Network Performance Assessment of C+L Upgrades vs. Fiber Doubling SDM Solutions

Emanuele Virgillito[1]**, Rasoul Sadeghi**[1]**, Alessio Ferrari**[1]**, Giacomo Borraccini**[1]**, Vittorio Curri**[1]

[1] *DET, Politecnico di Torino, C.so Duca degli Abruzzi 24, 10129 Torino, Italy*

emanuele.virgillito@polito.it

Abstract: We investigate on the network capacity enabled by C+L optical line systems (OLS) vs. fiber doubling showing that at optimal power, C+L OLS doubles the traffic of C-only with very-low penalty with respect to fiber doubling.

OCIS codes: 060.0060, 060.4256.

1. Introduction

The increasing capacity demand driven by the 5G revolution, together with the fast extension of cloud services and data-center interconnection, will continue in the following years [1]. The traffic growth is already saturating the state-of-the-art transparent optical backbone deploying coherent transmission and wavelength division multiplexing (WDM) enabling up to 96 WDM lightpaths (LP) over 4.8 THz in the C-Band ITU-T 50 GHz WDM grid. In order to increase capacity and maximize the operators CAPEX returns, two solutions have been proposed. On one hand, one can employ space division multiplexing (SDM) by lighting up dark fibers. On the other hand, the available bandwidth on a single fiber can be extended beyond C-Band, relying on the so called Bandwidth Division Multiplexing (BDM). BDM solutions are already commercially available enabling transmission over $\sim$10 THz on C+L band line systems. Although it has been demonstrated [2,3] that the capacity improvement is not as good as in SDM, BDM can be a cost-effective solutions especially when no dark fibers are available. However, due to severe stimulated Raman scattering (SRS) arising on such large bandwidth, power control strategies should be adopted in order to avoid spectral tilt of the generalized signal to noise ratio (GSNR), which can be taken as the overall figure of merit of the quality of transmission (QoT) [4] considering both the ASE noise and nonlinear interference (NLI) generation. In this work, we focus on a realistic upgrade scenario of a C-Band system. We evaluate the network traffic gains and penalties employing SDM by doubling the fibers and BDM by extending the bandwidth to C+L in the German and US-NET network topologies of Fig.1. First, the launch power profile over C and C+L Band has been optimized in order to maximize and flatten the GSNR. Then, the QoT estimation has been used to evaluate the network performance using the Statistical Network Assessment Process (SNAP) [5,6] SNAP is a Monte Carlo-based algorithm carrying out statistical benchmarks of a network by loading it with progressive LP allocation. For this work, SNAP allowed to evaluate the blocking probability vs. the allocated traffic in four considered cases: the reference case of C-Band transmission; the proposed upgrades using BDM on C+L band and SDM with 2 fibers with independent switching (InS) and core continuity constraint (CCC) [7]. For each solution, we first performed launch power optimizations, then, we run SNAP to the German and US-NET topologies of Figs. 1 We demonstrate that, while SDM ensures the largest capacity improvement, the BDM solution more then doubles the capacity with very limited traffic penalty with respect to BDM, for both the analyzed topologies.

2. Line System Power Optimization

To perform reliable statistical network performance evaluation, the physical layer impairment awareness is of crucial importance. It has been proved that the GSNR can be taken as the global figure of merit of QoT [4]. The

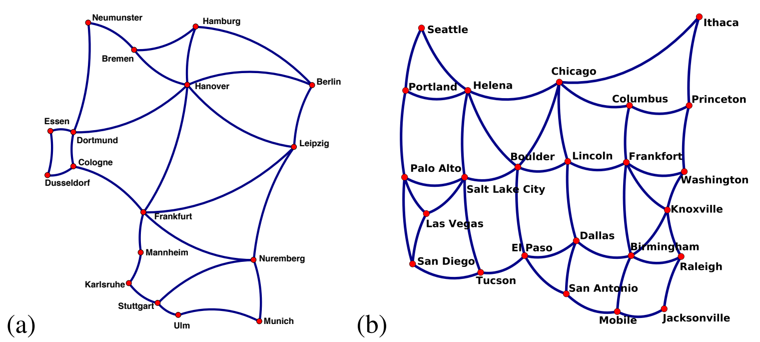

Fig. 1. Analyzed networks: (a) German and (b) US-NET topologies.

