MPI Impact in C+L+S Multiband Transmission Reach

Luís G. Cancela[1] and João O. Pires[2]

(1) Instituto de Telecomunicações and Dep. Information Science and Technology, Iscte - Instituto Universitário de Lisboa, Portugal

(2) Instituto de Telecomunicações and Dep. Electrical and Computer Engineering, Instituto Superior Técnico, Portugal.

luis.cancela@iscte-iul.pt; jpires@lx.it.pt

Abstract: Multipath interference (MPI) impact is assessed in a C+L+S multiband transmission scenario. For a typical -34 dB/span MPI, transmission reach in the L-band suffers a 20% reach penalty considering the QPSK modulation format.

1. Introduction

Multiband (MB) is being regarded as a near to midterm technological solution to, at least, postpone the announced optical network capacity crunch [1]. Despite being able to be implemented in a much shorter time and with a much lower cost than the superior capacity transport spatial-division multiplexing (SDM) solution it has several technical short comes, not present in common C-band systems, that must be addressed. For example, the optical amplified technologies for other bands, than the C and L bands, must be improved; the optical node architecture must be more carefully designed as the node dimension increase with the new bands used; and the physical layer impairments (PLIs) must be correctly assessed as several PLIs are enhanced when other bands than the C-band are used for transmission. Several works have already addressed and analyzed some of those PLIs, like the impact of the non-linear interference (NLI) noise and its dependence on the inter-channel stimulated Raman scattering (ISRS), a wideband phenomenon that is responsible for power transfer from high to low frequencies [2,3]. The multipath interference (MPI) is another PLI commonly encountered in optical communications systems operated in the C-band [4,5], that occurs when multiple replicas of the transmitted signal propagate over different optical paths. Recently this PLI has also been identified in MB systems using the G.654 fiber [6]. This fiber type presents a lower loss and non-linear coefficient than the typical G.652 fiber, and it has been reported that it is advantageous to use it in metro and long-haul networks [6]. However, the G.654 fiber allows mode coupling when bands with wavelengths below the cut-off wavelength are used inducing MPI. In [6] the signal-to-noise ratio penalty due to MPI has been assessed for the C+L band scenario considering several modulation formats and it has been concluded that to mitigate the MPI impact the transmission distance should be reduced, but this decrease was not yet quantified.

The main goal of this work is to assess the MPI impact on the transmission reach of a C+L+S multiband system, using the G.654 fiber, for two modulation formats, namely the quadrature phase-shift keying (QPSK) and the 16-quadrature amplitude modulation (QAM). A generalized signal-to-noise ratio (GSNR) that considers the impact of the MPI is presented and used to assess the quality of transmission of a given lightpath. The maximum transmission reach as a function of the MPI is quantified for each one of the three bands, C, L and S, and for both modulation formats considered, QPSK, and 16-QAM.

2. GSNR model

The quality of transmission of a given lightpath in a coherent dispersion uncompensated and amplified wavelength division multiplexed system can be estimated through the GSNR [3]. In the scenario, where the lightpath is composed by several spans and impacted by the accumulated amplified spontaneous emission (ASE) noise originated from the optical amplifiers, by the NLI noise from the optical fiber transmission and by the MPI noise from the mode coupling in the G.654 fibers, the GSNR of channel *i* after transmission along *N* spans can be given by [6],

$$\mathrm{GSNR}_i = \frac{P_i}{P_{\mathrm{ASE},i} + MPI \cdot P_i + P_{\mathrm{NLI},i}} \tag{1}$$

where P_i is the launch power in channel *i*, $P_{\mathrm{ASE},i}$ is the accumulated ASE noise power in channel *i* after *N* spans and modelled as in [3], $P_{\mathrm{NLI},i}$ is the NLI noise power in channel *i* after *N* spans and $MPI \cdot P_i$ is the MPI noise power in channel *i* after *N* spans. The NLI noise power is calculated using the analytical approximation of the generalized Gaussian noise (GGN) model proposed in [2] that allows faster and accurate GSNR estimations. We have used equations (10) and (11) of [2] to calculate, respectively, the self-phase modulation and cross-phase modulation contributions of the NLI noise power. We have also used the incoherent NLI accumulation assumption so that the coherence factor is set to zero [2]. The MPI noise power originated in G.654 fibers, where multiple replicas of the transmitted signal due to LP01-LP11 coupling appear, can be modelled as in [7]. The MPI noise power is just the sum of the MPI noise powers in every span along the lightpath, whereas the MPI level after *N* spans is given by

$MPI = N \cdot (MPI\ per\ span)$. Note, that the GSNR model is based on Gaussian statistics and although the statistics of the ASE and NLI noises can be quite well described by Gaussian statistics [3], this is not the case for the MPI statistics, that can be more rigorously described by fat-tailed statistics [7], like the extended skew-normal distribution [5].

