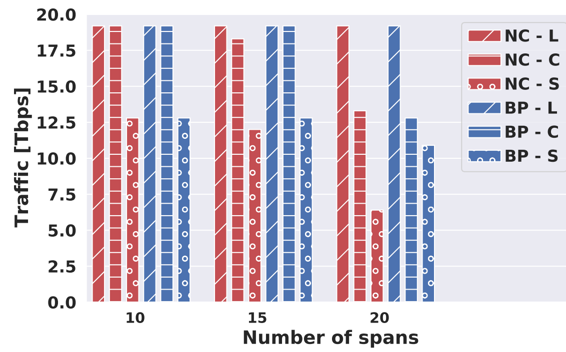

Fig. 4. OLS offered traffic per band versus number of spans.

with the best average GSNR and flatness [3], which we refer to as Best Profile (BP). We compare the BP with the profile using only the LOGO power per band with no compensation (NC). The control was performed in a C+L+S spectral scenario, with 64 channels for each band in a 75 GHz WDM grid and symbol rate of 64 GBaud using a 500 GHz of guard-band between bands. The amplifiers are assumed to completely recover the loss and have a frequency dependent noise figure, with average of ∼4.25, ∼4.68 and ∼6.5 dB for C-, L- and S-bands, respectively. The GSNR is computed with the GNPy [7] library using the generalized Gaussian noise (GGN) model [4] for NLI calculation. The NLI is computed for 5 channels per each band, in order to speed up the process, and the remaining channels NLI is determined by interpolation.

Firstly, Fig. 3 presents the GSNR profile for a single 75 km span using the launch power selected only by NC and BP approaches. It can be noticed that, using the launch power selected by LOGO (red lines), the GSNR profile is more impacted by the SRS effect, showing a high variance in QoT in L (32.7 to 31.1 dB) and C (31.1 to 29.8 dB) bands and depletion in S-band. With power control performed (BP-blue lines), the GSNR tilting is almost completely removed from L- and C-band, while still keeping approximately the same average GSNR. Regarding the S-band, the control strategy is able to increase the GSNR average by almost 1 dB with similar flatness.

Secondly, the impact of the launch power control in offered traffic per band on a single OLS transmission for each scenario (NC and BP) with 10, 15, and 20 spans, is depicted in Fig. 4. The allocated traffic computation for each channel is performed based on real C-band flexible transceiver [8] [1] with 3 modulation formats (QPSK, 8-QAM, and 16-QAM) and 4 different bit rates (100, 200, 300, and 400 Gbps) offered. The modulation format and bit rate selection are done based on the total path GSNR for each channel individually.

Fig. 4 shows that both power profiles offer the same traffic (19.2 Tbps for L- and C-bands and 12.8 Tbps for S-band) when transmission along 10 spans is considered. However, the offered traffic obtained with the power control starts differing from NC only after 15 spans, where our strategy is able to slightly increase the allocated traffic comparing with NC for both C- and S-bands, maintaining the same offered traffic for all bands as for the 10 spans case. For an OLS with 20 spans, both power optimization strategies were able to deliver the same traffic in L-band. Regarding C-band, the NC is able to perform slightly better than the application of the tilt/offset strategy. This can be explained due to the fact that, although the BP delivers a more flat GSNR profile, more than half of the channels in C-band present a higher GSNR. As our traffic is computed on a per-channel basis, some channels were able to use more efficient modulation formats and consequently deliver more traffic. It is worth mentioning that a common strategy, from a network controller point of view, is to assume the worst GSNR value inside a spectral band in order to determine the best modulation format and, consequently, the maximum delivered traffic for all channels within this band. In that particular case, our strategy would be able to deliver at least the same traffic for C-band, as it was able to deliver an almost flat GSNR profile with an average GSNR that is higher than the worst value obtained when the NC approach is employed. Finally, in S-band the best profile found was able to offer more than 10.9 Tbps while the NC approach would only offer 6.4 Tbps. These results show that a proper power control can increase the gains in transmission capacity with the usage of a wider fiber spectrum.

[1]400ZR IA defines only 400G transmission with 16QAM < 120km. Nevertheless, it is a common assumption in the industry that the other modes will be possible and this is often designated as OpenZR+.

III. Conclusions

This paper described a launch power control strategy suitable for C+L+S multiband transmission, targeting to optimize quality of transmission and offered capacity. We showed that, with the adopted strategy, it is possible to maintain or increase the average GSNR and flatness per span in all bands as well as increase the delivered traffic for OLS's with large number of spans in bands with lower QoT.

Acknowledgment

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