GSNR takes into account both the QoT degradation due to the linear ASE noise through the OSNR and the NLI generation through the SNR_{NL}:

$$\text{GSNR} = \left(\frac{1}{\text{OSNR}} + \frac{1}{\text{SNR}_{\text{NL}}}\right)^{-1} \tag{1}$$

The evaluation of the NLI has been performed by means of the generalized Gaussian noise (GGN) model, which has been proved to deliver reliable QoT estimation in presence of SRS [9]. Indeed, the interaction between SRS and NLI generation can lead to large inequalities among the SNR_{NL} of the channels due to the SRS power transfer if a launch power profile optimization is not performed. In order to keep the upgrade scenario realistic, we assume to avoid considerable Raman amplification, e.g., we consider only lumped amplification. So, C and L band propagation losses are transparently recovered by two dedicated EDFAs. Hence, due to the aforementioned power transfers leading to un-equalized received channel powers, even the ASE noise power spectral density (PSD) is non-flat so that the launch power optimization has to be performed on the GSNR rather than solely on the SNR_{NL} [8]. Furthermore, the EDFA noise figure has been considered frequency-dependent, with an average of 4.7 dB in L-Band and 4.3 dB in C-Band. The fiber spans are assumed to be 75 km of standard single mode fiber (SSMF). 96 and 192 channels on the ITU-T 50 GHz grid with $R_s = 32$ GBaud have been considered on C-Band/SDM and C+L cases, respectively. The C and L band WDM combs are separated by a 500 GHz guard-band. In order to perform the channel launch power optimization we have followed a brute force approach. Initially, C and L band channels have been set to their optimum power, which is -2.1 dBm and -1.99 dBm, respectively, obtained with LOGO strategy [10]. Then, for the C-Band only case, we have estimated the GSNR by applying a tilt on the transmitted power from -0.4 to 0.4 dB/THz with step 0.1 dB centered on the middle-band. For the C+L band case we have extended the space to an independent channel power offset applied to the optimum powers of each band. The offset spans in [-1, 2] dB and [-2, 1] dB with step 0.5 dB for C- and L-band, respectively, so that 3969 launch powers profiles and corresponding GSNR have been evaluated. Then, the optimal launch profile has been chosen as the one maximizing and flattening the GSNR. For C-Band only the choice was -0.4 dB/THz tilt, while for the C+L we found 1 dB offset, -0.3 dB/THz tilt for C-Band and 1 dB offset, 0.1 dB/THz tilt for L-Band. The resulting GSNRs, calculated on 5 channels under test for each band to speedup the process, are depicted in Fig.2. C-Band case delivers an average GSNR of 30.6 dB with a 0.25 dB difference between the largest and smallest values. BDM case delivers 29.8 dB and 29.6 dB of average GSNR on C and L band, respectively, with 0.20 dB of difference between maximum and minimum values. Hence, the 0.8 dB of QoT degradation going from C to C+L band accounts for the further NLI and SRS effect added by lighting up the L-band.

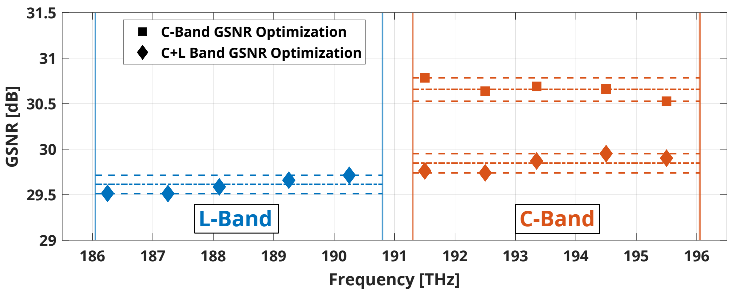

Fig. 2. Launch power optimization: (squares) C-Band only optimized GSNR with -0.4 dB/THz. (diamonds) C+L-Band optimized GSNR with 1 dB offset, -0.3 dB/THz tilt for C-Band and 1 dB offset, 0.1 dB/THz tilt for L-Band.

3. Networking Analyses

The obtained GSNR profiles have then been used by SNAP to asses the networking performance of the German and US-NET topologies Fig.1. The German topology has 17 nodes, 26 edges, and the average distance between two ROADM nodes is 207 km for an overall covered area with a diameter of 600 km and an average node degree of 3.1. Instead, the US-NET topology has 24 nodes and 44 edges and the average distance between ROADM nodes is 308 km for a covered area with a diameter of 4000 km and an average node degree of 3.6. The SNAP algorithm progressively loads the network with LP allocation requests between a random node pair until its saturation. Once a LP is allocated, the overall traffic in the network is computed. The process is iterated for N_{MC}, times, being N_{MC} the number of Monte Carlo random realizations, here set to $N_{MC} = 75000$. The routing policy is a k_{max}-shortest path with $k_{max} = 15$ and best-SNR wavelength assignment. This allows to obtain *dynamic* network performance metrics, such as the blocking probability (BP) vs. the average total traffic in the network, which is reported in Fig.3 for the German topology and in Fig.3 for the US-NET. At a first glance, the US-NET performs always better than the German. Although the average link is longer in the US-NET, thus having poorer QoT, the US-NET capacity is larger thanks to the higher average node degree enhancing the network flexibility and dominating the