3. Transmission reach assessment

We have considered a C+L+S MB optical transmission system occupying a bandwidth of 15.3 THz, which can accommodate 192 channels, each operating at 64 Gbaud, with a channel spacing of 75 GHz. Furthermore, there are two different 500 GHz bandgaps, the first one between the L- and C-bands, and the second one between the C- and S-bands, as in [3]. The considered optical transmission system is composed of a transmitter and a receiver connected by N spans of equal length (100 km). At the end of each span each band is individually amplified, so that a band demultiplexer/multiplexer must be used. The amplifier gains are set to compensate for the link optical losses. Different amplifier noise figures are considered for each band as in [3]. The optical G.654 fiber is characterized by a dispersion parameter of 21 ps/nm/km, a loss coefficient of 0.17 dB/km, and a Raman gain profile with $C_r = 0.018\ (\mathrm{W \cdot THz.km})^{-1}$ [6]. We additionally consider splice losses varying from 0.0043 to 0.068 dB every 4.2 km, which results in a MPI per span variation from -46 dB/span to -29 dB/span [6].

Figure 1 represents the GSNR for the three bands considered as a function of the number of spans for two MPI scenarios – no MPI and -34dB/span, for a typical splice loss of 0.034 dB [6]. A 1 dBm optical launch power was used so that the GSNR is maximized. As can be seen in Fig. 1, without MPI, the L-band has a greater reach than the C and S bands, as expected, due to ISRS induced power transfer [3], whereas when the MPI is considered, the reach decreases, especially for the L-band channels. For a 4000 km link (40 spans) the L-band suffers a 0.9 dB GSNR penalty for a -34dB/span MPI, whereas the S-band suffers only a 0.3 dB GSNR penalty.

Figure 2 represents the number of spans as a function of the MPI/span for the three bands considering two modulation formats, QPSK and 16-QAM. These two signal formats are considered feasible if the estimated GSNR is higher than the required SNR, taken from [8] for a bit error rate of 10^{-3}. From Fig. 2 it can be observed that the impact of the MPI is more severe for the L-band scenario for both QPSK and 16-QAM signals – an approximately 40% reach decrease is achieved when the MPI/span increases from -36 dB to -28 dB. The S-band scenario is less impacted by the MPI due to the reduction of signal power induced by the ISRS effect in this band.

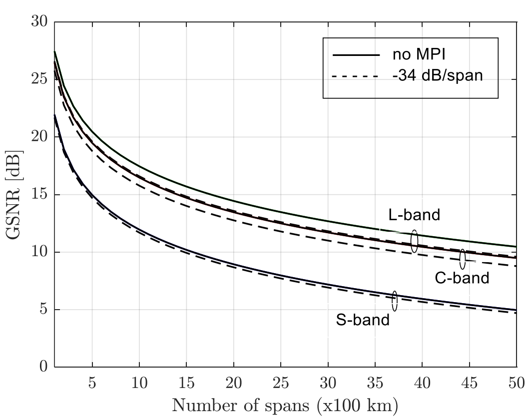

Fig. 1. GSNR as a function of the number of spans for the three bands and two MPI scenarios – no MPI and -34 dB/span.

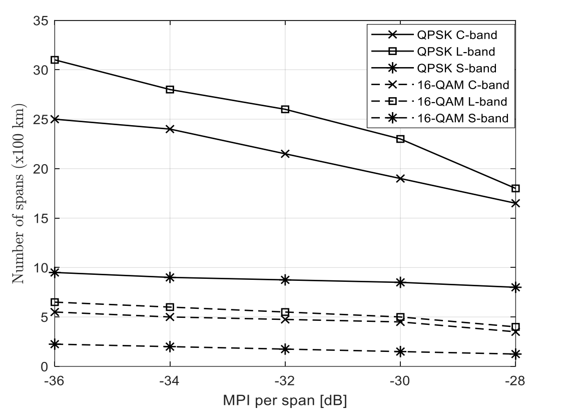

Fig. 2. Number of spans as a function of the MPI level per span for the three bands and for QPSK and 16-QAM signals.

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5. References

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