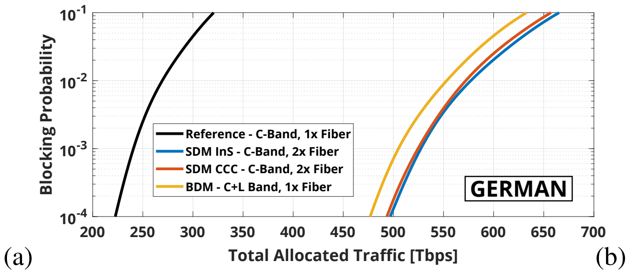

Fig. 3. Blocking probability versus total allocated traffic: a) German b) US-NET.

QoT degradation. From the upgrade perspective, instead, both SDM and BDM solutions deliver more than the double of the traffic provided by the single band-single fiber transmission. In particular InS and CCC for SDM provide exactly the same performance, so that the lower ROADM complexity allowed by CCC is preferable and its degradation in terms of network flexibility is negligible. BDM solution cannot reach the same performance, still delivering a significant upgrade with a small gap with respect to SDM. The penalty is here due to the lower QoT of the LPs and its poorer network flexibility due to its intrinsic wavelength routing constraints. Finally, in Fig.3 we have evaluated the Traffic multiplicative factor at a target BP of 10^{-3}, as the ratio between the upgrade solution average traffic and the reference case traffic. In any case, the traffic is at least doubled. SDM solutions deliver also further 20% and 9% gain with InS on German and US-NET networks, respectively, with a small decrease going to CCC. The gain is here allowed by the improved network flexibility offered by the SDM with no QoT degradation, as opposite to the BDM transmission. The BDM solution, instead, cannot reach the same gains, with a 10% in the German case and just doubling the traffic in the US-NET. US-NET gains are indeed lower because of the larger size and longer link length of the networks, so that the traffic is more affected by poorer L-band QoT.

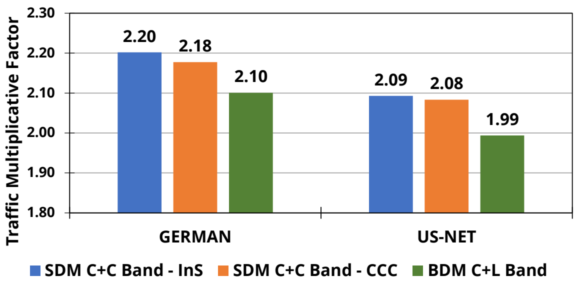

Fig. 4. Traffic multiplicative factor at BP = 10^{-3} for German US-NET networks.

4. Conclusions

In this work, we evaluated the networking performance improvements in a realistic upgrade scenario from single-band single-fiber transmission to SDM solution by doubling the fibers and a BDM solution extending the bandwidth to 4.8 to 10 THz in C+L bands. The launch power profile has been previously optimized exploiting the GGN model to evaluate the QoT. While SDM always gives better capacity improvements than BDM even when relying on simpler CCC ROADMs, the BDM does not present significant penalties with respect to SDM, always enabling the traffic doubling on both the analyzed topologies.

Acknowledgment

This work was partially funded by the EU H2020 within the ETN WON, grant agreement 814276 and by the Telecom Infra Project.

References

1. VNI Global Fixed and Mobile Internet Traffic Forecasts, Cisco
2. A. Ferrari et al., "Band-Division vs. Space-Division Multiplexing: A Network Performance Statistical Assessment," accepted by JLT, (2019).
3. J. K. Fischer et al., "Maximizing the Capacity of Installed Optical Fiber Infrastructure Via Wideband Transmission," ICTON 2018, **Tu.B3.3**
4. M. Filer et al., "Multi-Vendor Experimental Validation of an Open Source QoT Estimator for Optical Networks", JLT, **36**, 3073-3082, (2018).
5. V. Curri et al., "Elastic All-Optical Networks: A New Paradigm Enabled by the Physical Layer...," JLT, **35**, 1121-1221, (2017).
6. E. Virgillito et al., "Statistical Assessment of Open Optical Networks," Photonics, **6**, 1-18, (2019).
7. A. Ferrari et al., "A Networking Comparison Between Multicore Fiber and Fiber Ribbon in WDM-SDM Optical Networks," ECOC 2018.
8. A. Ferrari et al., "Power Control Strategies in C+L Optical Line Systems,", OFC 2019, **W2A.48**
9. M. Cantono et al., "On the Interplay of Nonlinear Interference Generation With Stimulated Raman Scattering", JLT, **35**, 3131-3141, (2018)
10. V. Curri et al., "Design Strategies and Merit of System Parameters for Uniform Uncompensated Links...", JLT, **33**, 3921-3932, (2015)